M. Mani · C. Shivaraju *Editors*

Mealybugs and their Management in Agricultural and Horticultural crops

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Dedicated to my wife Vijayarani who was involved with the work on mealybugs. She had helped me to carryout extensive surveys for mealybugs in different crops in India. She has also played a major role in finalising the draft on Mealybugs and their Management in Agricultural and Horticultural crops.

Foreword

Crop protection in the present day is as important as crop production. Pests have plagued mankind from the beginning and will continue to vex the people and thwart all their endeavors to the end. Mealybugs are sap-sucking insects named for the powdery secretions covering the bodies. Mealybugs are soft-bodied insects covered with waxy coating. They are sessile insects. They are phloem feeders and suck the sap from all plant parts and also transmit some plant disease thus causing serious economic losses to economically important crop plants. Many of the mealybugs are arboreal and some are subterranean feeding on the roots. They are windblown, and the spreading of mealybugs is facilitated by wind. Within 2 days of hatching, they are also covered by waxy coating making them hard to get killed with chemicals. Hence they are called as "hard to kill insects".

Mealybugs mostly live in protected habitats. They are found in cracks, crevices inside the fruit clusters, lower surface of the leaves, etc. Since they live in concealed plant parts, the chemicals will not reach the target pests making chemical control ineffective. Many a time, mealybugs become abundant in the fruiting phase of the plants. Several applications of insecticides are needed for mealybug control. Thus frequent application of insecticides for mealybug control leads to residue problem on the fruits, making unfit for export and hazardous to domestic market.

This book covers all the basic and applied aspects of the mealybug species ultimately useful to implement the integrated mealybug management in different agricultural crops. The book covers the information on identification of the mealybugs, morphology, cytogenetics, taxonomy, molecular characterization for identification, biology, damage, mealybugs as vectors, seasonal development, natural enemies, culturing of mealybugs, ant association, control measures, insecticide resistance and mealybug management in different crops.

This book on *Mealybugs and their Management in Agricultural and Horticultural crops* is first of its kind since there is no comprehensive book covering all aspects of mealybug available in the world. This will serve as a guide for crop growers, state goverment officials and other stake holders industry, besides researchers and students engaged in mealybug research and development activities.

Indian Council of Agricultural Research — N.K. Krishna Kumar
New Delhi 12, India,
July, 2014

Preface

Mealybugs throughout the world cause a variety of economic problems. The most obvious damage is caused by the sucking habits of these insects. Heavy infestations often cause stunting or death to the plant host. At times, mealybugs have toxins and act as vectors of certain viruses detrimental to plant life.

Information on morphology, cytogenetics, taxonomy, molecular characterization for identification, morphology, biology, damage, mealybugs as vectors, seasonal development, natural enemies, culturing of mealybugs, ant association, control measures, insecticide resistance etc are covered in this book. It also deals with the all the mealybug management practices, which include monitoring of mealybugs, use of pheromones, cultural practices, chemical control and biological suppression available in the world.

We tried to accommodate almost all the important information generated on the mealybugs up to 2014. A complete list of mealybug occurring in different crop growing regions of the world is also covered in this book, which will be ready reckoner for the crops. We sincerely hope that this book will provide useful information to many entomologists and students working on mealybugs. It is a pleasure to thank all those people who gave help, suggestions and encouragement in the preparation of our book *Mealybugs and their Management in Agricultural and Horticultural crops*.

Bangalore, Karnataka, India

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C. Shivaraju

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The beatitude and euphoria that accompanies successful completion of any task would be incomplete without the expression of appreciation of simple certitude to the people who made it possible to achieve the goal by their encouragement and support. We heartily thank Dr. N. K. Krishnakumar, Deputy Director General of Horticulture, Indian Council of Agricultural Research, New Delhi, for his technical guidance. We are immensely grateful to Dr. Amrik Singh Sidhu, Director, Indian Institute of Horticultural Research, Bangalore, for his genuine guidance, impeccable and scholarly advice, recurring encouragement, sustained interest and above all his affectionate way of dealing with things throughout the course of writing the book. We wish to express our extreme and profound sense of gratitude to Dr. Ameriksingh Siddu, Director, Indian Institute of Horticultural Research, Bangalore. Karnataka, India, for his valuable suggestions and useful guidance. We take this opportunity to convey our sincere thanks to Dr. Abraham Verghese, Director, National Bureau of Agriculturally Important Insects Resource, Bangalore, for the encouragement to write this book.

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About the Editors

Dr. M. Mani is an agricultural scientist with over 35 years of R&D experience in the entomological research. He has served in Indian Council of Agricultural Research and Tamil Nadu Agricultural University. His focal subject is pest control in horticultural crops including grapes. He has done work on mealybugs for 35 years. Currently, he is an Emeritus Professor of ICAR, New Delhi. He got seven awards including lifetime achievement for his contribution to the research in horticulture entomology. He is associated with five scientific bodies. The author has published two books in 2013: (1) *A Wonder Predator (Cryptolaemus)* by Lap Lambert Academic Publishing Company, Germany (2) *The Grape Entomology* by Springer.

Dr. C. Shivaraju has worked extensively on insects infesting several agricultural and horticultural crops in Indian Institute of Horticultural Research and National Bureau of Agriculturally Important Insects both located at Bangalore. Particularly, he contributed significantly in research on eucalyptus and papaya pest management. He has co-authored two books: *A Wonder Predator (Cryptolaemus)* and *The Grape Entomology*.

Introduction

1

M. Mani and C. Shivaraju

Mealybugs belong to the insect group that is commonly known as scale insects; They have soft segmented oval bodies, but without an outer shell. Mealybugs (Hemiptera, Sternorrhyncha, Coccoidea, Pseudococcidae, and Putoidae) are small, soft-bodied plant sap-sucking insects. The name *mealybug* is descriptive of the insect's body, which is covered by a white sticky powder resembling cornmeal. Their common name is derived from the mealy wax secretion that usually covers their bodies (Kosztarab and Kozár 1988). Because of their appearance, mealybugs are often confused for cushionscale insects or woolyaphids. Unlike their close relative scale insects, mealybugs retain their legs throughout their lives.

Mealybugs feed on a variety of herbaceous and woody plants, including the angiosperm, gymnosperm, and fern families. Most of the mealybugs are arboreal and some are subterranean feeding on the roots. They are phloem feeders and suck the sap from all plant parts and also transmit some plant disease, thus causing serious economic losses to economically important crop plants. Mealybugs take in great quantities of plant fluids and therefore excrete a lot of liquid waste called honey that supports the growth of a black fungus called sooty due to which a significant infestation of mealybug creates a black, sticky mess. Most of the economically important mealybug species are known to be associated with long lists of host plants, and the development of high population density, which eventually would kill the host plant. Plant growth conditions may strongly affect the development of the mealybug. Flowering and fruiting phases of plant support heavy mealybug population. Likewise, hot weather favors rapid multiplication resulting in the outbreak of mealybug population.

Many of the mealybugs show sexual dimorphism but parthenogenetic mode of reproduction is also observed in some species of mealybugs. Mealybugs may be oviparous or viviparous or ovoviparous. The eggs are usually laid in loose masses of cottony wax or felt-like ovisacs. Some species bear living young. Only newly hatched mealybugs, also called as crawlers, are not covered with wax coating, moving from one part to another within the plant and also between plants; this is the most vulnerable stage for chemical control. They are windblown, and the spreading of mealybugs is facilitated by wind. Within two days, they are also covered by waxy coating, making them hard to get killed with chemicals. There are three nymphal instars in female and four in male mealybugs also covered with wax. Adult male and female mealybugs are completely different from each other. Adult female mealybugs are characteristically elongate, oval, soft,

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and with distinct segmentation measuring as much as 8–9 mm in length. They are wingless and their mouthparts are thread-like, inserting through the plant tissue to suck juices from the host, thereby causing damage. The adult male has a pair of long opaque wings, slender body, and two multisegmented antennae that are about half the body length and a pair of halters with hooks. It bears two white, long anal filaments. Adult males are about 1.5 mm in length. They are active fliers but have abortive mouthparts and take no food. Their role in life is to fly and find a female to mate. Females release a pheromone to attract the winged males. Females are abundant in fields while male mealybugs are so rarely available. They reproduce sexually and parthenogenetically. The males, seldom seen, are delicate.

Outwardly, mealybug species look similar. However, each species has distinct biological and morphological characters. Identification of mealybugs is based upon adult females. They constitute the second largest family of Coccoidea, with more than 2000 described species and ca. 290 genera (Ben-Dov 2006; Downie and Gullan 2005).

Economic losses resulting from mealybug infestations have increased over a period of years. In response, there has been a cosmopolitan effort to improve control strategies and better understand mealybug biology and ecology as well as their role as vectors of plant pathogens (Daane et al. 2012).

For the most part in their life stages, mealybugs are covered with waxy coating, including eggs, making the control with chemicals difficult. Mealybugs mostly live in protected habitats. They are found in cracks, crevices inside the fruit clusters, lower surface of the leaves, etc. Hence they are called as "hard to kill insects."

Chemical control is still the most common control tactic used against mealybug pests. However, the cryptic behavior of mealybugs, their typical waxy body cover, and clumped spatial distribution pattern render the use of many insecticides ineffective. Repeated insecticide use, especially of broad-spectrum chemicals, also adversely impacts mealybugs' natural enemies. Insecticide resistance has also caused the use of some chemicals to be unsustainable. Furthermore, many of these products are increasingly unacceptable because of their human toxicity and low selectivity; some are no longer available and others are targeted for reduction under national programs and regulations for sustainable use of pesticides, in light of their risk or hazard assessments (Charles et al. 2006; Franco et al. 2004; Walton et al. 2006). Since they live in concealed plant parts, the chemicals will not reach the target pests, often making chemical control ineffective. Many a time, mealybugs become abundant in the fruiting phase of the plant. Multiple applications of insecticides are needed for their control. Thus, frequent application of insecticides for mealybug control leads to residue problem on the fruits making them unfit for export and hazardous to domestic market.

However, mealybugs have a very rich natural enemy complex. Biological control of mealybugs is widely recommended. It includes several general predators like coccinellids, chrysopids, lycaenids, drosophilids, and cecidomyiids. Mealybugs are known to be attacked by several parasitoids, mainly the encyrtids and some other parasitoids like aphlelinids, platgasterids, braconids, pteromalids, eulopids, eucilids, and signiphorids. Many are host specific and very effective against mealybugs. In the case of undisturbed or uninterrupted broad-spectrum and deleterious chemicals, the local natural enemies play an important role in the population regulation of mealybugs. Many a time, the local natural enemies appear a little late when mealybug population reaches very high numbers. Some local natural enemies have their own limitations like hyperparasitism or reach a biotic balance. Addition of these local natural enemies to the crop ecosystem may not enhance the natural parasitism or predation to bring down the mealybug population effectively. Exotic natural parasitoids/predators from other countries help extensively to suppress mealybugs sometimes completely. It is proved in the case of several mealybugs, particularly alien mealybugs. For the biological control, a thorough knowledge on mealybugs is highly essential, and identification up to species is mandatory.

Only very few books are available on mealybugs: *Mealybugs of California* by McKenzie (1967), *Australian Mealybugs* by Williams (1985), *Mealybugs of Central and South America* by Williams and Granara de Willink (1992), *A Systematic Catalogue of the Mealybugs of the World (Insecta, Homoptera, Coccoidea, Pseudococcidae and Putoidae): With Data on Geographical Distribution, Host Plants, Biology and Economic Importance* by Ben-Dov (1994), and *Mealybugs of Southern Asia* by Williams (2004). They deal mostly with the taxonomical aspects of mealybugs in different regions. Efforts have been made to present information comprehensively about all basic aspects of mealybugs and also management tactics known for mealybug species affecting different crop plants in different countries. Section I of the book presents a generalized description of morphology, cytogenetics, taxonomy, molecular characterization, biology, damage, ecology, natural enemies, ant association, control measures, insecticide resistance, pheromones, etc. Section II deals with management practices of mealybugs in different crops.

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Part I

Mealybugs

2 Morphology

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Mealybugs are characterised by their bodies being covered with mealy or wax secretions. They are elongate to oval in shape with distinct segmentation (head, thorax and abdomen). Mealybugs are often characterised as having a white, mealy or powdery secretion covering both dorsal and ventral surfaces of their body. Species that occur in concealed habitats such as leaf sheaths of grasses either lack this secretion or have only small amounts of it. Marginal areas of their body have a series of protruding lateral wax filaments. These filaments may be absent, confined to the posterior one or two abdominal segments, or occur around the entire body margin. A filamentous secretion often is produced that encloses the eggs and at least part of the body. General morphology of the mealybugs is based on common species, and morphological characters vary slightly from species to species in mealybugs (McKenzie 1967; Williams 2004).

2.1 Head

Antennae Antennae are well developed in adults, normally with five to nine segments, except in a few forms where they are reduced to mere two-segmented tubercles. The cassava mealybug *Phenacoccus manihoti* Matile-Ferrero has sensory equipment on its antennae that can detect, by olfaction and contact, chemicals released by the plant. Nine different types of sensilla have been identified on the antenna of the cassava mealybug. Antennae are remarkable in *Allomyrmococcus* Takahashi and other genera of the tribe Allomyrmococcini, in which they are often as long as the body and densely covered in slender setae.

Eyes In certain *Pseudococcus* species, there are tiny loculi or discoidal pores associated with the eyes, and these structures appear to have some taxonomic significance.

Mouthparts The rostrum or beak is a cone-shaped structure that lies approximately between, and slightly anterior to, the front coxae. As a general rule, the rostrum is approximately one-third longer than broad, although in some species it is almost as broad as long. The anterior sclerotised portion of the mouthpart is the clypeus, including the internal framework of the tentorium, mandibles and maxillae bases. The clypeus varies in shape from species to species and may, at times, be on taxonomic significance. The labium appears to be three segmented. The basal segment is quite small and inconspicuous, comprising a small, sclerotised piece at each side, which constitutes the cone. In mealybugs, there are three segments clearly visible on the anterior

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surface of labium. The basal segment usually possesses three pairs of setae. At the tip of the apical segment, there is a pair of minute setae that are usually stiff and spine-like, but because of their small size they are not shown in the accompanying illustrations. Immediately anterior to these apical setae on the anterior surface there are usually four pairs of subapical setae. On the remainder of the medial and apical segments there are varying numbers of setae, which reach their greatest numbers in members of the tribe Allomyrmococcini associated with herdsmen ants. There are only two pairs of anterior setae on the posterior surface of the apical segment in subfamily Pseudococcinae, whereas there are three such pairs of setae in the subfamilies Trabutininae, Rhizoecinae and Sphaerococcinae. One pair of the subapical setae is grooved on the labium of *Phenacoccus manihoti*.

2.2 Thorax

Spiracles The spiracles in the Pseudococcidae are represented by two thoracic pairs only. The anterior pair of spiracles is located in the intersegmental membrane between the prothorax and the mesothorax. In the same manner, the posterior pair of spiracles indicates the border between the mesothorax and the metathorax. In a few species of *Antonina* and certain other grass-infesting forms, the spiracles are noticeably enlarged, sclerotised and often have a conspicuous crescent of crowded trilocular-type pores situated around the lateral margin of the atrium. Usually, however, the spiracles are essentially the same size and shape throughout the family.

Legs A principal leg character was considered to be the presence or absence of a denticle or tooth on the plantar surface of the claw. This tooth has, at its very highest development, a quite insignificant character, yet it correlates very closely with other characters, which in their totality define the genera that may be referred to as the *Phenacoccus* series. The claws bear two apically spatulate or setose digitules that arise, one on each side, from near the claw bases. The digitules may be long or short. If they are long, they may extend to or slightly beyond the tip of the claws and may be either knobbed or setose at the apices. Digitules less than half the claw length are usually setose.

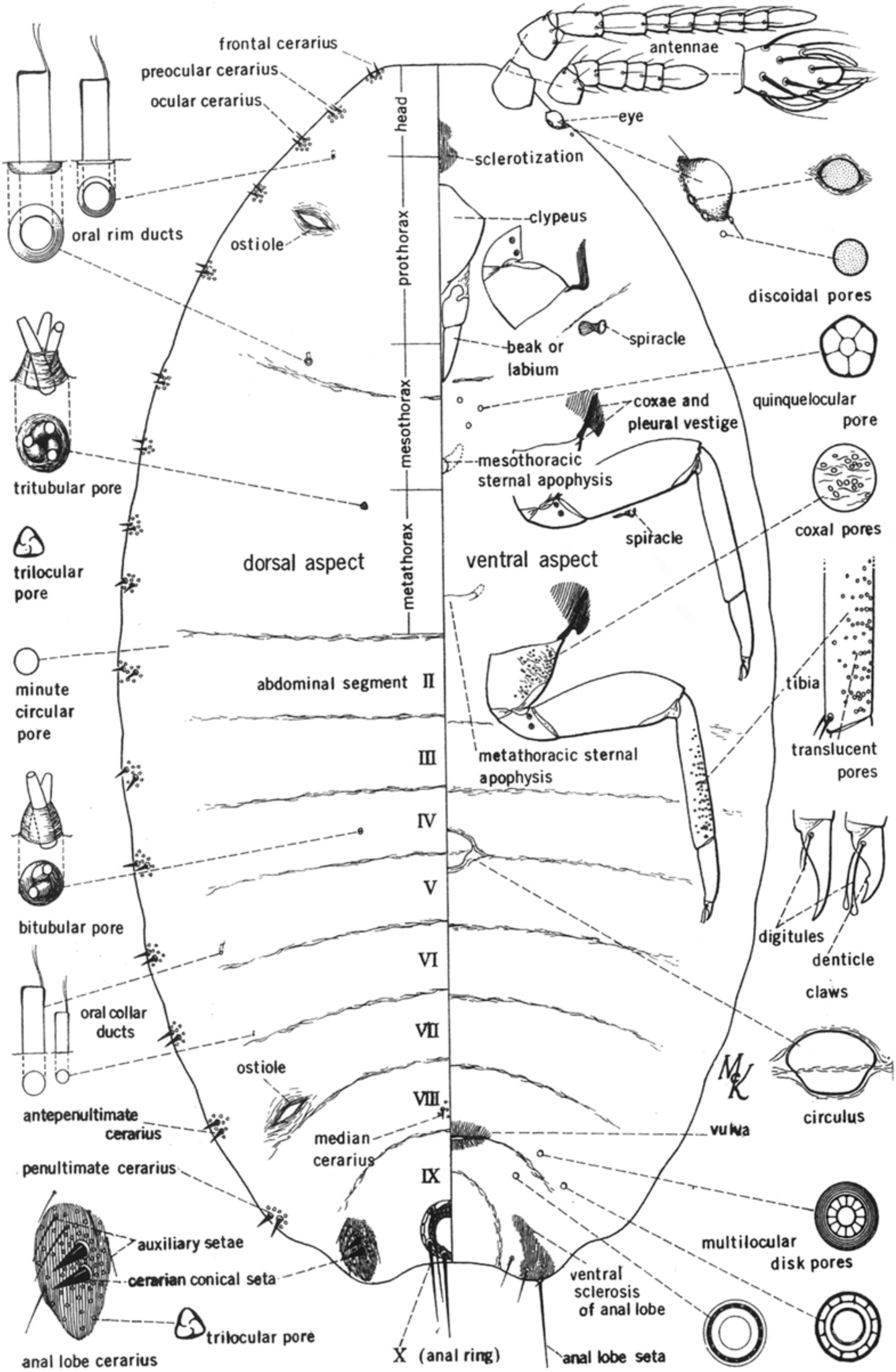
Translucent Dots or Pores They occur on the hind femur and tibia of quite a few mealybugs.

Clypeolabral Shield In some species, an anterior extension to the clypeolabral shield is present.

2.3 Abdomen

Dorsal Ostioles The most characteristic feature of the family Pseudococcidae is the occurrence of two pairs of slit-like openings on the body dorsum, here designated as dorsal ostioles. The posterior pair lies within the boundaries of the seventh abdominal segment, and the anterior pair appears to belong to the foremost part of the prothorax. The edges of the ostioles are invaginated to form anterior and posterior lips, and these are usually beset with setae and trilocular pores. When a living mealybug is disturbed or irritated, a globule of liquid is often discharged from one or more of these ostioles.

Cerarii These structures number at most 18 basic pairs. A cerarius is often composed of two or more conical to lanceolate setae and a compact group of trilocular pores. Each cerarius produces a lateral wax filament when viewed alive. The number of cerarii may vary even between species in the same genus or cerarii may be absent entirely. Sometimes a cerarius may consist of only a single conical seta or there may be multiple conical setae. In some species, there are additional, intermediate cerarii present and the cerarii may appear to form a continuous row, when it is difficult to determine the number of basic pairs. Usually in the second and third instars, the cerarii are more clearly defined so that the total number can be verified. In some cerarii, the conical setae may be replaced by flagellate setae surrounded by trilocular pores, or a cerarius may contain one conical seta and one flagellate seta. It has been a



Generalised and semidiagramatic drawing representing morphological structure of mealybugs (Courtesy: Williams DJ) custom to refer to the first three cerarii on the head as the frontal, preocular and ocular cerarii. They are numbered from the anterior end downwards, as are all body characters. Each of the full complement of cerarii is numbered as $C_{1-18,}$ with C_{11-18} occurring on abdominal segments I–VIII. The segmentation on the thorax is sometimes not clearly defined but by tracing the lateral ends of the intersegmental lines when possible, it seems that there are two cerarii present on each thoracic segment (C_{5-10}) and four on the head (C_{1-4}). There are many species with 17 pairs of cerarii, when C_2 (the preocular pair) is missing. When only a single pair of cerarius is present, it is located on the anal lobes only (C_{18}). Some species possess additional, dorsal cerarii.

Anal Ring The anal ring (anal opening) in the Pseudococcidae is situated on what is here interpreted as the tenth abdominal segment. The anal ring usually lies on the dorsal side of the body situated close to the posterior apex of the abdomen. In some cases, it may be displaced anteriorly on the dorsum and lie some little distance from the posterior apex of the abdomen, and in rare instances it may be displaced posteriorly to the venter. The anal opening is usually surrounded by a more or less sclerotised ring that normally bears six or more slender setae. In this sclerotised band in most members of Pseudococcidae appears numerous irregular pores. In a few instances, the ring is much reduced, the sclerotization is slight and the pores are absent.

Anal Lobes The anal lobes are situated on the more or less protruding posterior areas of the ninth abdominal segment. On the ventral surface, they possess at the apex usually the longest body seta, here designated as 'anal lobe seta'. On the dorsal surface of each anal lobe is a cerarius, probably more prominent than others along the body margin because of more trilocular pores, slender auxiliary setae, two to several stout conical setae and often a sclerotised dorsal surface.

Vulva The presence of vulva is an indication of full maturity of the adult female. It is important as a landmark to indicate the exact position on the venter of the anterior margin of the ninth and posterior margin of the eighth abdominal segments.

Circulus The circulus when present consists of a simple, sclerotised ring enclosing an area of variable size. It may be situated on the venter in the intersegmental fold between the fourth and fifth abdominal segments, or on the fourth abdominal segment above. It encloses an area which is free from pores and setae.

Pores and Ducts Several different types of pores and ducts on the body may be recognised in the Pseudococcidae, which include bitubular and tritubular (sometimes called bi- or tritubular cera res), trilocular, minute circular (sometimes called simple disc pores), multilocular (sometimes called discoid or genacerores) and quinquelocular types.

Trilocular Pores or Swirled Pores They are usually present in species of the family Pseudococcidae. Occasionally, they are larger on the dorsum than on the venter and in some species of *Rastrococcus*, those in and near the cerarii are different in shape and size to others elsewhere on the body. Some trilocular pores in *Antonina* and *Chaetococcus* are as deep as they are wide.

Discoidal Pores These are usually minute, simple, circular pores present in varying numbers over the dorsum and venter. In some species of *Dysmicoccus*, the discoidal pores have a granular surface. The rim of each pore may be thin or conspicuously wide and heavily sclerotised. In the genus Stricklandina, there are normal minute pores present and others with thick sclerotised rims and a granular or tessellated surface. Occasionally, discoidal pores are oval, as in some species of *Eurycoccus*. In *Hordeolicoccus*, some species possess remarkably large discoidal pores, each about the same size as a multilocular disc pore. An unusual type of discoidal pore is described herein for some species of *Exallomochlu*s, in which the centre of the pore is extended.

Tubular Ducts There are many variations in the tubular ducts. The presence or absence of oral rim ducts is sometimes difficult to decide because, although the rim may be present, it may not be elevated from the surface of the derm, as in *Leptococcus* species. Sometimes, oral collar tubular ducts possess indistinct rims, which are discussed in this chapter.

Microducts Structures that appear as minute dots on the surface of the cuticle are actually microducts. They may be common throughout the Pseudococcidae.

Ostioles Normally, they are present as two pairs and lie submedially on the dorsum but in the Allomyrmococcini they are situated on the lateral margins, when the sclerotised lips are prominent.

Body Setae Most pseudococcids have at least a few small dorsal setae, and some are quite setose. In certain species the setae are very slender, while in others they may be stout and conical or lanceolate, often the same size as that in the cerarii. Rarely the stout setae may be truncated apically, and at times they may be borne upon a sclerotised process. The setae on the venter are usually slender, and normally are situated in transverse rows on the abdominal segments, in a group anterior to the clypeus, and on areas designated as sternal in the thoracic segments. Infrequently the setae are of taxonomic value at the species level.

Bitubular Cerores and Tritubular Cerores They are structures peculiar to the subfamily Rhizoecinae, and in southern Asia they are present in the genera Rhizoecus and Geococcus.

2.4 Morphology of Various Instars of Both Sexes of the Mealybug

Maconellicoccus hirsutus (Green) is taken as model for detailed descriptions of the nymphs and adults of both sexes. Seven types of glandular structure are described, and their roles, mainly in the production of waxy secretions, are discussed (Ghose 1971).

2.4.1 First-Instar Nymph

At this stage, the male and the female cannot be distinguished. They are elongate to oval, on an average 390 μ long and 180 μ wide; anal lobes are prominent (Fig. 2.1). Only one pair of cerarii is present with two conical setae in the abdominal segment IX. Normally, one trilocular disc pore is present in the cerarian zone of each segment. Head: Six jointed antennae, average measurements of the segments in μ are I, 22; II, 21; III, 17; IV, 16; V, 16; VI, 55. Eye is about 15 μ in diameter at the base and 7 μ high. Beak is conical, on an average 62 μ long and 40 μ wide at the base. Thorax: Average measurements of posterior leg (in μ) are as follows: trochanter, 30×19; femur, 68×27; tibia, 55×18; tarsus, 65×15; claw, 16; tarsal digitule, 23; claw digitule, 15. Both anterior and posterior spiracles are about 6 μ in diameter at atrium and about 15 μ long. Abdomen: Anal ring is situated in between two anal lobes, 26 μ in diameter; anal ring setae are 44 μ long on an average. Apical setae are 135 μ long on an average. Anal lobe bar is weakly sclerotised. Dermal structures: Only one trilocular disc pore is present in each lip of both the anterior and the posterior pairs of ostioles. Trilocular disc pores, about 3 μ, are present in transverse rows on

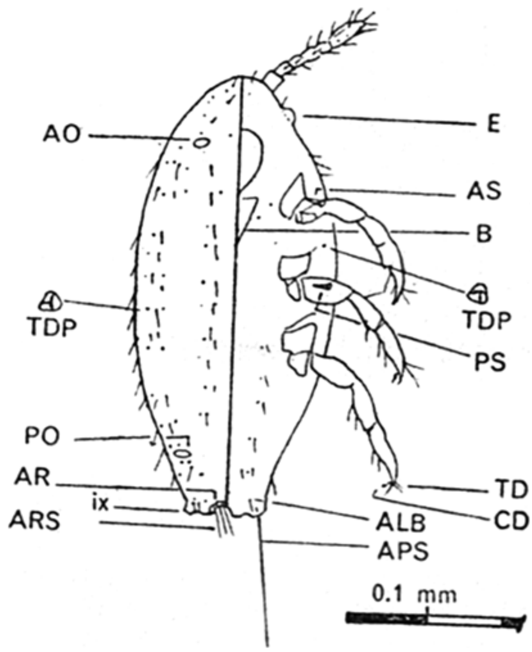


Fig. 2.1 First-instar nymph of *M. hirsutus*. *E* eye, *AS* anterior spiracle, *B* beak, *TDP* trilocular disc pore, *PS* posterior spiracle, *TD* tarsal digitule, *CD* claw digitule, *ALB* anal lobe bar, *APS* apical seta, *AO* anterior ostiole, *PO* posterior ostiole, *AR* anal ring, *ARS* anal ring seta (Courtesy: Ghose SK)

both dorsum and venter, but more in the former. Their approximate numbers are dorsal abdominal segments IX, 4; VIII, 4; VII, 8; VI, 6; V,5; IV, 7; III, 6; II, 6, metathorax, 10; mesothorax, II; prothorax, 14; head, 10; and ventral abdominal segments IX, 0; 2 in each of the segments VIII, VII, VI, V, IV and III; II, 4; metathorax, 5; mesothorax, 4; prothorax, 2; head, 4. The first instar nymph differs from other nymphal instars with the absence of tubular ducts.

2.4.2 Second-Instar Female Nymph

Body is oval with anterior end slightly broader and rounded; anal lobes are prominent, on an average 620 μ long and 360 μ wide (Fig. 2.2). Four pairs of cerarii with two conical setae on the abdominal segments VI–IX are present. The cerarian setae of the other abdominal segments are elongated and slender. Usually, two ducts of oral rim type and three trilocular disc pores in each cerarian zone of segments IX and VIII and two disc pores in the ceracian zone of all other abdominal segments are present. *Head*: Six jointed antennae, average measurements in μ are I, 35; II, 23; III, 33; IV, 21; V, 21; VI, 62. Eye about 21 μ in diameter at the base and 9 μ high. Beak is conical, on an average 83 μ long and 52 μ wide at the base. *Thorax*: Average measurements of posterior leg in μ are trochanter, 42×24; femur, 85×35; tibia, 70×23; tarsus, 70×18; claw, 21; tarsal digitule, 34; claw digitule, 19. Anterior spiracle is about 29 μ long and 10 μ wide at atrium; posterior one is about 32 μ long and 10 μ at atrium. *Abdomen*: Anal ring 41 μ in diameter; anal ring setae 64 μ long on an average. Apical setae 173 μ long on an average. A moderately sclerotised bar is present in each anal lobe. Circulus is present. *Dermal structures*: Anterior pair of ostioles with two trilocular disc pores and one seta on each lip; posterior ones each with three pores and one seta on the upper lip and two pores on the lower lip. Trilocular disc pores are present on both dorsum and venter. Dorsal pores measure 4.0–4.4 μ and ventral ones 3.2–3.6 μ wide. Their approximate numbers are dorsal abdominal segments IX, 6; VIII, 9; VII, 15; VI, II; V, 12: IV, 12; III, 10; II, 10; metathorax, 20;

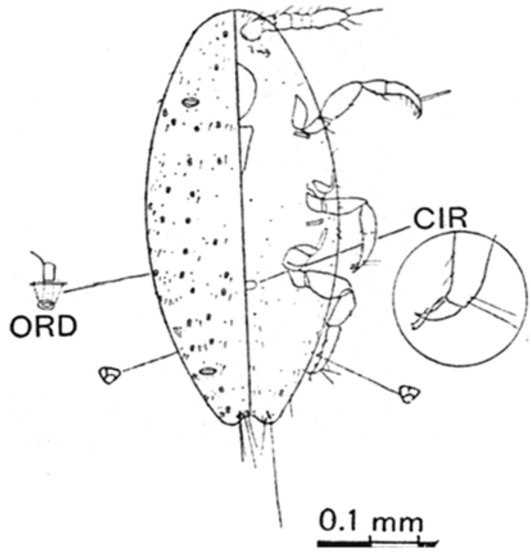
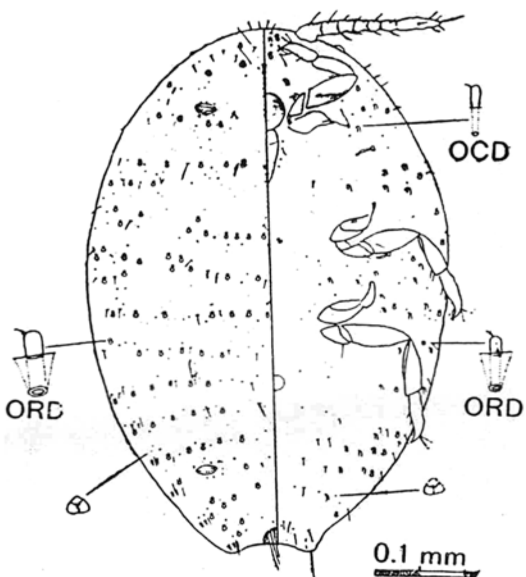


Fig. 2.2 Second-instar female nymph of *M. hirsutus*. *CIR* circulus, *ORD* oral rim duct

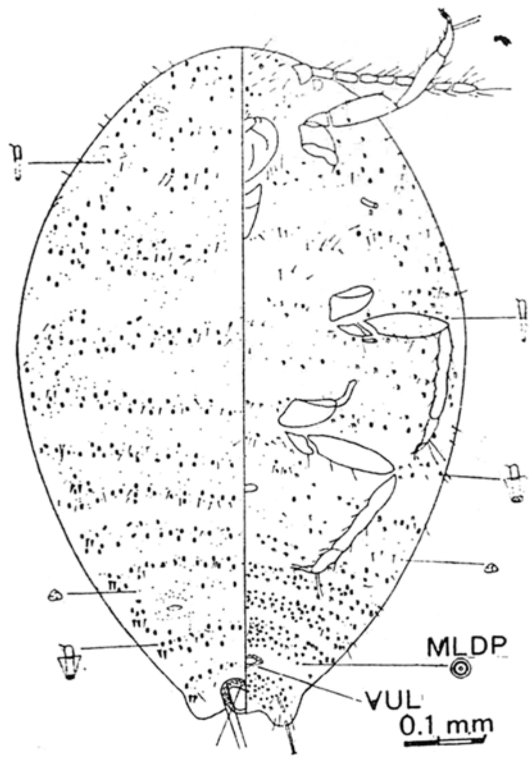
mesothorax, 35; prothorax, 40; head, 20; and ventral abdominal segments IX, 4; VIII, 2; VII, 4; VI, 6; V, 4; IV, 6; Ill, 4; II, 5; metathorax, 9; mesothorax, 14; prothorax, 15; head, 5. Tubular ducts of oral rim type about 8 μ long and 5 μ wide are present on dorsum. Their numbers are abdominal segments IX, 2; VIII, 2; VII, 0; VI, 3; V, 4: IV, 4; III, 5; II, 4; metathorax, 6; mesothorax, 7; prothorax, 10; head, 3. Only one duct is present in the venter of abdominal segment VIII.

2.4.3 Third-Instar Female Nymph

Body is oval with anterior end slightly broader and rounded; anal lobes are prominent, on an average 1.095 mm long and 0.678 mm wide. Five pairs of cerarii are present on the last five abdominal segments, usually with two conical setae in each. Anal lobe cerarii each with three trilocular disc pores and one oral rim duct and the remaining each cerarius with two disc pores and one oral rim duct are present. *Head*: Seven jointed antennae, average measurements in μ are I, 45; II, 39; III, 31; IV, 26; V, 27; VI, 30; VII, 74. Eye is about 25 μ in diameter at the base and 15 μ high. Beak is conical, on an average 98 μ long and 52 μ wide at the base. *Thorax*: Average measurements of posterior leg in μ are trochanter, 66×34; femur, 127×53; tibia, 121×30; tarsus, 87×26; claw, 27; tarsal digitule, 36; claw digitule, 24. Anterior spiracle is about 34 μ long and 13 μ wide at atrium; posterior one is 36 μ long and 13 μ wide. *Abdomen*: Anal lobes are prominent; anal ring on an average is 60 μ in diameter; anal ring setae are 84 μ long; apical setae is 209 μ long on an average. Anal lobe bar is moderately sclerotised. *Dermal structures*: Ostioles can be found with a few trilocular disc pores. Anterior pair with three pores and one seta on each lip; posterior ones with three to four pores and zero to one seta on each lip. Dorsal setae are of two sizes, longer and stout, and shorter and thin. Ventral body setae are longer and flagellate. Circulus is about 33 μ long. Trilocular disc pores, 3.2–3.6 μ, are present on both the surfaces of the body but more on dorsum. Their approximate numbers are dorsal abdominal segments IX, 14; VIII, 15; VII, 32; VI, 19; V, 18; IV, 19; III, 30; II, 30; metathorax, 23; mesothorax, 36; prothorax, 42; head, 20; and ventral abdominal segments IX, 4; VIII, 11; VII, 12; VI, 13; V, 10; IV, 10; III, 12; II, 12; metathorax, 15; mesothorax, 28; prothorax, 24; head, 13. Tubular ducts of oral rim type are present mostly on dorsum and a few on venter. Ducts on dorsum are 9 μ long and 6 μ wide. Ventral ducts are about 3/4 wide of those in dorsum. Their approximate numbers are dorsal abdominal segments IX, 6; VIII, 11; VII, 4; VI, 10; V, 11; IV, 14; III, 14; II, 14; metathorax, 21; mesothorax, 27; prothorax, 19; head, 7; and ventral abdominal segments IX, 0; VIII, 2; VII, 2; VI, 2; V, 2; IV, 2; III, 3; II, 3; metathorax, 2; mesothorax, 6; prothorax, 6; head, 4. Tubular ducts are of oral collar type, 3.5–4.0 μ long and 1.5 μ wide, mostly distributed in the marginal and submarginal areas of venter, rarely found on dorsum. Their approximate numbers in venter are abdominal segments IX, 0; VIII, 2; VII, 4; VI, 5; V, 4; IV, 4; III, 4; II, 7; metathorax, 10; mesothorax, 8; prothorax, 4; head, 4.



Third-instar female nymph of *M. hirsutus* (*Green*). *OCD* oral collar duct, *ORD* oral rim duct
(Courtesy: Ghose SK)



Adult female of *M. hirsutus. MLDP* multilocular disc pore, *VUL* vulva

2.4.4 Adult Female

Body is ovoid, slightly broader and rounded at the anterior end, on an average 1.7 mm long and 1.1 mm wide, attaining larger size (3.2 mm×l.7 mm) with maturity. Anal lobes are prominent, particularly in young adults. Six pairs of cerarii in the abdominal segments IV–IX, usually with two cerarian setae are present; occasionally a third one is present in the cerarii of segments VIII and IX. Segment IV has generally only one cerarian and one stout and longer setae on one side, the other cerarius has two normal cerarian setae. Cerarii are without auxiliary setae except the anal lobe pair. Each cerarius of segment IX has 5–6 trilobular disc pores and three oral rim ducts.

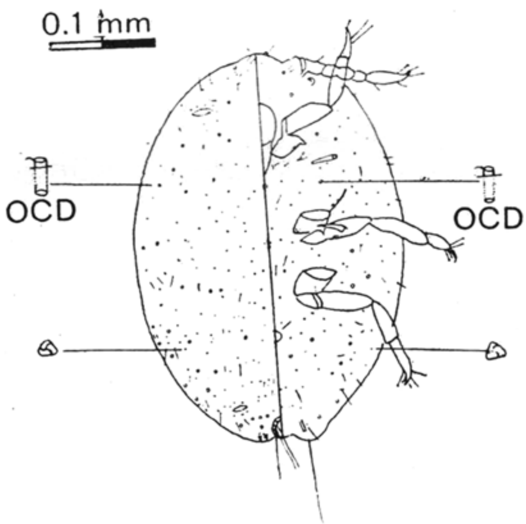
Head: Antennae appear to be nine jointed because of a pseudo-articulation in the terminal joint. Average measurements in μ are I, 54; II, 54; III, 52; IV, 34; V, 41; VI, 40; VII, 39; VIII, 37+56. Eye is about 32 μ wide at the base and 22 μ high. Beak is conical, on an average 141 μ long and 86 μ wide at the base.

Thorax: Average measurements of posterior leg in μ are trochanter, 97×36; femur, 217×68; tibia, 227×32; tarsus, 100×27; claw, 33; tarsal digitule, 49; claw digitule, 31. Tarsal digitule, of the anterior legs are unequal, one is about 49 μ, whereas the other is about 42 μ. Anterior spiracle is about 51 μ long and 26 wide at atrium, and posterior one 55 μ long and 29 μ wide.

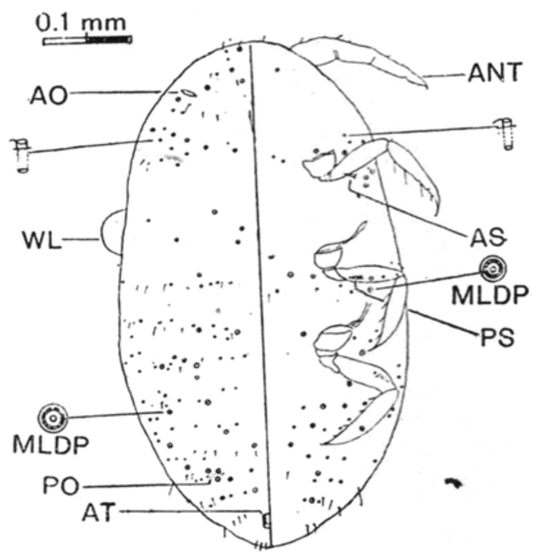
Abdomen: Anal ring on an average is 72 μ in diameter; anal ring setae is 154 μ long; anal lobe bar is moderately sclerotised; apical setae are 251 μ on an average. Dermal structures: Anterior pair of ostioles with nine to ten trilocular disc pores and one to three setae on each lip are present; posterior one with 9–12 pores and 1–4 setae on each lip. Body setae are of two sizes on both dorsal and ventral surfaces, the ventral ones being generally longer. Circulus is about 77 μ long. Trilocular disc pores are more numerous and larger on dorsum, about 4 μ, whereas those on venter measure about 3 μ. These pores are much more numerous (above 20 %) in the adult than in the third-instar females. Tubular ducts are of two types: oral rim ducts and oral collar ducts, the former being predominant in the dorsum and the latter in the venter. Oral rim ducts of dorsum are larger than those of venter and more or less arranged in transverse rows, about 9.5 μ long and 4–5 μ in diameter at the opening. Their approximate numbers are abdominal segments IX, 12; VIII, 20; VII, 10; VI, 22; V, 32; VI, 35; III, 34; I1, 36; metathorax, 54; mesothorax, 62; prothorax, 42; head, 18. A few rim ducts of venter are found in the marginal and submarginal regions of the body. Their numbers are abdominal segments IX, 2; VIII, 4; VII, 3; VI, 5; V, 5; IV, 7; III, 7; II, 6; rnetathorax, 4; mesothorax, 7; prothorax, 8; head, 4. Oral collar ducts of venter are variable in size, 2.4–2.8 μ in diameter at opening and on an average 10.5 μ long. The ducts of the dorsum are generally smaller. These ducts are much more numerous (six to seven times) in the adult than in the third nymphal female. Multilocular disc pores, 5 μ in diameter, are restricted to the submarginal and median regions of venter, mainly in the abdominal segments VI–IX.

2.4.5 Second-Instar Male Nymph

Body is oval with anterior end slightly broader and rounded; anal lobes are prominent. Average body size in the early stage is 625 μ long and 390 μ wide. It increases greatly and attains 970×438 μ at the end of the feeding period. Normally, one pair of cerarii present are in the abdominal segment IX; generally each with two and rarely stout conical setae, one auxiliary seta, one microduct of oral collar type and one trilocular disc pore. Segment VIII is occasionally with one or two cerarian setae in each. The cerarian setae of other segments are slender and elongated. Generally, two disc pores and one collar duct are present in each cerarian zone of other segments. *Head*: Six jointed antennae, but the joints cannot be recognised as and when the antennae of third-instar male nymphs develop inside this instar. Average measurements of the segments in μ are I, 32; 11, 27; III, 34; IV, 20; V, 22; VI, 62. Eye is about 22 μ in diameter at the base and 10 μ high. Beak is conical, on an average 94 μ long and 57 μ wide at the base. *Thorax*: Average measurements of posterior leg in µ are trochanter, 46×26; femur, 98×38; tibia, 84×20; tarsus, 74×18; claw, 21; tarsal digitule, 34; claw digitule, 20. Anterior spiracle is about 29 µ long and 8 µ wide at atrium; posterior one about 31 µ long and 9 µ at atrium. *Abdomen*: Anal ring on an average is 36 µ in diameter; anal ring setae are 66 µ long; apical setae are on an average 172 µ long. Anal lobe bar is moderately sclerotised. *Dermal structures*: Three trilocular disc pores and one to three setae on both upper and lower lips of anterior pair of ostioles and two to three pores and zero to one seta on each lip of the posterior pair are present. Circulus is present. Trilocular disc pores are about 3 µ and more numerous on dorsum. Their approximate numbers are dorsal abdominal segments IX, 9; VIII, 9; VII, 18; VI, 13; V, 15; IV, 16; III, 22; II, 19; metathorax, 20; mesothorax, 44; prothorax, 32; head, 26; and ventral abdominal segments IX, 4; VIII, 5; VII, 10; VI, 9; V, 8; IV, 7; III, 8; II, 7; metathorax, 11; mesothorax, 21; prothorax, 16; head, 17. The microducts are of oral collar type, about 7 µ long, present on both dorsum and venter. The ducts in dorsum are wider (3.2–3.6 µ) than those in venter about 2.4 µ; their numbers are dorsal abdominal segments IX, 2; VIII, 5; VII, 2; VI, 2; V, 2; IV, 5; III, 3; II, 7; metathorax, 4; mesothorax, 6; prothorax, 5; head, 4; and ventral abdominal segments IX, 0; VIII, 1; VII, 3; VI, 4; V, 3; IV, 2; III, 2; II, 2; metathorax, 2; mesothorax, 2; prothorax, 2; head, 3.



Second-instar male nymph of *M. hirsulus*. *OCD* oral collar duct
(Courtesy: Ghose SK)



Third-instar male nymph of *M. hirsutus*. *ANT* antenna, *AS* anterior spiracle, *MLDP* multilocular disc pore, *AO* anterior ostiole, *PO* posterior ostiole, *AT* anal tube, *WL* wing-bud

2.4.6 Third-Instar Male Nymph

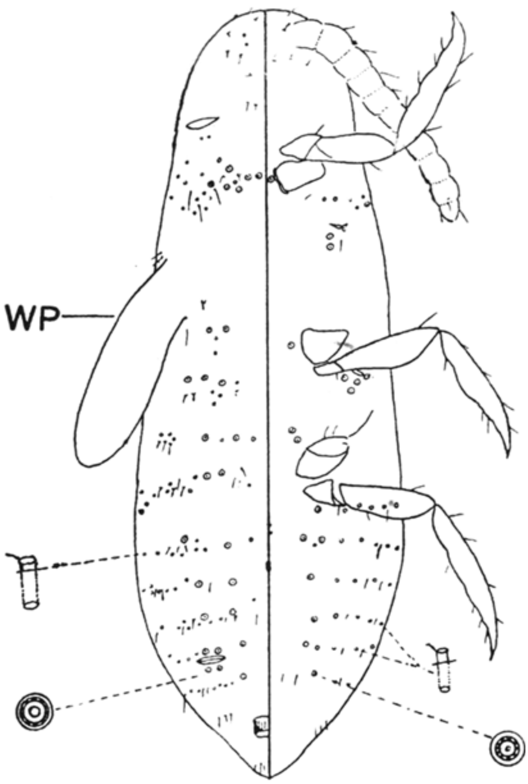
Body is oval, more rounded at the anterior end, on an average 1.138 mm long and 0.504 mm wide. Sclerotisation is in general very weak.

Head: Segmentation of antennae is obscure, with the average length being 276 µ. The joints of the antennae of fourth-instar male become prominent, as and when these are formed inside the antennae of third instar. Mouthparts are absent. Eyes are not discernible.

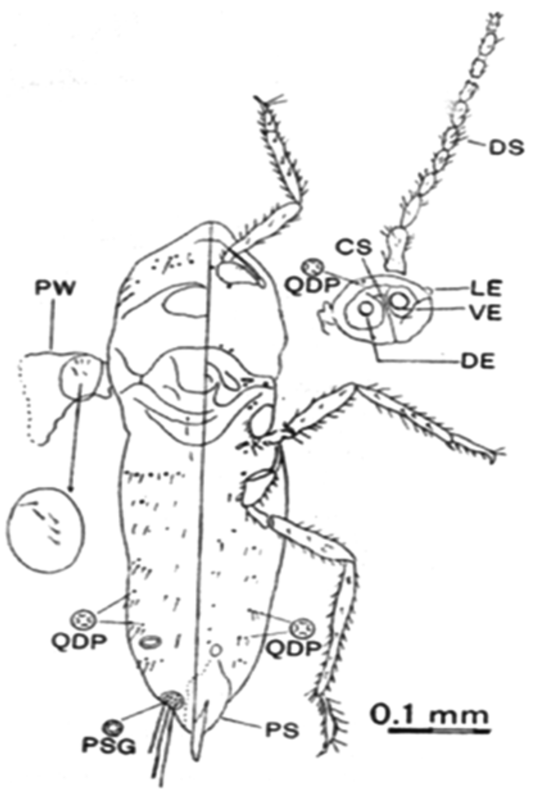
Thorax: Two small wing buds more or less at right angles to the lateral margins of the mesothorax. Legs are short in comparison with body length, with a few pointed setae. Average measurements in μ are trochanter, 52×32; femur, 112×43; segmentation of tibia, tarsus and claw is not well differentiated, their combined length and maximum breadth being 175×31. Tarsal and claw digitules are absent. Anterior spiracle is about 29 μ and posterior one is 29 μ long and 14 μ wide.

Abdomen: Anal ring is absent. A well-sclerotised anal tube, 23 μ long and 26 μ wide, is present in between the abdominal segments IX–X, but its opening on dorsum or venter is not discernible. Near the posterior end of the abdomen, six to seven setae are arranged transversely. Marginal and submarginal areas of segment IX dorsally with five to six more or less transversely arranged setae are present.

Dermal structures: Both anterior and posterior pair of ostioles are present. Trilocular disc pores are absent.



Fourth-instar male nymph of *M. hirsutus*. *WP* wing pad



Adult male of *M. hirsutus*. *CS* coronal suture, *DS* Digitiform seta, *QDP* quadrilocular disc pore, *PS* penial sheath, *PW* part of wing, *PSG* penta locular stellate gland, *DE* dorsal eye, *LE* lateral eye, *VE* ventral eye

Multilocular disc pores: It is 5 μ in diameter, found on both dorsum and venter. Their numbers are dorsal abdominal segments IX, 1; VIII, 4; VII, 11; VI, 3; V, 4; IV, 4; III, 9; II, 4; metathorax, 2; mesothorax, 6; prothorax, 13; head, 8; and ventral abdominal segments IX, 0; VIII, 2; VII, 3; VI, 3; V, 3; IV, 4; III, 2; II, 2; metathorax, 8; mesothorax, 7; prothorax, 6; head 0. Microducts are of oral collar type, about μ long, present on both dorsum and venter. Ducts of dorsum are about 3.2 μ wide, whereas those of venter are about 2.4 μ. Their numbers are dorsal abdominal segments IX, 0; VIII, 7; VII, 5; VI, 10; V, 10; IV, 14; III, 19; II, 19; metathorax, 14; mesothorax, 4; prothorax, 16; head, 4; and ventral abdominal segments IX, 0; VI, 3; VII, 4; VI, 7; V, 5; IV, 5; III, 8; II, 4; metathorax, 5; mesothorax, 2; prothorax, 6: head, 3.

2.4.7 Fourth-Instar Male Nymph

Anterior end of the body is round, narrowing gradually on the posterior end, on an average 1.061 mm long and 0.340 mm wide. Head, thorax and abdomen are more differentiated than the previous instar; sclerotisation is weak. *Head*: Ten jointed antennae, average measurements in μ are I, 34; II, 46; III, 34; IV, 24; V, 27; VI, 29; VII, 32; VIII, 37; IX, 34; X, 74; second segment is the broadest. Mouthparts are absent. Eyes are not discernible. *Thorax*: Average measurements of hind leg in μ are trochanter; 60×29; femur, 128×44; tibia, 142×28; tarsus, 101×25; claw, 16; tarsal and claw digitules are absent. Anterior spiracle is about 26 μ long and 13 μ wide at atrium; posterior one is about 31 μ long and 16 μ at atrium. Wing pads are obliquely attached to the mesothorax. *Abdomen*: In segment X, six to seven setae are transversely arranged on dorsum. Two marginal setae are on dorsum on each side of segment IX, the longest one about 63 μ, and two corresponding ones on venter about 17 μ. Anal tube, apparently without an external opening, is present in between segments IX and X, 22 μ long and 26 μ wide. Penial sheath of adult male is visible as and when it is formed inside this stage.

Dermal structures: Both anterior and posterior pairs of ostioles are present, with two multilocular disc pores and one seta on each lip of posterior pair. Multilocular disc pores, 5 μ in diameter, are present on both dorsum and venter. Their numbers are dorsal abdominal segments IX, 0; VIII, 3; VII, 9; VI, 3; V, 4; IV, 4; III, 4; II, 4; metathorax, 5; mesothorax, 3; prothorax, 12; head, 0; and ventral abdominal segments, IX, 0; VIII, 2; VII, 2; VI, 2; V, 2; IV, 3; III, 2; II, 4; metathorax, 5; mesothorax, 5; prothorax, 4; head, 0. Microducts are of oral collar type, about 7 μ long, present on both dorsum and venter. The ducts of dorsum are much wider (about 3.2 μ) than those of venter (1.8–2.4 μ) arranged more or less in transverse rows. Their approximate numbers are dorsal abdominal segments IX, 0; VIII, 13; VII, 10; VI, 13; V, 13; IV, 17; III, 17; II, 11; metathorax, 8; mesothorax, 4; prothorax, 30; head, 4; and ventral abdominal segments IX, 0; VIII, 4; VII, 8; VI, 8; V, 8; IV, 12; III, 0–1; II, 0; metathorax, 0; mesothorax, 0; prothorax, 10; head, 0.

Adult males are only of macropterous form, on an average 1.055 mm long, including the projected penial sheath, and 0.310 mm wide. *Head*: Ten jointed antennae, average measurements in μ are I, 39; II, 66; III, 79; IV, 69; V, 66; VI, 63; VII, 67; VIII, 67; IX, 58; X, 71. The antennae are clothed mainly with digtiform setae, up to about 39 μ; a few thicker specialised digtiform setae are present on the last three apical segments, the longest ones being 39, 49 and 49 μ on segments VIII, IX and X, respectively. Coronal suture is well developed. Dorsomedian sclerite is weakly sclerotised. Three pairs of eyes are present: dorsal, ventral and lateral. The average diameter of the dorsal and ventral pairs is 30 and 34 μ, respectively. Lateral pair is 25 μ in diameter at the base and 18 μ high on an average. Mouthparts are absent. *Thorax*: One pair of wings, on an average 0.92 mm long and 0 .42 mm wide; each wing has four to five sensory setae near the basal region; average measurements of the posterior leg in μ are trochanter, 62×26; femur, 216×39; tibia, 283×23; tarsus, 99×19; claw, 34; tarsal digitule is very slender, 34. As in antennae, legs are clothed with both digitiform and slender-pointed setae, their maximum length being 31 and 21 μ, respectively. The inner distal end of tibia has three spines. Tarsus has three to four spines at the inner distal end. Anterior and posterior spiracles are about 21 μ wide at atrium, their lengths being 23 and 26 μ. *Abdomen*: Penial sheath is about 179 μ long and 70 μ at the widest portion and 6.5 μ at the projected tip, which is rounded. It has two distinct median lobes, each more or less triangular in shape. Dermal structures: Only posterior pair of ostioles is present. Quadrilocular disc pores, 4.8–5.6 μ in diameter, are present on both dorsum and venter; numbers on dorsum are abdominal segments IX, 0; VIII, 4; VII, 2; VI, 2; V, 3; IV, 2; III, 2; II, 11; metathorax, 0; mesothorax, 0; prothorax, 8–16; head, 4; and ventral abdominal segments IX, 0; VIII, 3; VII, 3; VI, 3; V, 3; IV, 3; III, 0; II, 2; metathorax, 2; mesothorax, 4–8; prothorax, 4–8; head, 0. Two dorsal clusters of stellate or tail-forming pentalocular disc pores are present on each side of the abdominal segment IX. In the centre of each cluster, there are eight to ten disc pores of smaller dimension (about 4 μ in diameter) and three long setae, two of which on an average are 260 μ long. Around the central zone 38–44 disc pores, 5 μ in diameter, are present.

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3 Cytogenetics

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3.1 Introduction

The coccoids which include mealybugs are a relatively small group of highly specialized hemipteran insects. They are parasitic on plants and quite sedentary in behavior (Miller and Kosztarab 1979; Gullan and Kosztarab 1997; Mani 1989; Kondo et al. 2008). The chromosome system of coccoids is of special interest because it is characterized by chromosomal heterochromatization or elimination of the paternal endowment of chromosomes during early embryogeny of the male in the majority of scale insects. The first cytological insight into the nature of this remarkable system came from the pioneering cytology described by Schrader (1921, 1923a). Subsequent studies by Hughes-Schrader (1948) have provided insightful thoughts into the explanation of the genetic and evolutionary implications of "paternal heterochromatization" that could serve as an intermediate stage between regular diploidy and true male-haploidy.

Schrader's interpretation was later confirmed experimentally with a mealybug, for example, *Pseudococcus obscurus* and/or *Planococcus citri* by Brown and his associates (Brown 1958, 1959, 1963, 1964, 1965, 1969; Brown and Nelson-Rees 1961; Chandra 1962, 1963a, b; Brown and Nur 1964; Baer 1965; Nur 1963, 1966a, b, 1967; Brown and Weigmann 1969). Earlier cytological scrutiny had been reviewed by White (1973) and certain aspects of coccoid chromosome systems especially their possible role in the involvement in the chromosome imprinting processes, have been aptly dealt with by Brown (1977) and Brown and Chandra (1977), about certain unusual features by Nur (1980, 1990), and about recent achievements made with respect to biochemical-based cytology by Prantera and Bongiorni (2012). Enormous and extensive cytological and genetic studies of mealybugs belonging to worldwide fauna are available (Little 1957; Carter 1962). However, the efforts on the systematic and cytogenetic aspects of Indian coccoids are very limited. There have

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been sporadic reports that provide incomplete and contradictory information pertaining to Indian fauna for their chromosome systems (Tulsyan 1963; Dikshith 1964, 1966; Chauhan 1970, 1977).

3.2 Mealybug Chromosomes

All coccoids possess holocentric chromosomes, that is, diffuse centromeres (Hughes-Schrader and Ris 1941). Inverse meiosis is a second ancestral condition manifested in coccoids that is also shared with the other closely allied aphids (Ris 1942; Hughes-Schrader 1944, 1948).

Although the cell cycle sequence is different from that of typical meiosis, results are the same; each of the four chromatids of meiotic bivalents reaches one of the four nuclei produced by meiosis. Coccoids are also manifested by those systems in which at least some of the females are produced parthenogenetically, in addition to the usual bisexual mode of reproduction. They are considered to have unique chromosome systems and they offer enormous potential in our understanding of problems such as chromosome imprinting and differential regulation of homologous chromosome sets (Chandra 1971; Chandra and Brown 1973). Chandra (1971) suggested for the first time that there are some similarities and also contrasts between mammalian X-chromosome inactivation and the inactivation of paternal chromosomes in mealybugs. These include genomic imprinting, facultative heterochromatization, and differential regulation of homologous chromosomes. Subsequently, Brown and Chandra (1977) have drawn attention to emphasize that coccoids are at the pinnacle of an evolutionary pyramid of cytogenetic variants and complexity. In order to understand these variations in chromosome mechanics, it becomes essential briefly to review pseudococcid chromosomes.

3.3 Chromosome Numbers and Chromosome Forms

Coccoid chromosomes lack specified centromeric regions. It appears obvious to point out that chromosome fragments perpetuate themselves during successive divisions. In the absence of kinetochore-based cell divisions that prevail in coccoid chromosome systems, and also, in order to accommodate the occurrence of karyotypic changes, Brown (1961) assays chromosome fracture and fusions in the place of the prevalent nature of chromosomal rearrangements. It was also envisaged that simple breakage can determine increase or decrease in chromosome numbers unless a breakage–fusion–bridge cycle intervenes to eliminate the breakage points.

Species relationships can be explained by citing chromosome variability occurring with respect to either chromosome numbers or morphology. Brown (1961) insists upon spontaneous occurrence of chromosome breakage resulting in abundant availability of ruptured chromosomes for increase in the diploid numbers either by chance or incurred by selection. There are an abundant number of cases dealing with karyotypic changes incurring based on chromosome fragmentation in mealybug genomes (Nur et al. 1987; Cook 2000).

Changes in chromosome numbers with respect to pseudococcid species have been reported to be in the range of 8 to 64 and that ranges within coccoids are rather small compared to other insect groups (Hughes-Schrader 1948; Nur et al. 1987). Until now, 115 cytogenetically studied species of mealybugs belonging to 44 genera have been made known (Gavrilov 2007; Gavrilov and Trapeznikova 2007, 2010). Eventhough, the diploid number of chromosomes ranges from 8 to 64, the modal number seem to fall on 10 (Plate 3.6 Fig. 4, 6, 8). Few mealybugs showed intrageneric variation in their chromosome numbers; for example, in genera such as *Antonina* ($2n=12$, 16, 24+Bs), *Nesopedronia* ($2n=18$, 14, 10) and *Trionymus* ($2n=16$, 10, 8), such instances can be cited as useful in taxonomic and phylogenetic considerations of the genus. Accessory chromosomal elements (B-chromosomes) were found in several species of mealybugs (Nur et al. 1987; Gavrilov 2004). But, the detailed investigation of B-chromosomes has been done only in *Pseudococcus viburni* (Signoret; Nur 1962a, 1966a, b). The majority of pseudococcids possess $2n=10$ (Nur et al. 1987; Moharana 1990; Nur 1990; Gavrilov and Trapeznikova 2007, 2010).

Excepting *Planococcus citri* and a few other species, the number of species studied based on employing recently evolved cytogenetic techniques is very low. One of the reasons cited was the difficulties incurred in procuring enough cells for the preparation of chromosomes and of understanding of chromosome basics for detailed cytological analyses. For cytological investigations of Indian mealybug taxa, Parida and Moharana (1982) and Moharana (1990) attempted to enumerate chromosome numbers based on conventional cytological techniques and they were also able to present preliminary assessments of karyomorphological features for more than 20 different species. Based upon female pachytene chromomeric sequences, Raju (1994) made an initial attempt to describe karyotype and comparison of three species of the Indian genus *Planococcus* (viz. *P. citri*, *P. lilacinus* and *P. pacificus*) essentially based on differential banding patterns, but was unable to identify individualistic karyotypes because of lack of discriminating cytogenetic features (Plates 1–5). Gavrilov (2004a, 2007) and Gavrilov and Trapeznikova (2007, 2010) have made elaborate studies resulting in the elucidation of the karyotype for more than 25 species of Russian mealybugs based on squashing techniques for chromosomal preparations. Nur et al. (1987)

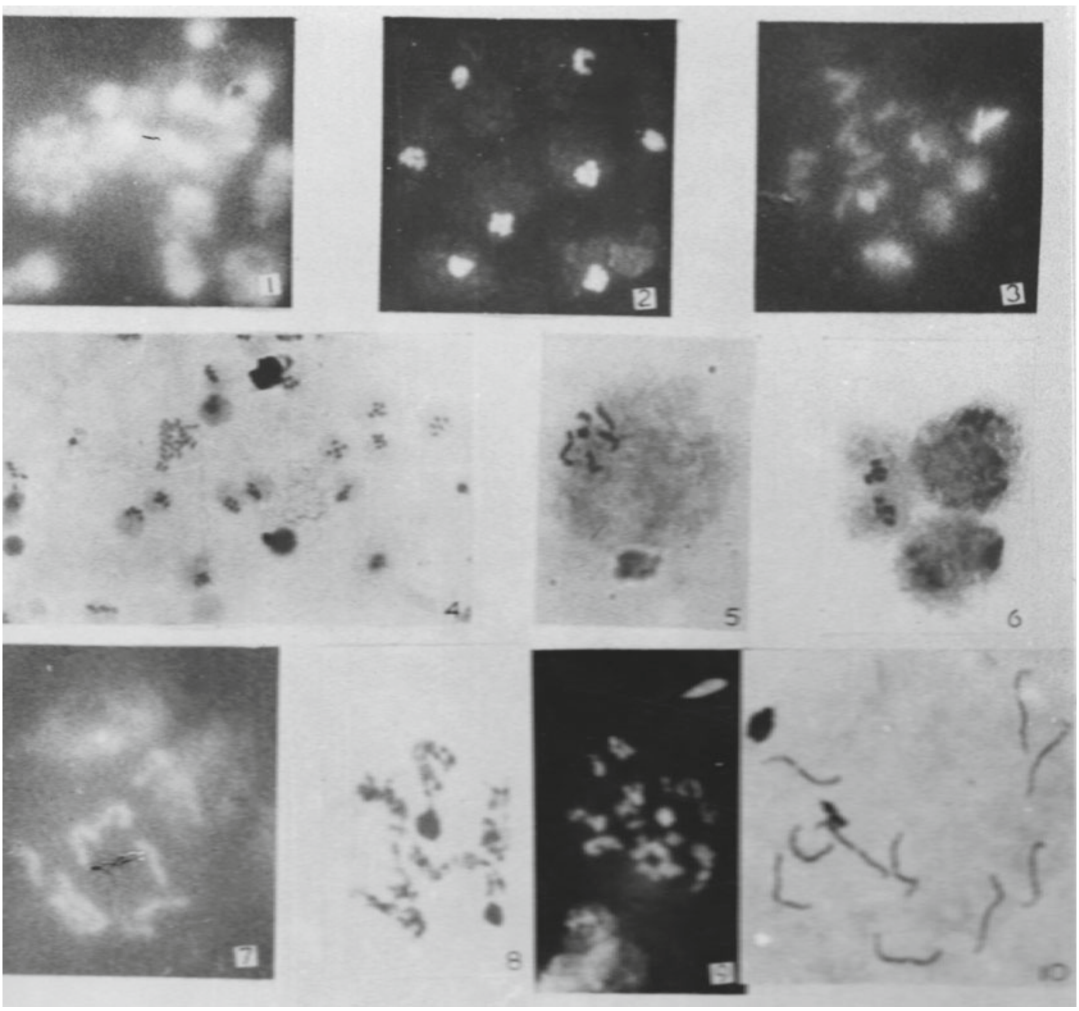

Plate 3.1 Planococcus citri

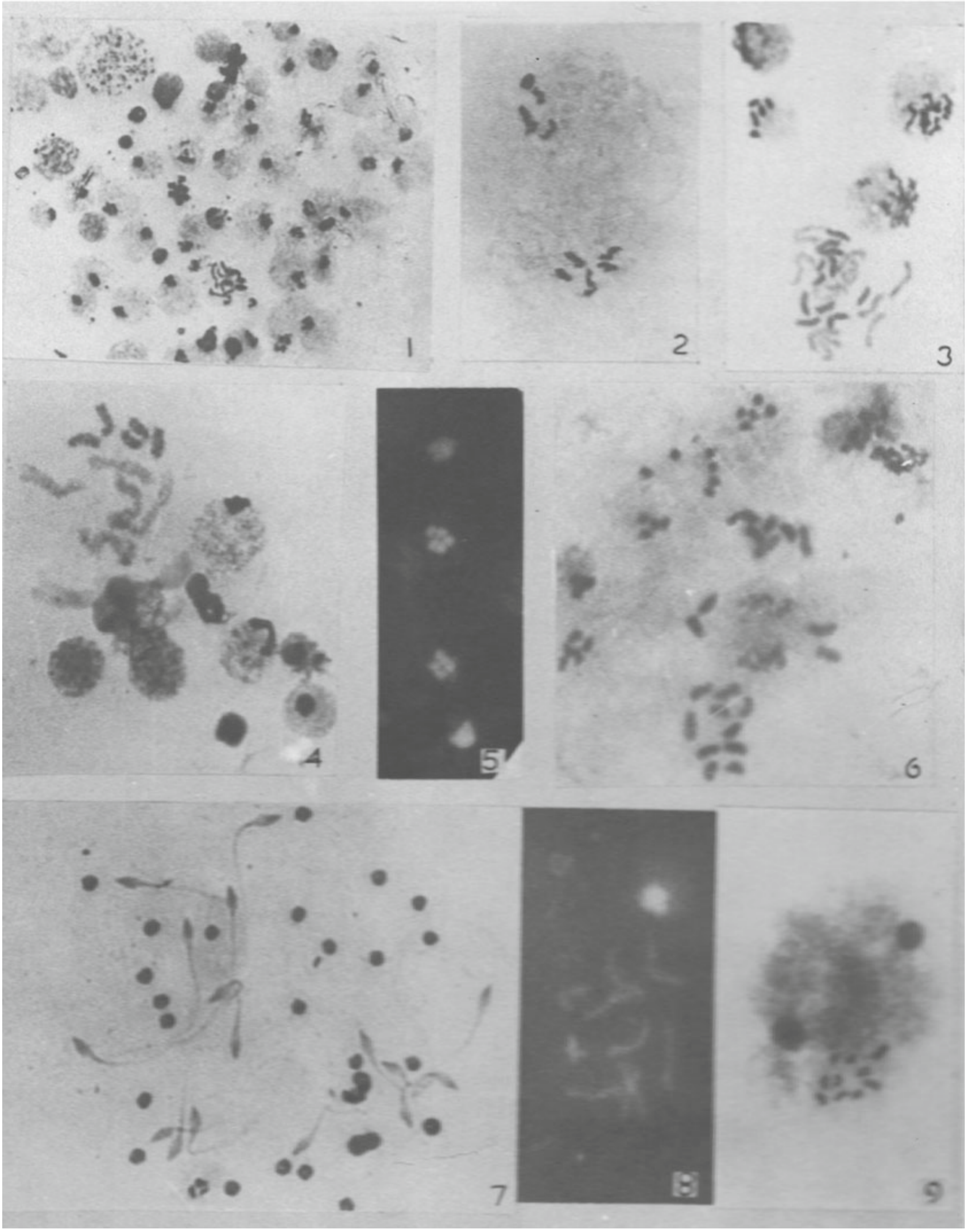

Plate 3.2 Planococcus lilacinus

were able to describe the karyotype of about 80 different species of mealybugs that were collected from various parts of Africa, America, and a few from South Asia. Tremblay et al. 1977 (Italy), Mckenzie 1967 (California), Drozdovskiy 1966 (Russia), Brown 1961 and Hughes-Schrader 1935 (USA), and Schrader 1923a (USA) have contributed enormously to the field of mealybug cytogenetics

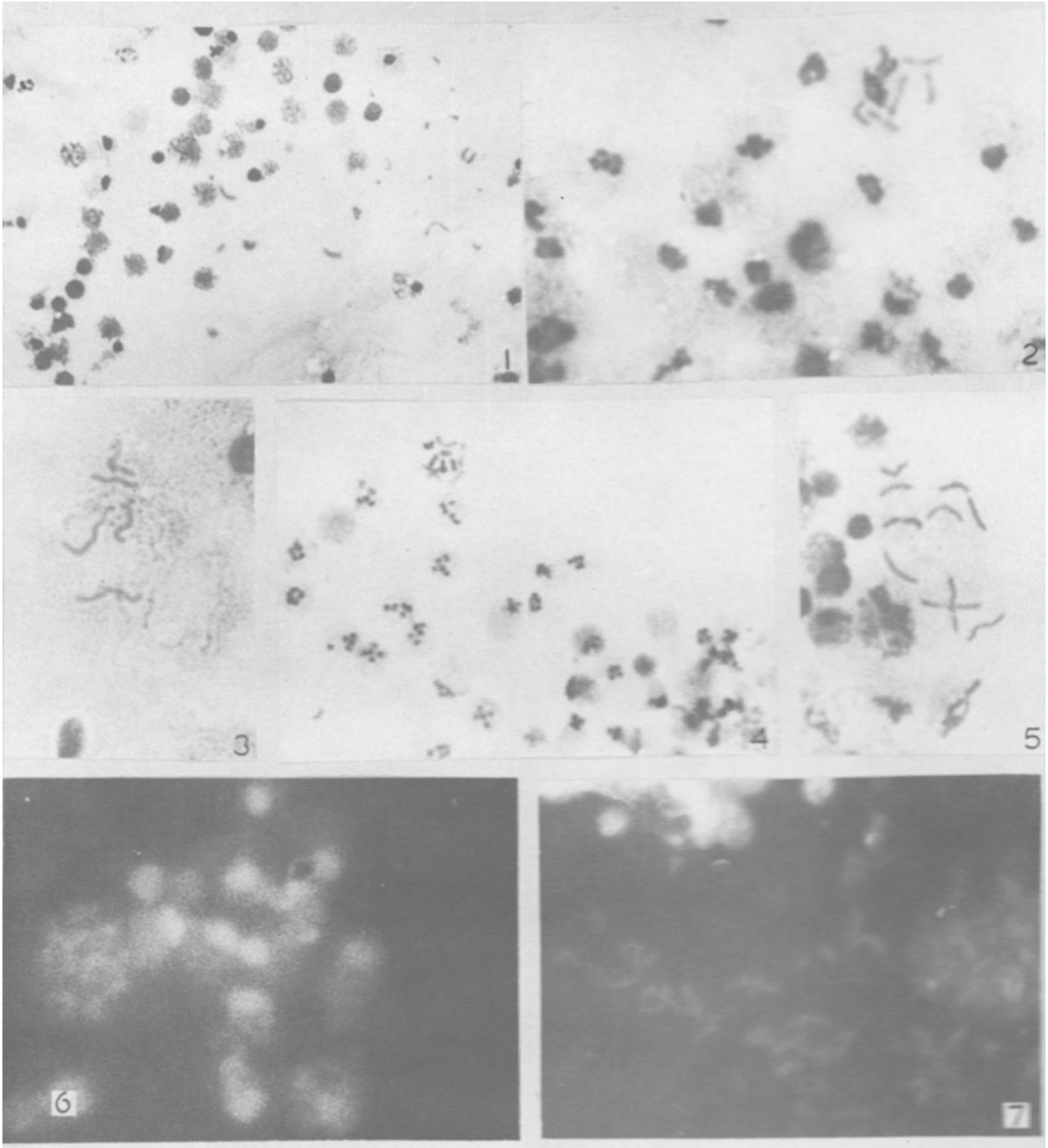

Plate 3.3 Planococcus pacificus

in the form of karyological studies. In an attempt to analyse mealybug chromosome morphology, chromosome preparations were studied through the fluorescent microscopy using appropriate dyes (e.g., Quinacrine Mustard (QM)/QM dihydrochloride), and it was found that these chromosomal complements did not provide any discriminative cytological signatures other than suggesting that they belong to and qualify themselves as belonging to the "Lecanoid type" of chromosome system (Jaipuriar et al. 1985; Venkatachalaiah and Chowdaiah 1987; Venkatachalaiah 1989).

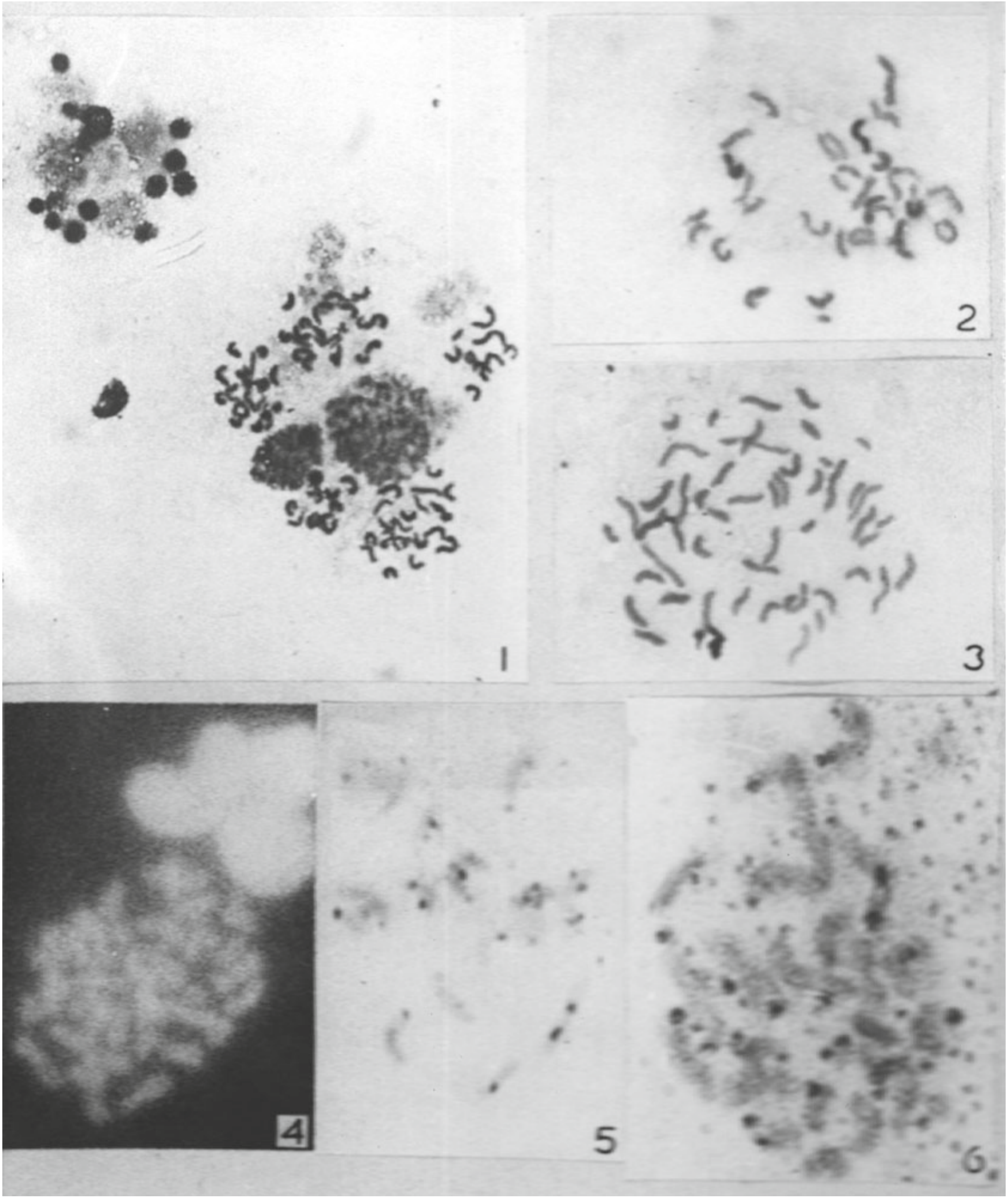

Plate 3.4 Planococcus pacificus

3.4 Telomeres and C- Bands

It is of interest to note that with particular importance to the diffuse nature of centromeric systems manifested by coccoid chromosome morphology it was expected to display discriminative C-staining profiles along the length of each chromosomal fragment in the complement. Employing classical C-staining protocol upon *Planococcus citri* metaphase chromosomal preparations, it was expected to highlight constitutively heterochromatic sites in the complement.

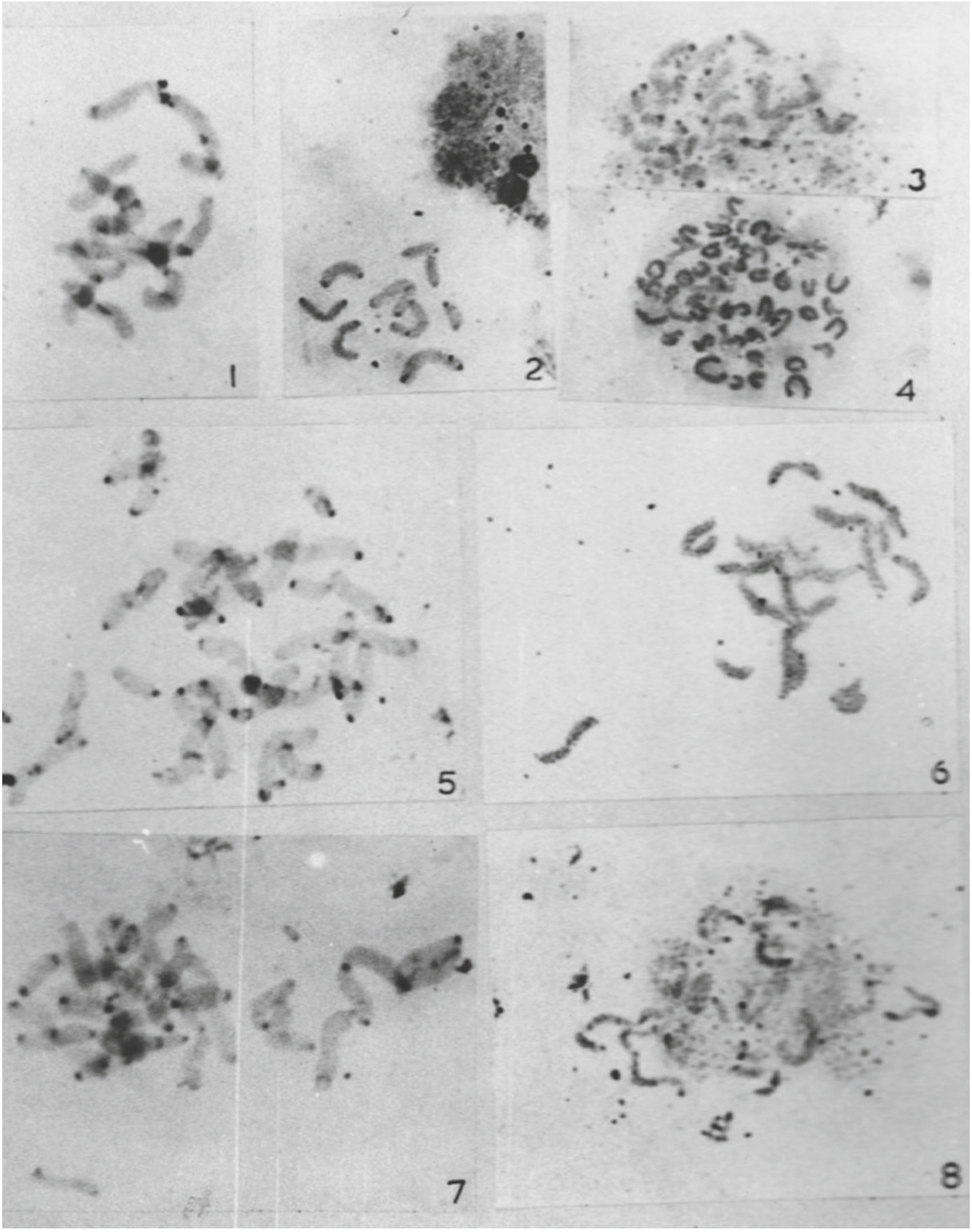

Plate 3.5 Planococcus citri

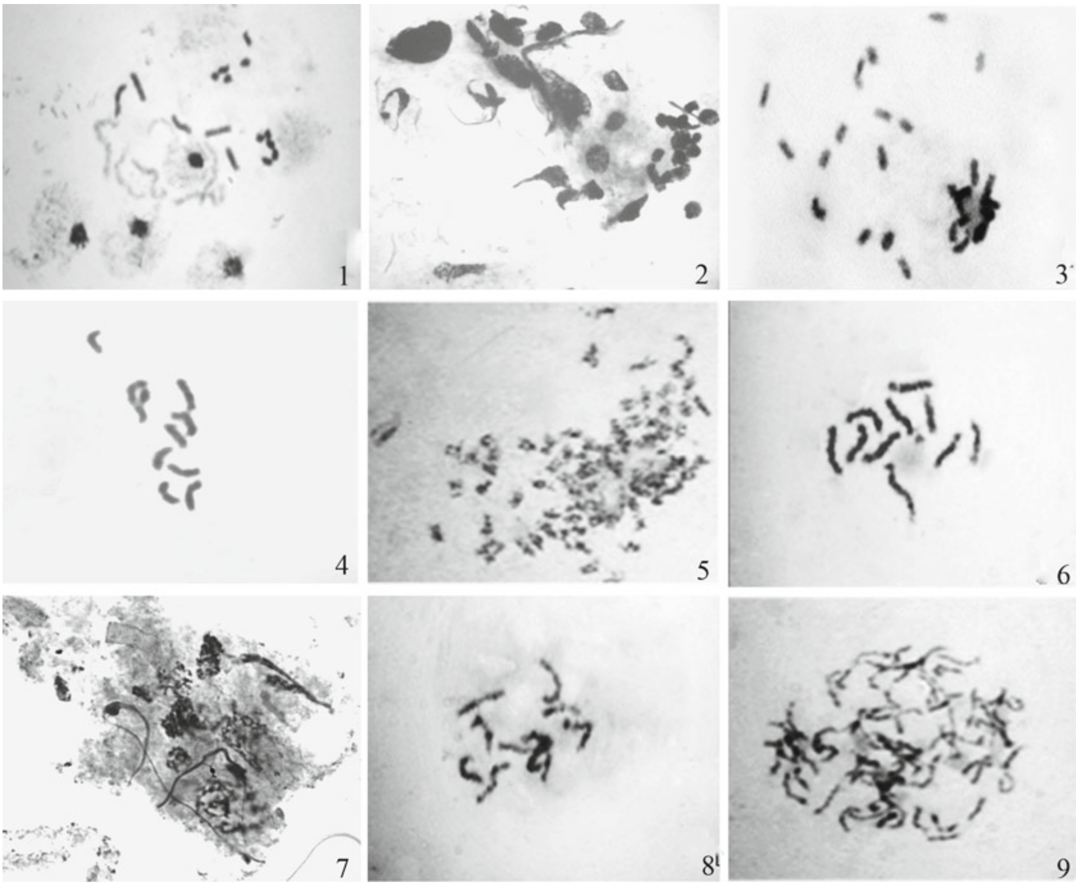

Plate 3.6 Representatives of other pseudococcids

But the cursory observations led in demonstrating that the C-specific bands were found specifically identifying the telomeric region specificity in the metaphasic chromosomal complement and this situation was ascribed as T-bands (Venkatachalaiah 1989; Raju 1994). However, the results obtained by Venkatachalaiah (1989) and Raju (1994) pertaining to C-banded stainings at telomeric ends of each chromosome in the complement were irrespective of a particular chromosome type (whether of mitotic, meiotic, or polyploid nuclei) or sexes (males or females), and thus, they contend that these cytological markers could be representing a particular type of constitutive heterochromatic component. The intense stainability at the telomeric regions in the chromosomal content allows one to assay that this chromosomal component may offer conveying information about its cytogenetic context. The situation acquires a genetic signature due to its co-orientation pairings during late meiotic (male or female) chromosome synaptic processes (Plate 3.7 Fig. 6, 7, 8, 9).

Ferraro et al. (1998), in their attempt to localize C-banded regions at *P. citri* chromosomal preparations, found evidence regarding C-positive bands localizing at the telomeric regions of all chromosomes in the complement. When they further insisted upon prior exposure to CMA_3 (chromomycin A_3) -methyl green and subsequent exposure to C-staining protocols, the implicit C-bands were found correspond to telomeric region-specific areas. This has led them to infer that these results could, however, representing

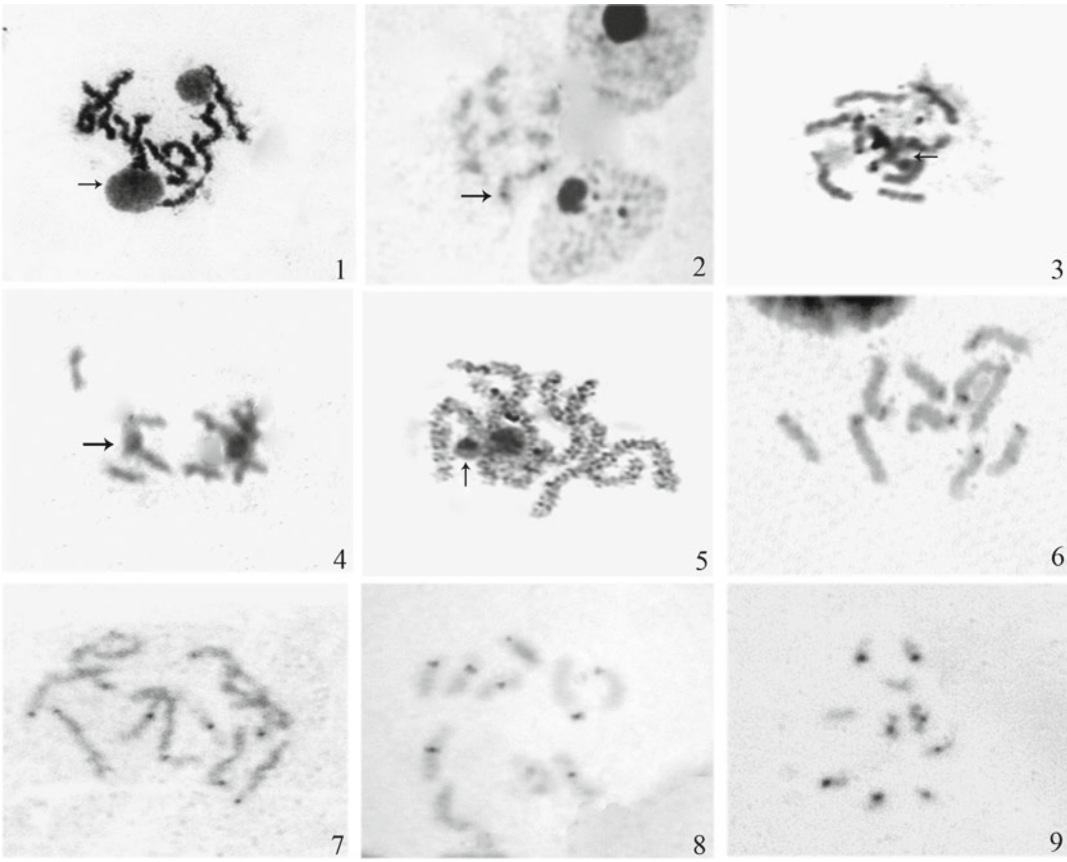

Plate 3.7 Representatives of other pseudococcids showing NOR- entities and C-band regions

GC-rich specific spots on chromosomes. However, when they insisted further upon H33258 fluorochrome to live cells prior to C-staining, they recovered images almost imitating C-banded telomeric-specific regions. Thus they were able to interpret the failure to find a dull appearance, instead of bright bands at the specified locales, and those of brighter and intense bandings could represent condensed constitutive heterochromatic regions, leading them to insist that there could be more DNA congregated per unit length per chromosome than in the euchromatic zones. Moreover, some of the telomeric regions being positive to DAPI stainings, it was inferred that the presence of AT-rich sequences were embedded within the predominantly GC-rich regions of individual chromosomes.

From the point of view of cytology, telomeres are marked by specialized DNA and protein components that usually decorate the chromosome ends or other specific loci. In several eukaryotes, their occurrence and prevalence has been tested, wherein they have been found composed of simple tandem pentameric (TTAGG) repeats localizable at specific chromosome loci accompanied by complex subtelomeric structures in close apposition (D'Aiuto et al. 2003; De Lange 2005). A large number of molecular cytological studies have led to the implication that telomeres of eukaryotes are usually composed of conserved short tandemly repeated GC-rich sequences. This kind of sequence conservation is reflected as a common mechanism for telomere region biosynthesis. This mechanism specifically dictates and involves the activity pattern of a telomerase, a ribonucleoprotein DNA polymerase enzyme that compensates any further loss of terminal sequences at every replication round by adding short tandem GC-rich sequences onto the chromosome ends (Greider 1995).

Studies in various insect species demonstrated characteristic presence towards the notion that TTAGG repeats are an ancient motif traceable in Arthropoda and that those pentameric TTAGG repeats that could have been originated from the vertebrate TTAGGG hexamers (Frydrychová et al. 2004; Vitkova et al. 2005).

Cytogenetic scrutiny undertaken by Mohan et al. (2011) with regard to *Planococcus citri* chromosomes have enabled them to delineate the presence of a characteristic pattern of telomeric sequences and also some of their placements upon the respective interstitial loci and the constitutive presence of active telomerases was detected and this was achieved by introducing single primer PCR and Southern hybridization protocols upon cytological preparations. The results so obtained suggest that in particular, *P. citri* chromosome complement seemed to provide as an efficient chromosome marker to demarcate the chromosomal loci at the site of the mechanism of formulation of TTAGG repeats at their respective chromosome ends. In addition, this study was also aided in identifying and thus disclosing whether some unrelated low copy repeats, called Intercept TTAGG Sequences (ITS) were displaying identifiable spots based on their presence, thereby intercepting the repetitive elements. It is well known that *P. citri* genomes are bestowed with diffuse centromere (holocentric) activity and as a consequence of this nature there could be an obvious presence of multiple centromeric zones occupying the length along individual chromosomes. Utilizing this extraordinary condition, in view of these genetic peculiarities persisted with elegant DNA repair machinery that ensures the protection of additional chromosomal elements localizing at interstitial zones; and thus they aptly recognize these sites as putative zones. Surprisingly, following X-ray irradiation upon these broken chromosomal ends it was disclosed that some loci were characteristic and were tagged with the association of TTAGG repeats decorating at chromosomal interstitial regions. Because of their resistance to higher doses of ionizing radiation, a unique feature characterizing the mealybug genome and this extraordinary chromosomal phenomena could as well serve as an asset towards relegating them to be considered as a "radiation-resistant coccid."

Mohan et al. (2012) further attempted to test responses with still higher doses of ionizing radiation exposure on *P. citri* genomes and were thus able to utilize this opportunity to suggest that mealybug genome may well serve as a unique genetic system. The results of their explorations revealed that especially pounding concentration on the centromeric property that was eventually recognized as sites of activity sporadically spreading over the length, and in spite of this enormity there is no significant loss of the genetic material. Furthermore, with respect to the mealybug genome, it was considered to contain highly tolerable radiation doses as high as 1100 Gy. Presently, it is apparent that mealybug genomes may serve as very efficient agents of the DNA repair machinery system that ensures proper healing of double-strand breaks (dsb) invaded by ionizing radiation. Despite several special qualities,proclaimed as containing, for example, of telomeric repeats along with interstitial sites of chromosomes and with respect to maintenance and sustainability of telomeres to higher radiation effects, some authors believe regardless of the vulnerability of the telomeric-independent mechanism it could also be operating in a *P. citri* genetic system.

Thus, the occurrence of C-heterochromatin occupying telomeric regions of chromosomes deserves some comments. In its usual courses of other cases, incidentally pertaining to holocentric chromosome systems, it was possible to ascribe that C-heterochromatin is preferentially located at or near telomeres (Muramoto 1980; Camacho et al. 1985; Papeschi 1998; Panzera et al. 1992). According to Heitz's (1933) "equilocal heterochromatin distribution" hypothesis, it was inferred that the C-banding material in both homologous and nonhomologous chromosomal sets tends to congregate at homogeneous and homologous regions, thereby occupying similar kinds of cytological sites, and thus probably represented by either telomeric and/or centromeric sequences. Schweizer and Loidl (1987) have proposed a model that explains how C-heterochromatin enhances and leads to adherence of such chromosomal zones confining and/or inducing towards effecting interchanges of heterochromatic material between nonhomologous and homologous chromosomes in the complement and thus leading towards annealing into a common platform resulting in such situation that they belong to as though in a monocentric type of chromosome system; that also insists upon those of chromosomal regions with holokinetic activity that do not fit into this model. In view of the limited information gathered from other homopteran examples, an effort was made to define that the nature and kind of telomeric components that were found enhanced to establish as a C-banded heterochromatin. Moreover, Panzera et al. (1992) and Pérez et al. (1997) based on their limited experience offer the opinion, especially of *Triatoma* meiotic systems, that the tendency of the heterochromatin component inferring to change in accordance with from one chromosome to another or from proximal to distal sites of the same chromosomes within a complement. However, this characteristic cytological feature was found on preferential localization of telomeric heterochromatic content of some instance cases alone probably thereby reflecting upon C-banded components. These proposals are in congruence with those of the Schweizer and Loidl (1987) hypothesis, but this type of chromosomal behavior is not in any way agreeable to certain terms with other instance cases analyzed from other homopteran examples for the said purposes including the coccoid chromosome systems.

Ferraro et al. (1998) had undertaken an eloborate proceedings in view of eliciting and appropriating the preponderance of the ribosomal cistrons and upon highlighting of their cytological localization based on the mealybug chromosomal preparations. This analysis had led to the results so obtained by means of the FISH technique and of subsequently staining the same with silver nitrate solution for localizing NOR (Nucleolar Organizer Region) specificities on metaphase chromosomes. These results point to have driven them to ascribe that the FISH technique might help in identify with *P. citri* chromosomes at specific zones on all chromosomes except at one pair in the complement. But silver nitrate staining specificity had enabled in specifying at a single pair in the complement but characteristically demonstrating the site at which bearing very prominent macer-shaped, silver nitrate stainable entities, irrespective of their origin whether of euchromatic or heterochromatic chromosomal pair (Plate 3.7 Fig. 1, 2, 3, 4, 5).

3.5 B- Chromosomes

During the courses of systematic cytological study in the case of *Pseudococcus affinis* chromosomal complement that possesses supernumerary B chromosomes which were transmitted without the reduction during spermatogenetic courses that were found exhibiting a strong "meiotic drive", in such processes (Nur 1962a, b, 1969). Prior to spermatogenesis, the B chromosome was heterochromatic, but during prophase I of spermatogenesis it became evident that even less condensed than the euchromatic set (i.e., negatively heteropycnotic) and this change in condensation property apparently makes this situation possible for the B^s to segregate with the euchromatic set and be transmitted over to 90 % of the offspring. Nur and Brett (1985, 1987, 1988) have presented subjective data supporting that acquisition of the condensation property of A^s and B^s during spermatogenesis seemed to infer that this situation is due to the presence of genotype that affects the rate of transmission of the B^s in males. However, it is somewhat clear that this situation became evident because of the influence of this genotype which has affected the condensation property of B, but not the property of heterochromatization. However, Klein and Eckhart (1976) theorized that difference between B^s and regular chromosomes of *Pseudococcus affinis* could be due to changes occurring at the DNA sequences level. Another probable reason sighted was the differences observed between the

A and B sets that could be due to the occurrence of DNA of the two types of heterochromatin that being methylated. Thus, the percentage of 5-methylcytosine in the DNA of *P. affinis* was found to be higher in males than in females, and higher in females without B^s than in females with B^s (Scarbrough et al. 1984).

3.6 Polyploidy and Endosymbionts

In most species of mealybugs the polar bodies re-enter the egg and contribute to or give rise to large polyploid cells (mycetocytes) that house intracellular bacterial symbionts (Brown 1965). In some mealybugs, cells formed by polar bodies 1 and 2 are known to be totipotent. In male mealybugs and in other coccoid families, one portion of the genome becomes heterochromatic and the other becomes euchromatic (genetically active) in several tissues or organs (Tremblay and Caltagirone 1973). These include the midgut, the Malpighian tubules, the salivary glands, oenocytes, and serosa (Nur 1967, 1972). One characteristic of most of these tissues is that their nuclei later become polyploid as a result of endoreduplication or endomitosis (Plate 3.6 Fig. 3, 5, 9). During oogenesis, polar bodies do not degenerate; instead they re-enter the egg cell, and fuse with each other and also with some of the cleavage nuclei and form polyploid cells called mycetocytes. These mycetocytes are invaded by certain maternally transmitted microorganisms generally referred as symbionts. Mycetocytes harboring such symbionts form an organ called mycetomes whose function is not known (Brown 1965; Nur 1977). Such symbionts are transovarially transmitted to the next generation and thus show maternal inheritance (Buchner 1965). Euchromatization, however, is apparently not an essential step in the development of these tissues, because these types of tissues involved may vary between congeneric species. Moreover, the frequency of cells in which euchromatization occurs sometimes varies between individuals. However, in those nuclei in which the paternal genome remained heterochromatic, it usually did not replicate or having replicated once, the euchromatic sets replicated several times (Lorick 1970; Nur 1966c, 1970, 1972).

The sex-specific association of the microorganisms has led to the suggestion that they may have a role in sex determination (Buchner 1965). However, the precise nature and role of endosymbionts in normal development has not been clearly assessed. Biochemical and morphological analyses of isolated endosymbionts have established their prokaryotic characteristics (Houk and Griffiths 1980; Ishikawa 1989). The 16 s rRNA gene sequences of several homopteran insect endosymbionts including those of certain species of mealybugs and aphids, have been considered for their role in the prevalence of phylogenetic relationships among those species probed for those purposes (Munson et al. 1991, 1992; Kantheti 1994). However, the nature and extent of type of expression of the concerned gene inquisition during the course of insect development are not clearly explained. Buchner (1965) reported that extracellular symbionts are present in the females of *Stictococcus* but absent in the males. Most coccoids contain intracellular bacteria or yeastlike symbionts present in the cytoplasm of special cells, the mycetocytes (Tremblay 1977, 1989). The origin of the mycetocytes is of interest because it may vary between, as well as within, families. Therefore, it appears probable that the origin of mycetocytes may have an important bearing on the pseudococcid genetic system (Hughes-Schrader 1948).

Interestingly, Kantheti et al. (1996) reported an isolation of the 16S rRNA gene sequenced segment, designated as P7 from an embryonic cDNA library of *Planococcus lilacinus*, which was found to be an encouraging attempt and by hybridizing to the genomic DNA of females to the assay, but not to that of males. Interestingly P7 showed no hybridization to nuclei of either sex, raising the possibility that it was extrachromosomal in origin. Using electron microscopic images, especially of P7 clones but not of P3, annealing was found to the adult female abdominal organ called mycetomes. Electron microscopy has disclosed the presence of symbionts within the mycetocytes. Sequence analysis showed that P7 is a 16 s rRNA gene confirming its prokaryotic origin. P7 expression is detectable in young embryos of both sexes but the absence of P7 in third instar and adult males suggests that the designated gene containing isolated gene sequences assay and hence, consideration of provisional endosymbionts are the subject and object of sex-specific elimination/acquisition type of operating processes.

3.7 Mechanism of Sex Determination

In many species, sex determination is associated with the inheritance of a heteromorphic chromosome pair in one sex. However, not all species have evolved from a common ancestor that possessed such an heteromorphic sex chromosome set. Rather, XX–XY sex determination appears to have arisen independently many times in evolution from the XX–XO type form. The XX–XY sex chromosomes of flies and mammals also arose independently, but, the underlying mechanisms of sex determination are quite different and difficult to predict except in molecular terms.

Coccoids are a unique and very peculiar group of insects in view of their possessing a highly variable mode of sex-determining mechanisms. This situation becomes evident through the course of studying complex meiotic processes incurred in a few select examples analyzed thus far. Thus, this situation has led to the creation of some academic interest by some earlier cytologists to pursue further upon attempting understand the intricacies of meiosis and mitosis. Interestingly, White (1973, 1978) took special interest in accommodating this opportunistic situation prevailing in mealybugs (scale insects) summarily termed as "aberrant genetic systems," and Nur (1980) proclaimed "unusual chromosome systems" but recent views indict them either as the "more diverse" or "asymmetric genetic system". Serendipity, as applied to these scale insects, which are characterized by possession of a peculiar genetic system, was not found in any other animal system of comparable nature.

These bizarre genetic systems are of immense help in our attempt to understand further upon the occurrence of a variety of sex-determining mechanisms prevailing in scale insects in the light of their inherent property of inverse meiosis effectively driving them through the efforts of holokinetic chromosome mechanics. Most species of coccoids are bisexuals with extreme sexual dimorphism but due to precariousness of male populations at times, some of them have become parthenogenetic. These complex genetic systems appear invigorating due to the involvement of both the bisexual as well as the parthenogenetic mode of reproduction. Another noteworthy feature is inflicted on them due to the deliverance of quadrinucleate spermatid formation in many mealybug (bisexual) chromosome systems. It is thus possible to surmise that the various types of meiosis that were confronted within the scale insect examples could have arisen in a derivative form or in a succeeding form from that of primitive homopteran (aphid–coccid line) examples including aphid chromosome systems (XX–XO system). It is thus possible to note that during the derivation processes it became inevitable in view of the penchant situation prevailing with those participants driving in through to the equatorial orientation of meiotic bivalents at first meiosis and of the preponderance of prereduction at chiasma.

3.8 XX–XO System

Sex determination in primitive coccoids could have taken its initiation based on the XX (♀)–XO (♂) type of sex-determination mechanism. Consequent upon this exigency, oogenesis is of conventional type progressing through inverse meiotic pathways, whereas spermatogenesis is highly modified in most coccoids, mealybugs in particular. In view of this unique situation, variable modes of expression pathways become imminent as represented among analyzed primitive margarodid examples. Currently, cytological records have become known from margarodid assemblage of species that include taxa belonging to Margarodidae, Ortheziidae, and Putoidae. The cytological descriptions of these primitive groups of species characteristically reveal that the sex of progeny is predetermined prior to and at spermatogenesis; spermatozoa with the X-chromosome produce females and spermatozoa lacking it produce males (Nur 1980). In this extent, Brown (1977) placed primary emphasis upon the coccoid chromosome system imparting the implicit nature of acquiring adaptive specialization and the same was found reflected in the progression of meiotic processes which in turn enabled categorizing into three types: (1) Margarodid assemblage, (2) Lecanoid types, and (3) Diaspidid systems (Plate 3.8). In some Margarodid examples studied, spermatogenesis resembles that of conventional oogenesis, as is especially evident in the case of *Puto*. Some species of *Puto* demonstrated conventional meiotic chromosomal features. These species follow a typical heterogametic mode of sex-determination mechanisms, in which the males usually possess one chromosome less than that of females; characteristically the example includes *Puto* species, $2n = 14♀–13♂$; *Puto albicans*, $2n = 20♀–19♂$; and *Callipappus rubigonosus*, $2n = 14♀–13♂$ (Brown and Cleveland 1968; Hughes-Schrader 1944). There are other taxa in which spermatogenesis is highly modified as was shown in meiosis of *Protortonia* and *Matsucoccus gallicola* defining multiple sex chromosome systems. Surprisingly, the only other report in which no morphologically identifiable sex chromosomes were shown is represented by an example showing cytological features for the whole Ortheziidae family, comprising $2n = 16$ in both sexes (Brown 1958).

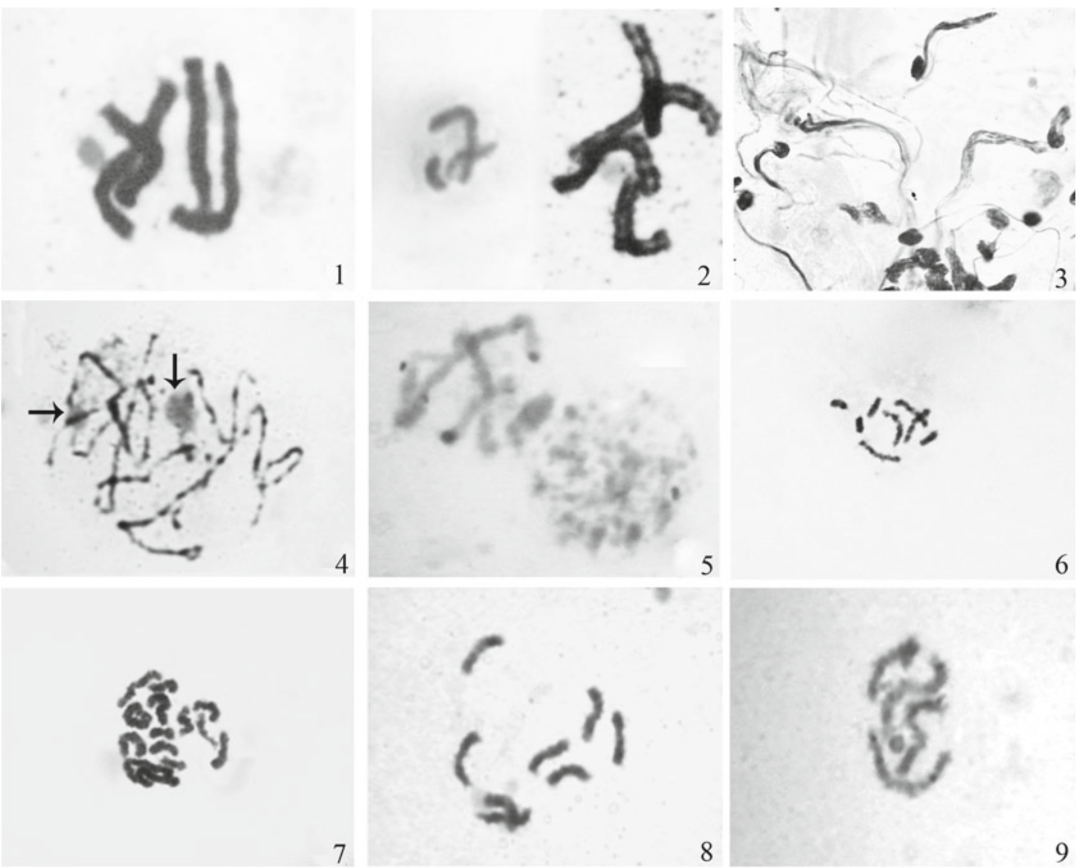

Plate 3.8 Representatives of other families of scale insects

3.9 Lecanoid System

In the Lecanoid chromosome type of coccoids that exhibit a peculiar situation among coccoid chromosome systems is one in which one "haploid" set of chromosomes acquires heteropycnosis during the developmental course and also in the germline cells. Those cells destined to become males acquire this status probably from mid-blastula onwards and persist through to adult life. In the females, both sets of chromosomes in the cell remain in the euchromatic state throughout the developmental course (Schrader 1921, 1923b; Schrader and Hughes-Schrader 1926). The basis for such an extraordinary situation in the mealybug chromosome is in the procession of acquisition of the mechanism of heteropycnosis in male embryos and this involvement facilitates functional inequalities with respect to males that may point towards proclaiming them as physiological haploids, even though they have a duplex set in their nuclei (Plate 3.6). Brown and his group have ventured into delineating the processes and involvement of genetic mechanics of genomic inactivation and of cytogenetics of heterochromatinization processes in the genome (examples include *Planococcus*, *Phenacoccus*, *Maconellicoccus*, etc. of the family Pseudococcidae and *Laccifer* of Kerridae). It is of interest to learn more about and probe further the processes of heteropycnosis of the paternal composition of the Lecanoid chromosomes and as such it becomes imperative to note that this set passed through the male phase but expressivity was confined only to genetic male zygotes. Brown and Nur (1964) demonstrated earlier through their hybridization experiments that in hybrid male embryos the mechanisms of heterochromatinization of the paternal set can occur in the cytoplasm of the foreign cell and thus this mechanism is not neccessarily a species-specific characteristic, because heterochromatinization progression processes occur after several divisions of cleavage, and the paternal set must somehow seemed to have been marked (or learned) which could have been done or did prior to the entry of sperm into the egg (Chandra and Brown 1975). Of the two processes, the marking (i.e., imprinting) of and the activity status (of heterochromatization), of which the earlier process seems likely to be an effective one at the ancestral stock and this attribute might reflect in bringing about differential condensation activity of the concerned chromosomes. At this juncture, Brown (1977) felt that this situation appeared premature to theorize about or make any generalization unless substantial molecular data were made available.

3.9.1 Parthenogenesis (Unisexual Reproduction)

While further pursuing the nature of the evolutionary trend involved during the course of sexuality of scale insects, Hughes-Schrader (1948) asserted that the prevalence of the parthenogenetic mode of reproduction could be due to concordance with a higher incidence of disparity in their reproductive potential. Thus, Hughes-Schrader (1948) was able to discriminate bisexuals from those parthenogenetic ones and further suggested the appraisal of three fundamental types of parthenogenetic products in them. Since then, there have been considerable amounts of coccoid cytogenetic information procured by Brown and his associates that also affirmed that this situation based on cytogenetic surveillance which acquired an innovative stimulus and prospects including overall frequency of both bisexual and parthenogenetic life cycle analysis from among the select taxa of Coccoidea (Schrader 1923b, 1931; Brown and Bennett 1957; Brown 1963, 1964, 1965, 1966; Nur 1963, 1967, 1969; Hartl and Brown 1970). Subsequently, White (1973), who placed greater emphasis upon the parthenogenetic mode of reproduction and furthermore, on the implication and validity of heterosis during the courses of haplo-diploidy to diplo-diploidy, was a matter of great antiquity. This and other cumulative studies (White 1978) have moved towards arriving at a conceptualization relating to efficiency of homozygosity that would more likely to have an effective impact upon haplo-diploids rather than diplo-diploidy. Brown (1977), Hughes-Schrader (1948), and Nur (1971) have drawn inclinations towards suggesting that it was at the cost of fragility and precariousness of males and of their implicit nature of effectiveness upon population measures, thereby imposing greater inconvenience on the part of life-cycle strategies. Consequently, this kind of adaptiveness could have been driven towards an alternative mode of reproduction. Thus, the parthenogenetic modes could be initiated by means of adapting and involving either of Arrhenotoky or Deuterotoky or Thelytoky. But it was at the greater behest of Nur's (1969, 1970) concerted efforts that had enabled him in eliciting and categorizing parthenogenomes each exhibiting distinct types of expression pattern. Subsequently, Nur (1980) was also instrumental in documenting a revised format for parthenogenetic modes of expression based on the following strategies: whether the unfertilized eggs develop into males (Arrhenotoky); or females (Thelytoky) or both (Deuterotoky); whether the males are haploid or diploid; and whether first meiotic products between bivalents and oogonia remain the same (Gonoid thelytoky) or different (agonoid thelytoky).

3.10 Arrhenotoky

Arrhenotoky is also called as haplo-diploid or haploid parthenogenesis in which males arise from unfertilized eggs. Males of haplo-diploids may be referred to as impaternate because they have no fathers. From the classical genetic point of view, haplo-diploid species may have been involved in recombinational processes (and hence, Mendelian in character) inasmuch as they behave much to the same extent as those of sex-limited characteristics, but possess no Y-chromosome. This, in a way, projects as a sort of male heterogamety in genetic characteristics; on the other hand, Thelytoky offers a non-Mendelian material thereby propelling it as a reproductive devise. Haplo-diploidy (Arrhenotoky), on the other hand, is a method of sex determination as well as a reproductive system that involves replacement of an original sex-determining mechanism by an entirely new one under extraordinary circumstances. Hence, it could have occurred rarely in nature and was estimated to have actively participated about eight times during the course of evolutionary history (Brown 1965; White 1973). It was also felt that the frequency of males (through Arrhenotoky) in such populations was determined by the frequency of haplo-diploids that arose in such considerations. It is thus characteristic of any group with haplo-diploidy becoming much more inclined towards responding to the oppressive impact of environmental factors that accrued in which sex ratio potential was deemed to have been highly variable and it was also found to differ from species to species and even to the extent of genetic strains or of population level extremes.

3.11 Sex-Ratio Potential

In a majority of animal systems studied for the prevalence of genetic-based sex-determining mechanisms the extent was revealed of separate sexes that direct each whether to become male or female, whereas in some taxa, hermaphroditism may serve the primary mode of reproduction. Whether a homomorphic (XX–XX) or heteromorphic (XX–XO) mode of sex determination prevails in them, the sex ratio proportion seems to be maintained in a harmonious manner (in a 1:1 ratio). In such cases, where conventional diploidy exists, fathers and mothers often obtain equal fitness potential through to their sons and daughters and hence, no sexual conflict. But in the case of alternative genetic systems, it becomes essential to involve Trivers and Hare's hypothesis (1976) that advocates the probabilities prevailing for reproductive success of sons and daughters that can differ markedly from parents. To that extent, they made a proposal in which males and females were drawn into evolutionary forces over the aspects of sex-allocation theory that depends on the inclusion and involvement of a particular genetic system (e.g., haplo-diploidy or paternal genome elimination). In such instances, a different set of reproductive trends seemed to follow in compliance with any biased genetic transmission event that ensues which in turn can offer scope for the eventuality of sexual conflict. With particular reference to mealybug examples, it becomes imperative to address the

Dusing–Fischer formula (1976) that insists upon fitness consequences of male and female offspring that can vary with respect to the direct influence or under duress of genetic and/or environmental factors, even though selection prefers operating in such a way as to bring each into an equilibrium state. These generalizations can evidently be tested upon certain cases wherein genes in fathers are only transmitted through daughters, with sons being of no reproductive potential to males. On the other hand, females gain fitness benefits through both sons and daughters thereby on demand for a possible expression of conflicts over sex ratio. Orienting primarily towards genetic consequences, the conventional diplo-diploidy (♀XX–♂XX system), becomes apparent, in which case they still attempt to maintain a rigid sex ratio in the form of 1:1 because mothers and fathers do not vary through to the contributions of daughters and sons and hence no sexual conflict. However, in unusual situations pertaining to scale insects either haplo-diploidy or paternal genome elimination (PGE) are offered as interesting but in extremity for an eventuality (as the case may be).

On the other side, scale insects exhibit a different array of genetic systems, including haplo-diploidy as well as PGE offering as extremities. The case of the mealybug (example *Planococcus citri*), provides an ideal system to pursue and probe the kind of involvement and promotion of sexual conflict that it exhibits. It has PGE wherein the male component is in possession of haploid nuclei, is (either it heterochromatized or) eliminated from meiotic cell lineage, and it is present in somatic cells but untranscribed (Nur 1980). In terms of genetic mechanisms, the role of genomic imprinting may be crucial. Scale insects are known to represent the case in point of genomic imprinting and imprinting of a paternal chromosomal set alone is affected and also acts as a marker system for sex-determination mechanisms. In the case of mealybug paternal chromosomes especially of Lecanoids it is essential to point out that they remain in a latent state during the course of cell lineages. However, they get transmitted at the cost of a selective advantage. Intriguingly, in *P. citri*, the site of genomic imprinting of the paternal set of chromosomes lies in the female germline tissues, suggesting that paternally inherited genes may still have the ability to influence the fate of paternal chromosomes in the germline but not in soma.

Scale insects consequently exhibit considerable variations in their expression patterns based on genetic and sex-determining mechanisms, in spite of exhibiting similarity in their life-style strategies (Gullan and Kosztarab 1997; Nur 1980; Ross et al. 2011). Due to compulsions of their adaptive specializations imposed upon the morphology of male and female coccoids, however, they differ enormously in terms of certain other anatomical features. As is well-known among scale insects, males are winged hence motile, but with fragile stature although they have a short life span based on acquisition of no feeding habituation, which may eventually succumb to shortage of male populations. In contrast, females are robust, ornamental, and sedentary in habituation but have a longer life span and are engrossed with gluttonous feeding habits that might propel them to do better in controlling sex-ratio propensities (Bull 1983). Earlier, Hughes-Schrader (1948) predicted that even though scale insects are besieged with variable life-cycle strategies leading towards variable modes of genetic schemes, impulsively adaptive specialization could have driven them to acquiring Thelytoky and hermaphroditism. In fact imposition of such kind of dwellings could have been forced to serve as a clever device to dispense with the shortage of males. However, Brown (1977) contends that in spite of the complexities of several chromosome systems within the scale insects genetic systems, he contemplates acquisition of adaptive specialization, in turn expanding towards acquiring exponential taxonomic diversifications. However, Nur (1980) asserts that the fragility of the males may serve as a primary instrument in an easing-out progression during the courses of acquisition of a particular mode of life-style activities or by adapting to a particular chromosome system in succession. The results obtained based on *P. citri*, have driven James (1937, 1938) and Nelson-Rees (1960) to address that in Lecanoids, it appears possible to ascribe that females might play an impressive role in selection and maintenance of sex-ratio variability by their so adapting towards changes and at times realigning to overcome any shortage of males. Changes in the sex ratio result in reinforcement of certain changes in developmental phases in the females which probably would make arrangements towards shifting in the proportion of procuring the requisite number of eggs and further upon imposing and resetting the paternal component onto the gambit of heterochromatinization drive and in addition in an effort to furthering towards a certain proportion of eggs to be obtained profusely or curtailment. All these adjustments mean amending changes in contemplation within the scope of remodeling themselves towards acquiring and procuring a sufficient number of males.

Consideration of imparting environmental forces upon such forces is based on the population structure of offspring in responding to fitness potential which would otherwise be driven towards differential expression patterns based on the part of engrossing of established conflict drawn between parents and offspring. It is known that natural selection operates on those ratios in which propelling forces rest on whether the parents or offspring are in driving mode (Shuker et al. 2009). It is also suspected that the offspring can manipulate the sex-ratio potential thereby affecting the sex allocation pattern.

Trivers and Willard (1973) have conceived of a pertinent opinion that environmental factors could present oppressive effects on parents with the possibilities of parental interference in an effort to adjust sex allocation efficacy in the sex-ratio potential. Environmental conditions experienced by parents can have direct interference during the course of sex allocation decisions possibly in one of two ways: either directly influencing parental conditions, or indirectly maintaining environmental factors as a cue to offspring fitness. In *P. citri*, several environmental factors have been explored especially pertaining to embryogeny and other biological features of female reproduction. These measures include the role of population density (Varndell and Godfrey 1996; Ross et al. 2010a, b), impact of temperature (James 1937; Nelson-Rees 1960), and age of females prior to mating (James 1938; Ross et al. 2010a). An increased understanding of sex allocation theory in mealybugs might therefore yield insightful opportunities to probe further into the potential ramifications that drive in eliciting evolutionary advantages operating in proceeding towards extraordinary modes of sex-determination mechanisms. The results obtained by Ross et al. (2011) upon *P. citri* experimentations seem to point out appropriate levels that were maintainable based on the role of high temperature, older age at matings, and the starvation level, all of which seem to impress during the course of the consideration of sex-allocation theories. These results may have influenced changes of expression patterns of female-biased sex ratios. But, they also propose that the effect of temperature seemed rather weak and upon the influences of food restriction could have strongly implicated in reduced longevity and a transaction of the unusual schedule of male and offspring production across a female reproductive lifetime.

3.12 Recent Innovation Made in Mealybug Genomes

3.12.1 Some Molecular Features

Heitz's (1928, 1929) unleashing of the operational definition of the term "heterochromatin" in terms of its role in cell-cycle progression has triggered momentum in cell biology to roll on towards its own toll. This situation came as a natural ingredient for Brown (1966) to elicit succinctly the ubiquitous nature of heterochromatinization serving as a pillar to the cytogenetic conundrum. While nurturing functional strategies, he succumbed to subdivide heterochromatin into two types: constitutive heterochromatin (CH) and facultative heterochromatin (FH).

As a constituent of chromosomal architecture, constitutive heterochromatin comprises considerable portions of the genome in higher eukaryotes that include specialized chromosomal domains that are endowed with repetitive DNA sequence specificities (e.g., centromeres, telomeres, and nucleolar organizer regions). CH at the molecular level is marked by distinctive structural changes incurred at the level of DNA sequences, and with active participation of constituent histones, and consequently upon its chromatin remodeling. In addition, recruitment of HP1 (heterochromatin protein 1) at times serves as an essential ingredient of heterochromatin structure. The interactions and dimerization activities of HP1 with that of DNA sequences, RNA, and histone moieties using appropriate combinations bring about repressive chromosomal complexes. This situation is thought to be widespread in many eukaryotic genomes and in some instances, this appears to be a conserved genome component lending its role appropriately from yeast to mammals (Nokayama et al. 2001; Nielsen et al. 2001). The CH could also be diagnosed by highly methylated DNA sequences, and/or histone modifications that are enriched with, for example, methylated lysines (H3K9Me3) and yet in depleted form in the case of both H3K4Me3 and acetylated H4 (acH4).

As the name implies, facultative heterochromatin comes into force or effectiveness upon their need to undertake any exigency purposes (such as gene regulatory activities). FH is a euchromatic component but upon developmental cues acquires a highly compacted chromatin structure to transform itself into an heterochromatic comportment. In its native state, FH is devoid of repetitive DNA sequences. Facultative heterochromatin differs from constitutive heterochromatin with respect to DNA sequence rearrangements but not at the nucleosomal level. At the nucleosomal level, FH has many molecular features similar to CH. From the pointing of its impaction among higher organisms and in cytogenetic context, FH affects only one of two homologous loci or homologous chromosomes, or homologous chromosomal set.

Genomic imprinting is defined as a parent-of-origin specific expression of selected or affected gene(s), and has generally been associated with specific changes in DNA methylation profiles and in histone modification processes. Even though there are numerous examples available for the study of genomic imprinting, operating at the level of a gene and/or at a single chromosome or a whole chromosome set, wherein inactivation of (1) one of the two X chromosomes in female mammals and (2) a male haploid set of mealybug chromosomes in a complement, serve as a unique example for the consideration of epigenetic phenomena.

There is good evidence that the control of transcription involves active participation of various proteins which bind specifically to methylated DNA, wring in histone modification complexes, and eventually in local chromatin remodeling processes.

Considering these features, the differential chromatin formation during the course of chromosome inactivation processes in the case of mammalian females and in the case of the paternal chromosomal set in male mealybugs represents a very clear case and an outstanding genetic manifestation offered in the studies pertaining to an effort to understand the modes and methodologies involved during such processes (FH formation).

This exceptional situation offers immense academic help in eliciting more on these topics; Lakhotia (2004) made efforts to shortlist achievements dwelling upon ongoing excitements that prevail in the arena of epigenetical phenomena contributing towards the current phase of knowledge available regarding heterochromatinization progression. Several recent reviews have been forwarded detailing the prospects of mechanisms and functioning of various epigenetical programs that incorporate during gene regulatory activities (Surani 1991; Li 2002; Cairns 2007; Kouzarides 2007; Skiniotis et al. 2007; Bell and Spector 2011). Of particular significant and recent progress are achievements heralded in the case of epigenetic regulatory activities during genomic imprinting programming of the mammalian X-chromosome (Sado et al. 2005). On the other hand, the present review focuses on recent achievements made in our current understanding of the role of DNA methylation, histone modifications, and some points upon the chromatin remodeling processes pertaining to genomic analysis (e.g., *Planococcus citri /P. lilacinus*) essentially based on chromosome organization have been targeted to serve as a model genetic system.

3.12.2 On Biochemical Paradigm

The regulation of gene expression plays a pivotal role in expediting complex phenotypes and in differential expression patterns of epigenetic mechanisms, in which the role of DNA methylation has been considered as playing an essential role in depiction of variable modes of operation elicited during the course of chromosomal mechanics. In order to understand better the functioning of DNA methylation processes is to learn more about its modes and methods and that reflect upon an operative course during distribution patterns in the genome of interest. Cytosine DNA methylation has been demonstrated in several eukaryotic organisms and has been demonstrated to play inquisitive roles in various developmental activities. Variable portions of the genomes are being subjected to the operative part of methylation with the help of 5-mehtylCytosine (5mC) along the lengths of DNA sequence moiety. DNA methylation has been cited in numerous physiological functions depending on the kind of model organisms utilized for said purpose and upon redesigning particular experimental protocols. Presence of DNA methylation in and around promoter regions is generally been thought to be associated with gene silencing processes and the loss of such kind of methylation processes is reported to be accompanied by virtual transcriptional activation.

Several ideal examples can be cited inciting activities based on a methyl-transferase enzyme conglomerate that operates during such instances that have been profusely documented in several vertebrate and plant examples. In animals, the spectrum of methylation levels and patterns is projected to reflect upon a broader range and also indicate a highly variable mode of expression. Excepting cases such as *Caenorhabditis elegans* and *Drosophila melanogaster*, most invertebrate examples are reported in specificities reflected in indicating possession of a low to moderate level of DNA methylation patterns. Vertebrate examples, on the other hand, have been shown as demonstrating having acquired in the range of higher levels of 5mC activities and were evidently documented, especially from among several higher animal examples. However, Bird (2002) is of the opinion that it was not possible to corroborate this situation to the same level of methylation processes prevailing by 5Me between the vertebrate level to that of an insect system. The available data indicate varying levels of methylation processes that do not seem to point out any conserved function. For example, the role of CpG methylation as an epigenetic mark responsible for genomic imprinting has been clearly established in some mammalian examples (Feil and Khosla 1999). Evidently, the case of human inactive X-chromosome in the female somatic chromosomal complement serves as an ideal one for such kind of enquiry.

On the other hand, the role of DNA methylation in insects is still in its infancy. Thus, this situation could reflect upon their leading a high diversity of life-cycle strategies prevailing from among individual cases pursued in each instance for said purposes. The familiar one is the case of *Drosophila melanogaster*, in which DNA methylation seems to be representing in an elusive way, because overall mechanisms prevail upon developmental phases and more non-CpG methylation processes controlled by the role of Dnmt2. In contrast, the case of *Mamestra brassicae*, a cabbage moth, based on HPLC analysis demonstrates the higher level of DNA methylation, which appears considerably closer to the standard level cited with respect to certain vertebrate examples. Methylation experiments including restriction enzymes as a parameter showed that CpG sites were more spread out in the genome, dispensing more towards the outer C of the 5’-CCGG-3’sequences. However, results based on transposons are intriguing because mobile elements are harboring and/ or congregating at or proximal to repetitive sequences that seem heavily methylated, as was shown effectively in some vertebrate and plant examples. However, a very interesting case was that of *Myzus persicae*, a peach-potato aphid, wherein the enzyme systems have been amplified drastically due to spurious developmental activities of insecticide (E4 & FE4) resistance genes and thus, forcing upon detoxifying esterases that have been spurred up due to spurt in DNA methylation processes (Hick et al. 1996; Field et al. 2004). Overt expression patterns of CpG methylation in these cases might have reflected upon the amplification events of the concerned genes, the situation of such kind may be considered reflecting upon the mechanics of methylation processes associated with the copious presence of DNA transposons as was found necessary in the cases of several vertebrates and in transgene experiments carried out in plants (Feil and Khosla 1999; Field 2000).

The historic findings of Schrader (1921, 1923b) and Hughes-Schrader (1948) in which male chromosomes were found to be characterized by the presence of a haploid chromosomal set acquiring precocious condensation property and thus, becoming inactive ones (in Lecanoids) or put into an ordeal of genomic elimination (in Diaspidids) during the course of embryogenesis. Brown and Nelson-Rees (1961) described such an event occurring by elaborating on chromosomal mechanics imposed upon heterochromatic components by means of undergoing a facultatively heterochromatinization program.

The condensation property of the paternal chromosomal set of mealybug chromosomes is correlated in parallel with the expression for maleness. In mealybugs and other coccoids, radiation-induced chromosomal fragments are not lost during mitosis but persist as stable entities in nuclei of both sexes, demonstrating that the centromere is diffuse and that freshly broken chromosomal ends can still form telomeres or telomerelike structures and regulate associated functions (Brown and Nelson-Rees 1961; Chandra 1963a). When broken chromosomes were transmitted by fathers to their sons, each chromosomal fragment underwent heterochromatization progression suggesting the presence of multiple centers of chromosome inactivation. This situation contrasts with the condensation property exhibited in mammalian females, wherein the inactive X-chromosome is identifiable with a single center of activity and is thought to control the whole of the inactivation program (Cattanach 1974; Lyon 1999; Brown et al. 1991). Characteristically, the mammalian inactive X-chromosome shows a typical characteristic organization as scored by micrococceal endonuclease treatment, because transcriptional factors do (or can) not bind to its condensed domains (Pfeifer and Riggs 1991). On the other hand, chromosomes play a different role in view of the situation that coccoid genomes have offered as a readily packed and amenable material of chromosome research in any cytogenetic and/or biochemical exploration activities.

One of the unique features while characterizing genomes is to introduce an enhancing mechanistic driving so as to yield differential organization of homologous chromosomal sets dwelling in one point of reference which allows one to pursue gratuitously such as, for example, to pursue more upon the mechanisms of sex-determination, genomic imprinting processes, and into inactivation progression (Hughes-Schrader 1948; Chandra and Brown 1975; Peterson and Sapienza 1993). For example, the mealybug genome is unique because it is in possession of unusual chromosomal characteristics, involving diffuse centromeric organization (holokinetic activity) that encompasses inverse meiotic processes, leading to a signaling of an unorthodox mode of cell-cycle manipulation in males (Hughes-Schrader and Ris 1941; Brown and Nur 1964; Nur 1990). Thus, some of these unusual genetic bounties could have driven Chandra and his collaborators in attempting and exploring further these genomic contents (e.g., *P. lilacinus* or *P. citri*) at the DNA sequence level and of modified version of bases in the DNA sequence organization.

Employing appropriate but standardized biochemical protocols (Jamaluddin et al. 1979; Achwal and Chandra 1982; Achwal et al. 1983, 1984; Karnik 1983; Deobagkar et al. 1982, 1986) have enabled their fruitful extraction of total nuclear DNA content based on an Indian *Planococcus* genome. These assays were utilized for the purposes of studying the primary nature of methylation status by means of HPLC and chromatography which enabled disclosing the presence of significantly higher amounts of 5-methyl cytosines in some portions of the genome. This was verified by dinucleotide analysis in which 5-mC seemed over represented with respect to other sequences (viz., CpA, CpT, CpC). Unusually higher amounts of 6-mAdinosine (6-mA), 7-mGuanosine (7-mG) were also encountered (Deobagkar et al. 1982). Achwal et al. (1983) reported a new protocol to isolate and characterize antibodies raised specifically to 5-mC, 6-mA, and 7-mG, a situation rarely found in higher eukaryotes at that time. With the use of immunobiochemical approaches they were able to evaluate the samples to the same level of contention to that of higher eukaryotic samples (viz., *Drosophila*, Human, etc.).

Devajyothi and Brahmachari (1989, 1992) present evidence of obtaining homogeneous extraction of DNA-methyl transferase enzyme that were found specific to the test material (*Planococcus citri/ P.lilacinus*). The enzyme extracts exhibited a proactive mode of action and found preference for salt extraction techniques, because that appeared equivalent to routine extraction protocols utilized in the case of mammalian methylase assays. These results demonstrate that the enzyme assays have had high specificities for denatured DNA substrates. Mohan et al. (2002) using random stretches of *P. lilacinus* DNA sequences, the technique of which was found to be helpful in delineating repetitive sequence analyses that were inferred as higher than those of other conventional sequences and were also found much higher than those of *Drosophila* samples scrutinized and compared wherein GCs were found less frequent. Thus, they infer based on this situation that seemed promising for the considerations upon influencing on CpG dinucleotide sequence frequencies which was found exclusively in those genomic samples. Methylation specific arbitararily primed (MS-AP), polymerase chain reaction (PCR), and subtraction hybridization protocols were found helpful to Mohan and Chandra (2005) and thus to describe the isolation and sequencing of sex-specific CpG methylation sequences that were prevalent in genomic DNA samples of *P. lilacinus*. These sequences showed male specific methylation processes and were found to occur about 2.5 times more frequently than those showing female specific methylation sequences. Bisulphite modified DNA samples revealed an interspersion of CpG and non-CpG methylation among sex-specific methylated sequences. This study also pointed out that there were more non-CpG methylates and/or at least twice as many sex-specific methylated sequences found in males than in females. They thus based on those sequences that there could be offering a closer association between sex-specific methylated sequences located in transcriptionally silent chromatin zones and those assays resistant to DNase I zones.

Scarbrough et al. (1984) studies were based on the differential levels of 5-mC in the males and females of *Pseudococcus calceolariae* and *P. obscurus* and thus they were able to relate their findings and that these results driving them to arrive at conclusions that males display higher incidences of methylated sequences than those of female samples. Kantheti (1994) describes, with the help of specific antibodies raised against 5-mC, that there were more 5-mC localization spots identifiable on male cells than on female ones in the case of *P. lilacinus*. There were also two more studies reported on *Planococcus citri* (Bongiorni et al. 1999; and Buglia et al. 1999) whose genomic exploration of *P. citri* samples related to the prevalence of sex-specific cytosine specificities but arrived at conflicting inferences.

Khosla et al. (1996) present evidence suggesting existence of specific DNA fragments that were perhaps offering to serve as a primary signal during the elaborate mechanism as a contributing factor towards chromosomal imprinting activities. Chromatin organization of *Planococcus lilacinus* was chosen for the purpose of extrapolating rather than to consider offering as contributory factors to their functional spectrum. Digestion of *P. lilacinus* samples with micrococcal nucleases showed 3–5 % of the male genome samples were different and the same were assayed and found to be more resistant to the introduction of enzymatic activities; as such these samples were designated nuclease resistant chromatins (NRCs) fractions. This component was present invariably in both sexes and throughout the genome. However, cloned NRC DNA contained A+T rich sequences that were found revealing some homology towards that of samples of mouse α- satellites. Salt fractionation techniques revealed that these sequences were found to be matrix-associated. Based on these experiments, they were tempted to offer some solutions in the form of those DNA sequences present explicitly in NRC fractions and it was possible to infer that this sample would serve as a resource material for a future course of genetic studies. Thus, Khosla et al. (1996) findings thus are directed towards offering these parameters that could as well be serving as a mode of strategy and further to consider them as putative centers for initiation of facultative heterochromatization processes. However, they also cautioned that there are other contributory factors that they might interact with this grand executive operation. In the meanwhile a thorough scrutinization is necessary and required in an extensive way prior to arriving at any kind of generalization in this regard.

With the help of southern hybridization and FISH techniques, Khosla et al. (1999) provide results proclaiming the extrapolation of NRCs and further about prevalence of subdivisions of these fractions in the form of two middle repetitive sequences, designated as nrc50 and nrc51 samples. It was also found that they were differentially organized within NRC composition and more interestingly they have enabled distinguishing the sexes based on the placement of differential proximity. The NRCs were also found resistant to both MNase and DNAase I treatment and thereby enable exhibiting indistinct patterns that may help in identifying two sexes. Their enrichment in NRC accounted to contain 50 and 83 % for nrc50 and nrc51 type, respectively. Thus, 25–30 % of samples remain resistant in males but none in females. It has been shown consistently that NRC is associated with the nuclear matrix. On a nuclear matrix isolation platform regarding male and female sample nuclei, it was found evident that the NRC fractions were present only in males but not in females. They further imply that it is the paternally derived hypomethylation set that drives towards processing of the heterochromatization program. It was also felt that some nrc51 fractions were not accessible to MNases even in euchromatic chromosomes. For the same they offer the suggestion that these sequences might have been inferred to contribute towards centromeric-type activity; instead, they were found to be dispensed with all along the length of the chromosomes. It was well known that a single inactivation center exists in the case of the mammalian inactive X-chromosome, in contrast to the situation prevailing in the mealybug chromosomes exhibiting multiple centers along the length of individual chromosomes that serve as a model system for the chromosomal inactivation program. In the light of these findings, these are the distribution specificities for nrc50 and nrc-51fractions over the mealybug chromosome samples and considering them for their presence in the form of several heterogeneous NRC–DNA fragments and of enrichment within the unusually organized chromatins of the male would raise the possibility of examining them and perhaps serving as putative nuclear sequence loci in the form of expression of multiple inactivation centers.

Extending these experiments as an extrapolation undertaken by Khosla et al. (1999), they provide descriptions based on their explicit pattern of expression of this unusual chromatin organization designated as NRC fractions during the course of cytologically identifiable regions and during spermatogenesis and especially over sperm nuclei even though their expression was on a maternal background. Furthermore, it was made possible for them to infer that this component can perpetuate through mitotic and meiotic progression.

It also appeared interesting that differential chromatin organization forms procured from the samples of the mealybug (*Planococcus lilacinus*) provide an important biochemical tool in consideration of assessing and identifying maleness or femaleness based on the presence or absence of NRCs from the total genomic organization. Thus, based on this important biochemical discovery, it was made possible for Khosla et al. (2006) to hypothesize and suggest a biochemical model that may be able to answer some of the vexing problems confronted by geneticists included during the course of understanding genomic imprinting mechanics. They are of the opinion that by regulating NRC as a discriminating organization in the paternal/maternal genome, it becomes possible to discriminate male- oriented cells from those of females while attempting to recognize facultatively heterochromatinized chromatin organization in one or the other sex. At this juncture, their inference was to ascribe that in the preceding zygote formation, the zygote is in possession of the paternal genome in the form of the NRC positive state and as such, the status of heterochromatin is in the form of negative effect. Subsequent to sixth cleavage divisions, the said NRC-positive paternal genome acquires heterochromatization status based on the developmental decision made at some point in the ooplasm, in order to acquire a decision either to procure or lose heterochromatin mediating proteins, thereby acquiring a specific functional role based on a NRC-positive or negative fraction.

Subsequently, Mathur et al. (2010) present a genomic organization of another pseudococcid, *Maconellicoccus hirsutus*, thereby evaluating the obvious presence of the effective NRC fraction and its mode of association with that of nuclear histone matrix content. They insist based on previous experience that the affinity patterns between NRC and histone matrix form an important binding property for a meaningful differential expression especially eliciting developmental courses promoting the paternal mode of inheritance. The exhaustive study revealed by means of extraction and the identification of H3K27Me3, H4K20Me3, and H3K9Me3 proteins in both in male- and in female-based samples and with a significant enrichment of H3K27M3 in the nuclear matrix of males compared to that of females form an important and critical contribution. This particular biochemical component seems pointing towards and directing a cell-based signal for a male sex-specific discriminating factor. Furthermore, the analysis of cytologically sorted nuclei indicates the presence of NRC in nuclei with different DNA content including the haploid nuclei from males, is another interesting phenomenon disclosed in this genome.

3.12.3 Molecular Cytogenetics

HP-1 (Heterochromatin Protein-1) is a nonhistone chromosomal protein with two highly conserved domains. The amino terminal "chromodomain" (CD) has the capacity to bind either mono-, di-, or tri-methylated histone moiety (e.g., lysines) of H3 or H4 or others. The carboxy terminal "chromoshadow" (CS) domains are involved in mediating protein– protein interactions (Eissenberg and Elgin 2000; Lachner et al. 2001). Historically, HP-1 was identified and isolated originally based on *Drosophila melanogaster* polytene chromosome heterochromatin regions and subsequently, were procured from several other sources and from several other organisms, considering these format posed us as the basis for isolation and they were acquainted through to the cloning experiments. By raising antibody (CIA 9) against those subdivisions of several homologues were procured. HP-1 are highly conserved and play a role in gene silencing efforts in a diverse range of organisms (Singh and Georgatos, 2002). There appear to have been instances wherein euchromatic zones require HP-1 s for stabilization of their elongating transcripts (Vakoc et al. 2005).

Epstein et al. (1992) were keen on extrapolating the molecular biology of HP-1 and their efficiency towards cloning and thus isolated several patterns of expression from *Drosophila* HP-1 homologues and the same were used to compare with samples drawn from several other sources wherein their genomes were known towards exhibiting heterochromatin programs in which the role of HP-1 takes dominance. Because they knew that the degree of similarity between chromodomains (of polycomb) and HP-1 at the nucleic acid level it was found sufficient to detect and isolate other genes from other organisms using low-stringency nucleic acid hybridization (Singh et al. 1991). Epstein et al. (1992) were exploring the possibilities of procuring HP-1 homologues from several other sources; however, they preferred to examine HP-1 s from mealybug genomes because it was well-known that these scale insect provide a robust example for such kind of consideration and thus may serve as a suitable target (Hughes-Schrader 1948; Nur 1990).

Thus, the coccoid genetic system is well recognized as one of the first examples to pursue for examining parent-of-origin (parental imprinting) specific effects; subsequently, other examples were perused for said purposes including humans (Solter 1998). But Epstein et al. (1992) were able to describe their attempts by means of molecular characterization of two chromodomain-containing proteins called PCHET-1 and PCHET-2 (for putative coccid heterochromatin proteins 1 and 2), from the mealybug genome, *Planococcus citri*. They were able to prepare cDNA encoding these proteins realized in cloning and in which it was shown that PCHET-1 seemed to have more potential than that of PCHET-2. This fusion product was later utilized for exploring the expression patterns of PCHET-1 in other mealybug tissues and it was confirmed that it assisted in a male tissue-specific manner. However,, the specificities of tissue distribution of this protein may suggest the most sought after gene, but it was not at the level of correlating to the extent of identifying the male-specific heterochromatic chromosomal set. Moreover, PCHET-1 was not found traceable on female cells. Thus, they opine that PCHET-1 in combination with other factors may help in providing a role for the sex-determination device.

Many decades of concentrated work on heterochromatization in terms of cytological and molecular characterization reveal that this chromosomal component (whether constitutive or facultative) consists based on a macromolecular mould in the form of a repressive chromatin complex (Spofford 1976). It is well known that methylation of lysine 9 of H3 by Suv (3)9 methyl transferase creates a binding site for HP-1 (CD) resulting in the formation of a repressive protein complex; since it was considered the most robust histone modifications known.

While attempting to elicit mutual relationships existing between heterochromatin, HP-1, and trimethylated lysine 9 of H_3 (Me(3)K9H3) as a requirement in analyzing X-chromosome inactivation program is resolvable us in the mammalian examples including humans, Cowell et al. (2002) observed that there were elevated levels of trimethylation at the notified sites resulting in chromatin suppression. An extension of such kind of exploration made on the mealybug genome (*P. citri*) was represented and shown by intense staining of DAPI; but male cells were highlighted by discrete staining localization rather than that of interphase nuclei. Only flecks of stainability marks were found over the euchromatic portions, but the representation at the male prometaphase stage was by and large very clear (Cowell et al. 2002). Thus, they made an assertion towards this effect that the role played by the HP-1 protein in silencing of concerned genes is thought to be a conserved function (Nokayama et al. 2001; Nielsen et al. 2001).

Recent studies on methylated histones have revealed that the level of methylation of the specific lysines may have an important functional consequence for the assembly of heterochromatin formation. Acetylation and methylation are the two types of post-transcriptional modifications known that have been identified in histones (Wu et al. 1986). The histone "code" is a suggestion made in which covalent modifications may be brought about by the kind and mode of the participation of chromosomal proteins and as such, a modification will have effects on driving towards tissue-specific expression patterns. Kourmouli et al. (2004) have made observations that on the N-terminal tails of lysine 20 of H4, it is trimethylation of this lysine that occurs; but if it is dimethylation of lysines it was shown to be associated with euchromatic portions of the genomes (Fang et al. 2002; Kourmouli et al. 2004). Furthermore, Kourmouli et al. (2004) have reported that in the murine examples, the trimethylated lysine 20 of H4 (but not the Me(2) K20H4) establish specific relationships in the presence of Suv(3)9 histone methyl transferase activity, with that of Me(3)K9H3 thereby accounting for epigenetic crosstalk between H3 and H4. Extension of such kind of study revealed that in the coccoid examples analyzed as a target for action it was expounded that its expressivity was observed on the facultative heterochromatized paternal chromosomal set. They made a detailed assessment of this situation by means of DAPI stainings where the heterochromatic component forms a brightly stained property

(Epstein et al. 1992; Bongiorni et al. 2001; Kourmouli et al. 2004). In the female mealybug cells, Me(3)K20H4 is found scattered uniformly throughout the chromosomal set.

Most imprinted loci may have key regulatory elements that are methylated on one of the parental chromosomes. For several of these differentially methylated regions, recent studies establish that the unmethylated chromosome has a specialized chromatin organization that is characterized by nuclease hypersensitivity. In such a situation, the question is raised as to whether associated chromatin features regulate the allele specificity of DNA methylation at those imprinting control regions.

Taking cognizance of a lead from the biochemical front that was well demonstrated from the reports of Scarbrough et al. (1984) and Devajyothi and Brahmachari (1992) and its relevance to the possibility of establishing prevalence of relationships between two states, DNA methylation processes and chromosome imprinting phenomena in the coccoid genetic system is a jerk in our understanding of chromosome imprinting phenomena and is considered monumental in coccoid genetic research. In order to probe further this important component of scale insects, Prantera and his team (2012) have initiated unearthing several molecular cytogenetic complexities. Following is a descriptive account of their research accomplishments.

In order to probe and enlighten based upon implications of molecular and chromosomal level investigations undertaken by Bongiorni et al. (1999) who made a beginning towards prevalence of procuring knowledge of the *P. citri* genome of Italian origin. They utilized the RE/NT technique (restriction enzyme directed in situ nick translation) upon exploring of DNA sequence-level organization, thereby extrapolating the *P. citri* chromosome (Ferraro et al. 2001). Concentrating specifically based on MSPI and its methyl-sensitive isoschizomer HPa II when used as nicking agents, led them to make incisions into the genome by exposing organizational differences prevailing between homologous chromosomes and subchromosomal regions (Prantera and Ferraro 1990). The *P. citri* genome was targeted for such an exploration in order to delineate chromosomal differences, especially pointing out DNA sequences pertaining to differences occurring at the organizational level, to the extent of identifying methylated and nonmethylated chromosomes.

Bongiorni et al. (1999) have made a detailed account of the structural organization in respect to both males and females, and the paternal derived haploid set was found to be hypomehtylated to that of the maternally derived chromosome. In males it is the paternally derived hypomethylated haploid set that is heterochromatized. To their surprise, in female embryos, half of the chromosomal complement was undermethylated and thus, they inferred that the undermethylated chromosomal set in females represented was of paternal origin, emphasizing that DNA methylation could be at the basis of imprinting phenomena at the chromosomal level. Thus they suggest that the two haploid sets are imprinted by parental-of-origin-specific DNA methylation with no correlation with the known gene silencing properties of the base modification.

In their next venture (Bongiorni et al. 2001), they carried out experiments based on western blotting and immunolocalization with fluorescent microscope-level observations upon mealybug genome *P. citri*. Their intuition was to identify a cross-reactive protein epilope whose properties suggest that of a homologue of *Drosophila* HP-1, present in this species. By analyzing the distribution patterns upon immunofluorescence spottings they could infer the distribution of this HP-1-like protein in male and female cells during the cell cycle and in the early embryogenesis. It was evident to point out this (HP-1-like) protein colocalizes with male-specific heterochromatin, thereby implying that this protein plays a role in the process of facultative heterochromatization.

However, they allay some doubts as to the nature of the presence of *P. citri* HP-1-like protein in embryos of both sexes which had led them to infer a protein factor was involved in the recognition of the imprint signal, suggesting that at least there could be another factor provision which was found to be involved in the induction of facultative heterochromatization and thus this factor should be male-limited in characteristics. Moreover, as to the nature of C-banding staining, it was not a strict cytological correlative measure to assign any heterochromatic role. It is well known that C-bands always coincide with constitutive heterochromatic composition.

In their next exploration of coccoid chromosome systems, Bongiorni et al. (2004) concentrated on detailing the inverted meiotic cycle established by means of indirect immunefluorescent tapping. This issue drew special features because *P. citri* genetics revolves around diffuse centromeres and inverted meiosis. This study also focused specifically on second meiotic division in which the male cell-cycle was manicured by monopolar spindle activities and as a part of this special system, they dwelled more on the mode of meiotic drive enforced upon this genetic system. They were more interested and engrossed on interpretation of meiotic spindle activity in which the cytological preparations made were based on the use of an antibody that was directed against insect α–tubulin.

Earlier, Hughes-Schrader (1948) suggested the prevalence of monopolar spindle during male meiosis and interpreted that heterochromatic chromosomes are the ones participating in such kind of activity. However, based on the introduction of recent protocols (Bongiorni et al. 2004) upon *P. citri* meiosis revealed that the spindle is associated with the euchromatic set facilitated by enhanced staining by DAPI that distinguishes each set by differential fluorescent stainability.

The monopolar spindle could originate either from a lack of centromeric duplication or from the lack of separation of duplicated centrosomes. These authors were of the view that the formation of a monopolar spindle and the lack of microtubule binding by heterochromatic chromosomes are a necessary condition to ensure the nonindependent segregation of homologous chromosomal sets at the second meiotic division. The nonindependent assortment at the reductional division together with the degeneration of the heterochromatic spermatid nuclei formulate a basis of the strong meiotic drive that leads to exclusion of the heterochromatic chromosomes from genetic continuum.

Earlier experience was driven to understand that the HP-2 protein, a homologous HP-1 partner acquired from the *D. melanogaster* genome, acts as a dominant suppressor of PEV, therefore demonstrating a role involved in the structure and maintenance of heterochromatin structural integrity. Implying the foregoing concept, Volpi et al. (2007) wanted to probe more of its effectiveness upon the mealybug (*P. citri*) genome. With the help of an antibody raised against *Drosophila* HP homologue epilope samples, they acquired the set that was able to present cross-reactive epilope and thus they designated the product as an Hp-2-like protein. Following the life-cycle patterns through to the male phase of the mealybugs revealed that they became with acquainted with a heterochromatinized chromosome set containing the requisite amount of antibody deposition that was estimated by immunofluorescent scanning. During the observations of the euchromatic chromosomes, HP-2-like impressions were sometimes traceable over the telomeric regions. The interplay between HP-2-like and HP-1 was critically examined based on the introduction of ds RNAi experiments. Knocking out HP-1-like protein expression with the introduction of the RNAi method did not prevent the association of HP-2-like with facultative heterochromatization, thereby endorsing that the latter and its presence by binding to chromatin is independent. They also utilized that this property extended to the processes of condensation or decondensation upon other cell types.

It is now certain that the HP-2-like protein binding to chromatin is a perquisite for facultative heterochromatization assembly and it indeed poses an interesting possibility that this component must be tested by inactivation of HP-2-like. Hp-2 antibody signals aggregate over distinct chromatin areas, which identify the future chromocenters after they have already been bound by HP-1-like. This suggests that the recruitment of HP-2-like to the potential heterochromatic domains depends on the presence of HP-1-like. In adult tissues, where the heterochromatization reversal occurs, the HP-2-like epitope is lost by the chromocenter remnants before the HP-1-like, which thus seems to be insufficient to anchor HP-2-like to chromatin. It has also become evident that the strict colocalization of HP-2-like with the chromocenter is not abolished in HP-1-like knockout embryos.

Molecular results based on some mammalian examples, also including the mealybug genome, were obtained independently by Kourmouli et al. (2004) and Schotta et al. (2004) in an experiment to certify the effect that Me(3)K9H3 employing Me(3)K20H4 through the participation of HP-1 promoting heterochromatin formation appears to be a global-level event. But what was not clear about this was how HP-1 modulation is involved during gene activation processes in the case of the mealybug genome (*P. citri*; Bongiorni and Prantera 2003; Bongiorni et al. 2007; Kourmouli et al. 2004). In contrast, acetylation of histone H_4 (AcH4) was found to be absent on the male-specific heterochromatization processes (Ferraro et al. 2001), whereas the depleted level of activation of AcH4 was observed in the case of human X-chromosome inactivation (Jeppesen and Turner 1993). The foregoing issues have driven to an understanding with a suggestion that Me(3) K9H3 via HP-1 to the Me(3)K20H4 pathway in an evolutionarily conserved mechanism of action for an epigenetic route to silencing large chromosomal domains by facultative heterochromatization (Chadwick and Willard 2004).

While establishing the prevalence of Me(3) K9H3 to HP-1to Me(3)K20H4 relationships in the case of *P. citri* genomes, Bongiorni et al. (2007) proceeded further to interrelate the position of the HP-2-like protein (PCHET-2) based on RNAi experiments. With the intermediation of ds RNAi (Fire et al. 1998) and by interference of knocking down PCHET-2 in *P. citri* embryos, it was resolved that the consequential depletion of the heterochromatization pathway resulted in deheterochromatization with respect to gut cells and Malpighian tubules, whereas Hp-1 and Me(3)K20H4 in the same nuclei are either dispersed or absent. Embryos treated with ds RNAi (double-stranded RNA interference) targeting PCHET-2 also exhibit chromosomal abnormalities (such as chromosome lagging, abnormal condensation, segregation defects), more so on structural maintenance components (SMCs).

3.12.4 Chromatin Remodeling

In many diverse organisms, gamete formation originates in a cytoplasmic, but highly conserved structure, known as germ-line cysts. Germ-line cysts (or saclike structures) are composed of a group of cells; it is apparent that they took their initiation from a single cell that underwent synchronous cell divisions followed by incomplete cytokinesis. Modification of the chromatin structure is one of the main epigenetic regulations conceived to carry out its operation in order to undertake unique gene expression modalities. The male germ-line cyst is the organ that facilitates executing the meiotic and/or post-meiotic mode of gene regulation activity sharing during gametogenesis. The germ-line cyst morphogenesis acquires the responsibility of delivering the respective genomic content to their destined sites.

Male meiosis of scale insects is interesting because meiotic sequence progressions proceed in accordance with those of inverse meiosis. Thus, during male meiosis each spermatogonial precursor cell nucleus produces a bunch of synchronously dividing spermatogonia in a cytoplasmic cyst. Each spermatogonium divides four times to produce a cyst of 16 primary spermatocytes which then undergo two meiotic divisions. Subsequently, each spermatogonium undergoes the first equational and then the second reduction division, which is characterized by specialized movements directed and dictated by some unknown sources. But recent studies undertaken by Buglia and Ferraro (2004), Buglia et al. (2009), and Bongiorni et al. (2009) have provided some clues to learn more about the extent and nature of expression, wherein these chromosomal movements were maintained and manipulated by the monopolar spindle in which microtubules make physical connection with the euchromosomal set, rather than with the heterochromatic component as was contended earlier by Hughes-Schrader (1948). Even though *Sciara* chromosomes practice monopolar spindle activities, it seemed to be maintained through the occurrence of monokinetic activity wherein meiotic products were manicured by sister-chromatid cohesion (Esteban et al. 1997).

By utilizing antibody-specific tracings, Buglia and Ferraro (2004) describe an immunofluorescent staining protocol backed by enhanced active participation of fusomal elements, such as F-actin, included in the elaborate descriptions of factors that demarcate local morphogenesis essentially demarcating the cytoplasmic composition of the male germ-line cysts. The co-localization of all these factors is an indication of the triggering action that could be measured by densitometric profiles which further enable in providing descriptions about the prevalence of two kinds of sperms emerging but equipped with variable loads with respect to individual sperm content.

A continuing search by Bongiorni et al. (2009) proceeded towards extrapolating procurement of the resources to be used during the gametogenetic processes and seemed to be in possession until early embryonic development. Immunolabeling of such components in order to probe has enabled identifying the presence of protein components such as H3K9Me2 & 3, H4K20Me3, HP-2, and PCHET-2-like, that were concentrated in the paternal part of the meiotic stages throughout, but not in the female line to the extent of oocyte formation. On the other hand, there were no traces of these modifiers in the female gametogenesis. The redistribution of epigenetic signaling marks in spermatids might be related in the tracings of the processes concerned with the establishment of parental imprinting. Bongiorni et al. (2009) narrate the modes of operation through to the entry of sperm into the oocyte environment, where they are in possession of distinct H3K9Me2 and 3 methylation marks that were found in the early pronucleus. Observations were made of such kind of effect during the course of spermatogenesis indicating the presence in the form of heterochromatic components decorated by H3K9Me2 & 3 and PCHET-2. Regarding the euchromatic component, it was shown containing HP-2-like and H4K20Me3. This was found to be a consistent expression pattern until the spermatid formation, thereby demonstrating the supremacy of histone modifications throughout the male part of the meiosis. This situation is in congruence with that of Khosla et al. (1999, 2006) observations and of their proposals advocating the presence of NRCs on paternal cell lineage until sperm maturation. By now, it seems evident by pointing out that by the end of spermatogenesis PCHET-2 may be losing its grip. Bongiorni et al. (2009) contend that the presence and supremacy of H3K9Me2 & 3 methylation processes dominate throughout the course of gametogenesis, and with respect to the content of these proteins, they are in disagreement with the contention of Buglia and Ferraro's (2004) observations. This pertains to the quantum of differential distributions regarding euchromatic spermatids, because these products take their origin from a single meiotic event. However, Buglia and Ferraro (2004) strongly define that values they procured were essentially based on densitometric tracings, citing differing values with respect to H3K9Me2 & 3 and of CIA9.

In their subsequent study, Buglia et al. (2009) have elaborated mustering of resources pertaining to the development of female phases of gametogenesis of *P. citri*. Their results provide the presence of a proteic component; this time the presence of HP1 and Su (var) 3–9 (a different chromosomal protein), makes all the more important contributions occurring during female gamete formation. Pertaining to the deposition of variable contents of eggs it was found to contain two different kinds of cell inclusions, deposited in eggs, thereby categorizing in such a way as to act differently upon different ages of females. Based on these biochemical characteristics, females with 40-days older age were considered as a younger group and those of 80-days old as an older (aged) group. The findings of larger amounts of epigenetic factors accumulated in the group of aged females in comparison to the younger ones was found to be an important deciding factor. These studies have led to the supposition of playing as a primary role based on differential maternal contribution.

It was observed that the concept of genomic imprinting phenomena seemed to be lending effective support in the cases of both *Sciara* and coccoids, that the primary sex determination mechanism relied upon considering consequences of occurrence of chromosome imprinting (Chandra and Brown 1975; Brown and Chandra 1977). It also appears obvious in the case of mealybugs, that possibly it was at the instance of mothers that enable directing and discriminating the sex of her offspring. In addition, the extension of this provision should yield mechanistic support to the concept that maternally controlled sex determination could also give way or leverage for control of the progeny sex ratio. Earlier, Nelson-Rees (1960) had contended that the sex ratio in mealybugs fluctuates among females and is markedly influenced by mother's age at conception towards the brood. In both sexually reproducing and in parthenogenetic mode of reproduction, the imprinting process initiates at and in the egg cytoplasm at the time of the fertilization program.

Parental genomic influences on the fate of offspring development are evident in both invertebrate and vertebrates. Maternal effects are commonly mediated through deposition of the cytoplasmic transcripts essaying protein products in oocytes during oogenesis in the female germline. These then exert their effects on the fertilized eggs and drive impulses upon early embryonic developmental processes (De Robertis et al. 2000; Gosden 2002), unlike some mammalian examples that may provide guidelines for any kind of eventuality (Li et al. 2008). However, there are no specific studies undertaken pertaining to the operating mechanisms responsible for maintenance of genomic methylation imprints, even though the *P. citri* genome may serve as very good material for such kind of expeditions.

In view of this trepidation, it is possible to infer that the mother can embark upon an initiation or directing a particular path towards the choice of her offspring and its bestowing effectiveness on the sex-ratio potential. In promulgating the imprinting phenomenon, in terms of evolutionary consequences with reference to a choice-based progeny sex ratio, it was also postulated that the role of the mother's cytoplasmic environment might have been inflicted by imposition of environmental disturbances. Thus, during routine life-style courses, a one-to-one ratio in the case of sexually reproducing and one-to-none in the case of parthenogenetic system, the sex ratio will operate in an expected line. However, if any change is incurred with respect to the sex ratio it could possibly be envisioned and perceived as operating under constraints due to the external forces that thrust upon maternal environmental cues.

Currently, the mechanism of the genomic imprinting phenomenon is still unclear although the role of PCHET-2 and histone modifications seems evidently involved in effecting the facultative heterochromatization process in the case of the mealybug genome (*P. citri*). Females may volunteer and might offer to alter the concentration of those proteins in their eggs to their contention so as to modulate the sex ratio of their broods. Along this line, Buglia and Ferraro (2004) and Buglia et al. (2009) observations point towards the situation that under the varied concentration of CIA9-based positively stained protein and of those of observations pertaining to the eggs of females possessing variable amounts of proteins and at variable ages prior to mating should bring forth more differences in the egg chamber. They also apprise that females would produce male-biased offspring whereas the opposite effect of maternal aging prior to mating was also observed in other studies.

Prantera and Bongiorni (2012) postulated that the embryonic cytoplasm at the blastoderm stage determines whether the paternal chromosomes, which are marked by DNA hypomethylation and H3K9me3 methylation marks, could be able to drive towards undergoing heterochromatization processes or not, and thereby giving rise to a male or female embryo, respectively. Given the causative role and presence of PCHET-2 on male-specific heterochromatin formation and also based on the amount of PCHET-2 in the developing embryo, may prefer it as a crucial factor to drive the embryo either towards maleness or femaleness. It is already envisioned that the effectiveness of facultative heterochromatinization makes its presence in the seventh cleavage division onwards regarding male embryos and moving in the form of a wave from one pole towards the other, suggesting a graded distribution on the part of PCHET-2. Inasmuch as PCHET-2 could not possibly be observed either in sperm or in ooplasm, its presence only in the embryo should be at the courtesy of an early de novo synthesis under the control of above-said maternal factors.

Investigations pertaining to finding answers to several questions have been raised and are still pending for clarity with respect to our current understanding of mealybug genomes and of their possibly related roles in expression patterns of chromosomal facultative heterochromatization (inactivation) processes. However, the molecular and cytogenetic data acquired by both the Indian and the Italian investigators' offer us highly commendable efforts since these contributions have driven towards arriving at a mutual interest in the form of a common platform of subjective comprehension.

As part of a supposition made by Prantera and Bongiorni (2012) and with those of the Khosla et al. (2006) and Mathur et al. (2010) opinion that NRC composition may have been influenced by DNA hypomethylation and histone H3K9Me3 methylation mark and furthermore, upon such a drive seemed to have made markings and then spread over the whole of paternal but not maternal chromosomes. Then, in the cleavage embryos, some maternal factor(s) present in the ooplasm might be able to regulate the imprinting process by means of having acquired the requisite amount of PCHET-2 that gradually spreads from one pole towards the other end of the developing embryo. A critical amount of regulated PCHET-2 will then determine whether the paternal imprinted chromosomes will become heterochromatic, thus picking up the path leading towards male embryonic development or will remain euchromatic, thereby losing repressive histone modifications and NRCs, and that eventually by not acquiring the requisite amount of markers, hence rely on the path leading towards female embryonic development.

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4 Taxonomy

M. Mani

The insects coming under Hemiptera, Sternorrhyncha, Coccoidea, Pseudococcidae, and Putoidae are named as mealybugs (Williams 2004). Following the application by Miller (1975b), the family-group name Pseudococcidae (Cockerell 1905) was placed on the Official List of Family-Group Names in Zoology (Melville 1983) (type genus *Pseudococcus* Westwood 1840). Afifi (1968) attempted a higher classification of the Pseudococcidae based on a study of the characters of adult males of 17 species. The scale insects are generally divided into two groups, namely the archeococcids and the neococcids. The archeococcids possess two to eight pairs of abdominal spiracles, which are absent in the neococcids (Koteja 2008). The family Pseudococcidae (mealybugs) belongs to the neococcid group.

After extensive studies on the labium of 84 species of Pseudococcidae, Koteja (1974a, b) proposed that the family is composed of four subfamilies: Trabutininae, Rhizoecinae, Sphaerococcinae, and Pseudococcinae. This classification has gained wide acceptance. A recent phylogenetic study, based on the analysis of nucleotide sequence data, supported the existence of three subfamilies: Pseudococcinae, Phenacoccinae, and Rhizoecinae (Downie and Gullan 2005). This estimate was recently revised in light of integrated molecular and morphological data, and only two subfamilies emerged: Pseudococcinae and Phenacoccinae (Hardy et al. 2008). Molecular studies may either verify this grouping or show a different picture. By the study of prokaryotic primary endosymbiont (P-endosymbiont) nucleotide sequences, Thao et al. (2002) showed that *Antonina pretiosa* Ferris, presently included in the Sphaerococcinae, is closely related to the blue-green or blue-black mealybugs of the genera *Amonostherium* Morrison and Morrison, *Australicoccus* Williams, *Melanococcus* Williams, and *Nipaecoccus* Sulc. These genera are included in the Trabutininae, as discussed by Koteja (1974a, b).

Pseudococcidae constitutes the second largest family of Coccoidea, with more than 2000 described species and ca. 290 genera (Ben-Dov 2006; Downie and Gullan 2004). Pseudococcids occur in all zoogeographical regions of the world. Pseudococcids are distributed in different geographical regions as follows: Australasian region (459 spp.), Afrotropical region (298 spp.), Nearctic region (424 spp.), Neotropical region (283 spp.), Oriental region (431 spp.), and Palearctic region (710 spp.). Of the described species, pseudococcids are most abundant in the Palearctic region and least numerous in the Neotropical area. There are about 2000 species of mealybugs worldwide. In southern Asia, 353

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species of mealybugs have been recorded under 61 genera of which 105 species occurred in India with maximum species reported from Karnataka (40 species) followed by Tamil Nadu (35 species). India is rich in species of *Formicococcus* Takahashi (10 spp.), *Antonina* Signoret (six spp.), *Dysmicoccus* Ferris (12 spp.), and *Paracoccus* Ezzat and Mc Connell (six spp.). The genera, which are endemic to the Indian region, are *Aemulantonina* Williams, *Coccidohystrix* Lindinger, *Eriodes* Green, *Lankacoccus* Williams, *Pedronia* Green, and *Pseudantonina* Green (Williams 2004).

Identifications of mealybugs in practically all cases are based upon the adult female. A sum of the morphological characteristics of the mealybug used in identification of species belonging to family Pseudococcidae are as follows: Anal ring is always present, divided longitudinally into two halves, each with single inner and outer rows of angular cells and three setae; in a few instances, the ring is very much reduced, the sclerotization is slight, and the pores apparently are nearly or completely lacking. Two pairs of dorsal ostioles are normally present in the adult female. In some species, the number of these structures may be reduced, or they may be entirely lacking; thus, in some forms, the posterior pair is clearly present, but the anterior pair is lacking; in a few forms, the ostioles seem to be lacking in the adult but are present in the first stage. Others lack ostioles in all stages; nevertheless, the totality of their characters places them in this family. The antennae have been used in diagnoses of mealybug genera for a long time and even for species separation. Hence, more emphasis has been placed on the antennal structure than on any other physical detail. In *Antonina* and related genera and species of *Eumyrmococcus*, antennae may be reduced to one or two segmented stubs. It has been noted that in certain genera, exclusive of *Rhizoecus, Geococcus*, and *Pygmaeococcus*, where the antennae are noticeably short, small, five to six segmented, and geniculate, the comparative slenderness or stoutness of the normal cylindrical antenna in relation to its length has proved of considerable taxonomic value. This is exemplified in certain species of *Chorizococcus* and *Spilococcus*. The distance between the base of one antenna and that of the other is of considerable value in separating species, particularly in certain members of *Rhizoecus.* Most coccidologists have placed little taxonomic emphasis on the eyes of mealybugs. However, the presence or absence of eyes in *Rhizoecus* and related genera has proved to be taxonomically useful. The labium varies considerably in shape and form and may be elongate and slender in some species, while in others, it is short and broad; in certain species, there appear to be significant differences in the shape of both the basal segment and the tip of the rostrum. Some species exhibit a sclerotized area on the derm just anterior to the clypeus. In some instances, this has been of taxonomic assistance. The body form normally elongate; legs are normally present and usually well developed. Considerable taxonomic emphasis has been placed on the mealybug legs in the past by certain coccidologists. Denticle or tooth on the plantar surface of the claw offers an especially excellent key character for the recognition of this series of genera. Although the denticle or tooth still generally is quite helpful in defining the members of the genus *Phenacoccus*, it cannot be completely relied upon as exemplifying this group alone. In many species of *Chorizococcus* and *Spilococcus*, this tiny denticle or tooth on the claw is present, and it occurs in combination with other characters that are not at all typical of the *Phenacoccus* series.

The body is normally with lateral groups of pores and has enlarged, conical setae, which form cerarii, that at times are evident only on the anal lobes, occasionally lacking, normally with pores of the trilocular type present, rarely lacking. Tubular ducts of a distinctive type are normally present as cylindrical invaginations in the derm, the tube usually more heavily sclerotized at its opening, and with one side of the inner end of tube showing a delicate filamentous prolongation. Combinations of these characters will define the few aberrant forms of mealybugs that are known to exist.

Translucent dots or pores on the hind femur and tibia have definite significance for species segregation. In some mealybug forms, each hind coxa bears a cluster of pores at its base, and the area in which these occur is usually wrinkled. This pore cluster is taxonomically important for differentiating certain species. The trochanter usually possesses a long seta at inner distal end and the variation in its length and thickness proved to be a useful distinguishing character in species of the Allomyrmococcini. The stoutness or slenderness of the pseudococcid legs in relation to their length has proved to be of much taxonomic importance.

Clypeolabral shield structure seems to reach its greatest development in certain bamboo-feeding species of the tribe Serrolecaniini, and sometimes reaches almost the same length as the clypeolabral shield. The structure is now known to occur in many species but sometimes it is barely perceptible. The extension is present mainly in grass-infesting species and occasionally in mealybugs feeding on the other groups of monocotyledons but, apparently, never in dicotyledon-infesting species.

Cerarii situated on the dorsum of the body, their total number, the number of enlarged conical setae, the presence or absence of auxiliary setae, and the presence or absence of the accompanying sclerotization have proved to be important specific taxonomic characters.

Ventrally, the anal lobe is often sclerotized, and the character of this pigmentation is sometimes used as a taxonomic feature at the generic and specific levels.

The presence or absence of a circulus is exceedingly helpful as a "key character" within a genus. At times, they vary in size, form, or number to such a degree as to be of taxonomic value. In some genera, several circuli may be present.

4.1 Temporary Mounts

The following steps are used in the preparation of temporary pseudococcid mounts:

1. Place the entire specimen in a 6-ml., 1-in. handled porcelain casserole dish approximately half-filled with Essig's Aphid Fluid (see formula below), cover with 1½-inch watch glass, and heat (120–130 °F) to dissolve (10–15 min). A lateral incision made between the mid- and forelegs will help to clear the specimens more rapidly.
2. Remove the porcelain dish from the hot plate and tease out the body contents while the fluid is still hot.
3. Transfer the cleared specimen to a droplet of gum-chloral hydrate or chloral-hydrate medium (see formula below). Apply a cover slip and heat the slide on hot plate until the medium boils slightly. The specimen is then conditioned for examination under the compound microscope. (Polyvinyl alcohol is also considered a good temporary-type medium. The specimens should be transferred from Essig's Aphid Fluid directly into the solution.) Valuable specimens are recoverable from this medium for permanent embedding in Canada balsam, although this should not be delayed longer than 3 or 4 months.

4.2 Permanent Mounts

The following steps are used in the preparation of permanent pseudococcid mounts:

1. Place the entire specimen in a 6-ml., 1-in. handled porcelain casserole dish approximately half-filled with Essig's Aphid Fluid (see formula below), cover with 1½-inch watch glass, and heat (120–130 °F.) on a hot plate until the body contents are dissolved (30 min to 1 h). A lateral incision made between mid- and forelegs will help to clear specimens more rapidly.
2. Remove the porcelain dish from the hot plate and tease the body contents while the fluid is still hot. If the specimen is not thoroughly cleared, tease out the loosened body contents

and transfer the specimen to a fresh solution of Essig's Aphid Fluid. Add three or four drops of the prepared staining solution, consisting of either acid fuchsin, lignin pink, or erythrosine (stain No. 2) (see staining solution formulae below), or even more of this solution if a deeper staining is desired. Heat again until the specimens have absorbed the stain (15–30 min depending on the specimens involved.)

3. Transfer the specimens directly into a clear 6-ml porcelain casserole dish half-filled with tetrahydrofuran (C4H8O) and tease out the remaining body contents and excess stain. Leave the specimens in tetrahydrofuran for not more than 5 min, since prolonged periods may cause shriveling. In the case of very fragile specimens, add a few drops of tetrahydrofuran to the Essig's Aphid Fluid before transferring straight to tetrahydrofuran; this will prevent shriveling.
4. Transfer directly into Canada balsam and apply the cover slip. Specimens should be transferred rapidly form tetrahydrofuran to balsam, as little carry-over of tetrahydrofuran as possible. Air bubbles are often left under the cover glass because the solution evaporates quickly, but they will ultimately work their way to the edge of the cover glass. It is advisable to burst these bubbles with a needle dipped in tetrahydrofuran solution before placing the mount on heat to cure. This curing should not be done at more than 100 °F, and 30 min to 1 his required to sufficiently harden the mount.
5. When the balsam has hardened, the cover slip may be ringed with shellac or other suitable media to prevent later fracturing of the balsam. It is good to remember that the clearing and straining process cannot be hurried. However, when the specimens are properly cleared and stained and the mounting techniques are mastered, excellent mounts will result. Because of the high volatility of tetrahydrofuran, some of the smaller and more delicate mealybugs tend to collapse when transferred into it. In such a case, step 3 should be modified as follows:
6. Transfer the specimens to cellosolve in a clean depression slide and leave in this solution for not less than 5, preferably 20, min.
7. Transfer the specimens to xylene in a clean depression slide and wash thoroughly for 1 or 2 min.
8. Place the specimens in a droplet of Canada balsam on a glass-cover slide and apply the cover slip. Use as little balsam as possible to facilitate examination under the compound microscope, especially under the oil-immersion magnification.

The formula used to prepare Essig's Aphid Fluid is as follows:

Lactic acid (reagent grade 85 %)	20 parts
Phenol (saturated in distilled H_2O)	2 parts
Glacial acetic acid	4 parts
Water (distilled)	1 part

The formula used to prepare chloral-hydrate medium is as follows:

Gum arabic	1 g
Dextrose	1 g
Chloral hydrate	10 g

Iodine crystals	1/10 g
Glycerin	1 cc.
Water (distilled)	1 cc.

The formulae used in preparing the staining solutions Nos. 1 and 2 are as follows:

No. 1	Essig's Aphid Fluid		15 ml.
	Acid fuchsin	(2 % aqueous solution)	20 drops
No. 2	Essig's Aphid Fluid		15 ml.
	Acid fuchsin	(2 % aqueous solution)	20 drops
	Lignin pink	(2 % aqueous solution)	20 drops
	Erythrosin	(2 % aqueous solution)	20 drops

Staining solution No. 1 gives excellent results. One slight drawback, however, is that the specimens from certain lots may begin to fade after 3 or 4 months. Preliminary observations made over approximately a 2-year period indicate that the staining solution No. 2 tends to overcome this feature, at least to some degree. It is interesting to note that the species vary in their response to staining, some turning to darker red than others after the same time in the staining solution. This has been advantageous in certain instances, especially where two species are mixed on a single host and are indistinguishable from each other when collected in the field. In such instances, the specimens may be easily segregated by species before they are mounted.

Brief instructions for slide-mounting scales and mealybugs have also been provided by the United States Department of Agriculture (USDA) in their Systematic Entomology webpage. Keys available in the identification of mealybugs are the mealybugs of California by McKenzie (1967), the Australian mealybugs by Williams (1985), and the mealybugs of Central and South America by Williams et al. (1992). A systematic catalog of the mealybugs of the world (Insecta: Homoptera: Coccoidea: Pseudococcidae and Putoidae) has data on geographical distribution, host plants, biology, and economic importance by Ben-Dov (1994) and the mealybugs of Southern Asia by Williams (2004). The above keys may be referred for identification up to species level.

4.3 Field Identification of Major Species of Mealybugs

All mealybug species resemble each other to the untrained eye, so it is very important that an expert is brought to identify the mealybug species involved. The following characteristics are useful for field identification. The adult female mealybug is considered for the identification of body shape, size, and color (Table 4.1):

Table 4.1 List of mealybug species with field-identifying characters with their respective images

Mealybug species – Field characters	Images of mealybug
Antonina graminis (Maskell) (Rhodesgrass mealybug) Broadly oval to circular body; rotund in lateral view; dark purple or brown body; without lateral wax filaments; enclosed in a white, felted sac that turns yellow with age; usually with a long, slender, white waxy tube protruding through a hole in the ovisac at the posterior end of the body. Usually present on the crown or nodes of the grass host. Ovoviviparous; first instars are cream colored; legs absent.	
Noxious bamboo mealybug (*Antonina pretiosa*) Adult body, brown; about 2–3 mm in length; immature stages (i.e., crawlers) yellow; generally found at the nodal regions of various bamboos. Sooty mold occurring at the nodal regions and long wax filaments arising from the nodal areas are common symptoms.	

(continued)

Table 4.1 (continued)

Mealybug species – Field characters	Images of mealybug
Coccidohystrix insolita (Green) (Brinjal mealybug) Adult females are light yellowish green in color with many long glassy filaments; very little dorsal wax; secretes a white, waxy ovisac up to six times as long as the body of the female; immature stages with no secretion of thick layer of mealy wax; the body being shiny yellow-green with submedian gray spots on two abdominal and one thoracic segments.	
Dysmicoccus brevipes (Cockerell) (Pineapple pink mealybug) Body oval or rotund; pink or pink-orange; legs yellowish brown; body covered by thin layer of white mealy wax allowing body color to be visible, without bare areas on dorsum; dorsal ovisac absent, a few filamentous strands on venter; with 17 pairs of conspicuous lateral wax filaments, often slightly curved, posterior pairs longest, one third to one half as long as body, anterior filaments shorter than posterior pairs. Occurring on all parts of plant, usually in protected area. Ovoviviparous; eggs pink.	
Dysmicoccus neobrevipes (Beardsley) (Pineapple gray mealybug) Body oval or rotund; gray or gray-orange; legs yellowish brown; body covered by flocculent white mealy wax, without bare areas on dorsum; dorsal ovisac absent; a few filamentous strands on venter; with 17 pairs of conspicuous lateral wax filaments, often slightly curved, posterior pairs longest, one third to one half as long as body, anterior filaments shorter than posterior pairs. Primarily occurring on the above-ground parts of the host. Ovoviviparous.	
Dysmicoccus boninsis (Kuwana) (Gray sugarcane mealybug) Body elongate or elongate oval; body gray; legs yellowish brown; covered by white mealy wax, without bare areas on dorsum; dorsal abdomen covered by filamentous ovisac; with four to six short lateral filaments, posterior pair longest and thickest. Usually present in leaf sheaths of sugar cane or other grass host. Oviparous; eggs yellow.	

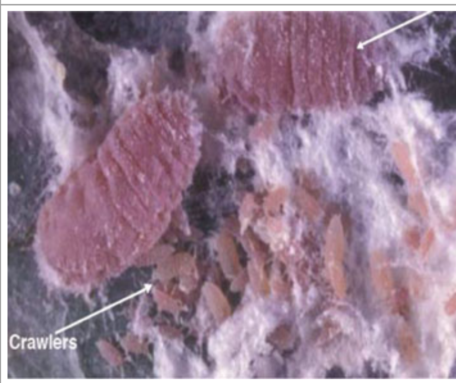
(continued)

Table 4.1 (continued)

Mealybug species – Field characters	Images of mealybug
Ferrisia gilli (Gill's mealybug) Body 2–5 mm in length and pinkish grey in color; often covered with white wax secreted from a pore, creating the appearance of two stripes (darker areas) on their backs. Larger nymphs and mature females produce a network of white filaments (5–10 mm) that protrude from the back of the insect.	
Ferrisia virgata (Cockerell) (Striped mealybug) Body elongate oval; body dark gray; legs dark brown; covered by white mealy wax; with a pair of dark dorsal stripes on the body measuring 4–5 mm in length with two long tails; body covered with long slender crystal like filaments/glossy threads in all directions; without lateral filaments. Usually ovoviviparous; eggs hatch immediately after laying.	
Hypogeococcus pungens (Granara de Willink) Body rotund to elliptical; rounded in lateral view; body pink to pink-yellow; legs light yellow; dorsal ovisac present in all instars, covering entire dorsum; very filamentous; mealy wax lightly dusted over body; lateral filaments absent. Occurring on all above ground parts of plant, often in clumps at nodes, usually in protected areas. Oviparous; eggs pink, hatch soon after being laid.	
Maconellicoccus hirsutus (Green) (Pink hibiscus mealybug) Adult female elongate oval; 3 mm in length; body pink in color sparsely covered with white waxy coating; no to few lateral (side) wax filaments; body fringe absent; no stripes on the back; body fluid dark red; anal filaments short; ovisac irregular and beneath the body; ovisacs covering orange eggs while crawlers are orange to light brick red in color. Feeding causes twisted or distorted foliage.	

(continued)

Table 4.1 (continued)

Mealybug species – Field characters	Images of mealybug
Nipaecoccus nipae (Maskell) (Coconut mealybug) Body round; somewhat flat dorsoventrally; body red to brown-orange; covered by thick white or yellow-orange wax, without bare areas on dorsum; dorsal ovisac absent; with ten to 12 pairs of broad lateral wax filaments, posterior pairs longest and thinner; anterior pairs broad and conical, longest filament about one fourth as long as body. Primarily occurring on foliage of host. Apparently ovoviviparous; dorsum with five to eight waxy filaments similar in shape and size to those on lateral areas of thorax and head. Specimens turn black in 70 % alcohol.	
Nipaecoccus viridis (Newstead) (Lebbeck/Spherical mealybug) Body round or broadly oval; somewhat flattened dorsoventrally; purple; covered by thick white, creamy, or pale yellow wax, without bare areas on dorsum; ovisac covering dorsum; probably with five or six pairs of lateral wax filaments. Primarily occurring on foliage and fruits of the host. Apparently oviparous; eggs purple; dorsum probably with waxy filaments. Specimens turn black in 70 % alcohol.	
Acute mealybug (*Oracella acuta*) Body red to pink; about 3 mm in length; without side (lateral) wax filaments. Generally found both underneath bark and on needles of hosts.	
Palmicultor browni Body reddish brown to pink; about 3 mm in length; with side (lateral) wax filaments; no ovisac produced.	
Palmicultor palmarum (Maskell) (Palm mealybug) Body round or broadly oval; somewhat flattened dorsoventrally; body red-brown; some specimens covered by thick flocculent mealy wax, others with less dense wax, without bare areas on dorsum; ovisac absent; with eight to 14 or 15 lateral wax filaments, posterior filaments longest and broadest, sometimes coalescing, filaments on anterior thorax and head shorter and thinner, posterior pair about 1/8 length of the body. Primarily occurring on foliage of the host.	

(continued)

Table 4.1 (continued)

Mealybug species – Field characters	Images of mealybug
Palmicultor lumpurensis Body grayish pink, about 3 mm in length, with large amounts of white wax visible on host plant; body with few side (lateral) wax filaments; no ovisac produced.	
Paracoccus marginatus (Williams and Granara de Willink) (Papaya mealybug) Body light yellowish white; 2–3 mm in length, with many lateral (side) wax filaments; ovisacs present with greenish yellow eggs; wax pattern on body lacking any stripes on its upper surface (i.e., dorsum); ovisac position is beneath and behind the body and can be as much as twice as long as the body; female adults also possess a series of short waxy caudal filaments less than a quarter of the length of the body around the margin. When preserved in 80 % alcohol, *P. marginatus* turn black within 24–48 h.	
Phenacoccus madeirensis (Green) (Madeira mealybug) Body oval; somewhat flattened dorsoventrally; body gray; legs red; covered by thin, white, mealy wax, with dark dorsosubmedial bare spots on intersegmental areas of thorax and abdomen; these areas forming one pair of dark longitudinal lines on dorsum; ovisacs present with yellow eggs; ovisac covering entire dorsum; with 18 pairs of lateral wax filaments, posterior pairs longest, about the same length or less length of the body.	
Phenacoccus solenopsis (Tinsley) (Solenopsis mealybug/ cotton mealybug) Body oval, often quite large (5 mm); somewhat rounded in lateral view; dark green almost black; legs red; covered by thin, white, mealy wax, with dark dorsosubmedial bare spots on intersegmental areas of thorax and abdomen; these areas forming one pair of dark longitudinal lines on dorsum; ovisac absent from dorsum, but well developed ventrally; with 18 pairs of lateral wax filaments, posterior pairs longest, up to the same length of the body. Normally occurring on the crown of the host; surface of lateral filaments rough.	

(continued)

Table 4.1 (continued)

Mealybug species – Field characters	Images of mealybug
Phencoccus solani (Ferris) (Solanum mealybug) Body with short filaments; absence of long tails; absence of stripes on the body; fringe present; no ovisac; similar to *Ph. solenopsis*, but in *P. solani* on the other hand, bare spots absent; and it has a medial wax crest with faint submedial bare areas on the abdomen forming a pair of extremely faint longitudinal lines on dorsum.	
*Phenacoccus manihoti (*Matile-Ferrero) (Cassava mealybug) Female mealybugs are ovoid; 0.5–1.4 mm in length; rose-pink and dusted with white, powdery wax; the eyes are relatively prominent; legs are well developed and of equal size; body segmentation is apparent; very short lateral and caudal white wax filaments in the form of swellings that produce a toothed appearance to the body outline; body is usually covered with a waxy, with tufts of flocculent waxy secretion at posterior end and around the margins. The species always reproduces parthenogenetically.	
Phenacoccus aceris (Apple mealybug) Adult female 3–4 mm in length; with a sage green body color visible through the white waxy coating; "tails" on the caudal end of the mealybug are shorter than those of grape mealybug; and the body color (green vs. pale purple) distinguishes it from grape mealybug.	
Phenacoccus herreni (Cox and Williams) (Cassava mealybug) Very close to *Ph.manioti*, but yellowish; reproduces bi-parentally.	
Phenacoccus peruvianus (Bougainvillea mealybug) Adult females (about 3 mm in length); elongate oval; grayish-white; lack marginal wax filaments; produce relatively long, white waxy ovisacs on the leaves and stems of their host plants.	

(continued)

Table 4.1 (continued)

Mealybug species – Field characters	Images of mealybug
Phenacoccus parvus (Morrison) (Morrison's small mealybug) Body oval to elongate, light yellow covered with thin white wax powder with peripheral small wax filaments of uniform size (17–18 mm); without bare areas; ovisac absent dorsally, present ventrally, long and cylindrical, up to three times length of body; with 18 pairs of lateral wax filaments, all about same length, about 1/8 or less length of body. Occurring on roots and foliage of host.	
Planococcus citri (Risso) (Citrus mealybug) Body oval; slightly rounded in lateral view; body yellow when newly molted, pink or orange-brown when fully mature; legs brown-red; mealy wax covering body, not thick enough to hide body color; with dorsomedial bare area on dorsum forming central longitudinal stripe (more obvious than on *P. ficus*); ovisac ventral only, may be two times longer than body when fully formed; with 18 pairs of lateral wax filaments, most relatively short, often slightly curved, posterior pair slightly longer, filaments anterior of posterior pair small, posterior pair about 1/8 length of body. Oviparous; eggs yellow.	
Planococcus ficus (Signoret) (Vine mealybug) Body oval; slightly rounded in lateral view; body yellow when newly molted, pink or orange-brown when fully mature; legs brown-red; mealy wax covering body, not thick enough to hide body color; with dorsomedial bare area on dorsum forming central longitudinal stripe (not as obvious as on *P. citri*); ovisac ventral only, may be two times longer than the body when fully formed; with 18 lateral wax filaments, most relatively short, often slightly curved, posterior pair slightly longer, filaments anterior of posterior pair small, posterior pair about 1/8 length of body. Oviparous; eggs yellow.	

(continued)

Table 4.1 (continued)

Mealybug species – Field characters	Images of mealybug
Planococcus kraunhiae (Kuwana) (Japanese mealybug) Body oval or rotund; slightly rounded in lateral view; dark purple or red; mealy wax covering body, not thick enough to hide purple body color; dorsomedial bare area either absent or unobvious; ovisac not described in literature; 18 lateral wax filaments, most relatively short, straight, posterior pair slightly longer, filaments anterior of posterior pair small, broader than on *P. citri*, posterior pair about 1/8 length of body; surface of lateral filaments rough.	
Planococcus lilacinus (Cockerell) (Coffee mealybug/ Oriental mealybug) Body rotund; conspicuously rounded in lateral view; brownish red or tan; mealy wax covering body, in thick segmental clumps on mature females; body color evident at segmental lines; with dorsomedial bare area on dorsum forming central longitudinal stripe or oval area; ovisac absent; with 18 lateral wax filaments, broad, convergent, posterior pairs sometimes curved, others straight, all filaments about same length, about 1/8 length of body. Primarily occurring on the fruit, stems, and foliage of host; specimens have been reported on the roots of coffee. Ovoviviparous; first instars pale maroon; surface of lateral filaments rough.	
Planococcus minor (Maskell) (*Pl. pacificus* Cox) The mealybug undergoes four development stages for the male and three for the female. The total developmental period (egg to adult) lasts 28–30 (28.79) days for the male and 28–30 (33.70) days for the female. The female lays 7–132 eggs/mass for its entire life span. A male to female ratio of 1:4.43 is recorded. Adult male lives shorter (1–4 days) than the female (4–11 days).	

(continued)

Table 4.1 (continued)

Mealybug species – Field characters	Images of mealybug
Pseudococcus calceolariae (Maskell) (Citrophilus mealybug) Body oval; slightly rounded in lateral view; dark in color, red when crushed; ostiole fluid red; mealy wax covering body, usually thick enough to hide body color except on intersegmental lines; with longitudinal lines on dorsum formed by bare areas occurring in submedial and submarginal areas; ovisac ventral only; with 17 lateral wax filaments, most relatively short, straight except posterior pair, which may be slightly curved, posterior pair longest, about 1/4 length of the body. Primarily occurring on foliage, stems, and fruit of host. Oviparous; eggs yellow or orange; surface of lateral filaments rough.	
Pseudococcus jackbeardsleyi (Gimpel and Miller) (Jack Beardsley mealybug) Body light grayish in color and oval, slightly rounded in lateral view; about 3 mm long with 17 lateral wax filaments, becoming progressively longer posteriorly of the body; anal filaments equivalent to body length or more; ovisac ventral only covering hind part of the body; no stripes on the back; body contents crushed are reddish brown; mealy wax covering body, not too thick enough to hide the body color.	
Pseudococcus longispinus (Targioni Tozzetti) (Long-tailed mealybug) Body oval, slightly rounded in lateral view; body color variable from light yellow to gray, mealy wax covering body, thin enough so that the body color shows through; with three longitudinal lines on dorsum, with single, broad dorsomedial line, with two thin submarginal lines; ovisac absent, with 17 lateral wax filaments, with posterior pairs conspicuously longer than others, posterior pair as long as or longer than body.	

(continued)

Table 4.1 (continued)

Mealybug species – Field characters	Images of mealybug
Pseudococcus maritimus (Ehrhorn) (Grape mealybug) Body oval; slightly rounded in lateral view; body dark orange or pink; body contents crushed dark orange; ostiole secretion light orange; mealy wax covering thin enough so that the body color shows through; sometimes with faint, wide medial longitudinal line on dorsum; ovisac encloses all but head of female; with 17 lateral wax filaments, becoming progressively longer posteriorly, anterior pair about 1/8 width of the body, straight, unusually thin, posterior pair longest, varying from 1/4 to 1/2 length of body. Oviparous; eggs orange.	
Pseudococcus viburni (Signoret) (Obscure mealybug) Body oval; slightly rounded in lateral view; pink or light purple; mealy wax covering usually thin enough so that the body color shows through; without longitudinal line on dorsum; ovisac encloses all but head of female; with 17 lateral wax filaments, becoming progressively longer posteriorly, anterior pair about 1/8 width of body, straight, unusually thin, posterior pair longest, varying from 1/4 to 1/2 length of body. Oviparous; eggs yellow.	
Rastrococcus iceryoides (Green) Body oval to round; slightly rounded to convex in lateral view; light yellow; legs light yellow; mealy wax covering thick, in median area forming medial longitudinal ridge on thorax and abdomen; without longitudinal bare areas on dorsum; ovisac ventral, copious, tilting posterior end of female off of host substrate when fully developed, similar in appearance to cottony cushion scale (*Icerya purchasi* Maskell); lateral wax filaments variable in number, coalescing through time, when separate, broad at base narrowing to rounded point at apex, ultimately forming plate-like fringe around body, anterior filaments nearly 1/2 as long as width of the body, posterior filaments slightly longer than others, about 1/4 length of body. Oviparous; eggs honey yellow.	
Rastrococcus invadens Ovoviparous; a tuft of hairs in the anterior region; lateral filaments increase in length from anterior to posterior region; infestation confined to midrib of the leaves.	

(continued)

Table 4.1 (continued)

Mealybug species – Field characters	Images of mealybug
Rastrococcus mangiferae Similar to *R invadens*, body without tuft of hairs in the anterior region; lateral filaments increase in length from anterior to posterior region.	
Rhizoecus and *Ripersiella* Very small mealybugs (1–2 mm in length); body white to yellowish white; lacking side (lateral) wax filaments. Roots infested with ground mealybugs generally have areas of white wax present and these mealybugs may be visible with use of a hand lens.	
Saccharicoccus sacchari (Cockerell) (Pink sugarcane mealybug) Body elongate oval, often quite large (7 mm); convex in lateral view; body pink; mealy wax thin, allowing body color through; without longitudinal bare areas on dorsum; ovisac ventral; lateral wax filaments normally absent, one short pair may be visible in the newly matured adult females.	
Vryburgia amaryllidis (Bouche) (Lily bulb mealybug) Body elongate oval, sometimes quite large (up to 4 mm); slightly rounded in lateral view; body light to dark purple; ostiole secretion clear or light yellow; legs pale; mealy wax thin, allowing body color through; without longitudinal bare areas on dorsum; ovisac large, covering body of female; with two pairs of caudal wax filaments, posterior pair longer and broader than anterior pair, conical about three or four times longer than the anterior pair, posterior pair about 1/8 length of body. Occurring at bases of leaves of *Haworthia* and aloe and similar hosts; also on the roots and bulbs of other liliaceous host. Oviparous; eggs pink; surface of lateral filaments rough.	

(continued)

Table 4.1 (continued)

Mealybug species – Field characters	Images of mealybug
Vryburgia brevicruris (Short legged mealybug) Small mealybugs (2–3 mm long); red to purple; lacking side (lateral) wax filaments; two thick wax filaments arising from tip of the abdomen.	
Vryburgia trionymoides (DeLotto) Color pinkish-purple; with a light coating of white wax over the body; and thick white filaments arising from the tip of the abdomen. The pinkish-purple body color may be obscured by the powdery wax coating.	
Stemmatomerinx acircula Body gray with white wax; about 2–3 mm long; some wax seems to be filamentous; no lateral wax filaments produced.	
Trionymus haancheni (Barley mealybug) Adult female is quite small reaching a length of approximately 1/5 in. (5 mm); body in some cases covered with a white waxy secretion that extends as thin wispy filaments along the edges of the body and at the posterior end; body shape elongate-oval, segmented, rather slender, and with well-developed legs.	

- The number of wax filaments protruding from the side of the body.
- Presence and length of wax filaments at the end of the body (i.e., terminal wax filaments).
- Color of eggs (if present).
- Presence of an ovisac (a waxy mass covering the eggs).
- Stripes on the body.
- Color of fluids when crushed.

There are two types of mealybugs. One is leaf mealybugs/foliar mealybugs/arboreal mealybugs infesting the plant parts above the ground level. The second type is root mealybugs/soil mealybugs/subterranean mealybugs living in the soil and feeding on the roots.

4.4 Role of Taxonomy in Management of Mealybugs

Success in pest management tactics including the biological control programs depends on the correct identification of both the biological control agent and the pest species. In last few decades, there have been more than five major outbreaks of mealybugs causing alarming damage to crops, as a result of accidental introduction.

The pink cassava mealybug, *Phenacoccus manihoti* Matile-Ferrero, appeared on cassava in Africa in 1973 and soon spread throughout the whole cassava belt. To locate the source of this mealybug and to compare it with a morphologically similar species, which causes almost identical damage to cassava in northern Brazil and Guyana, required a considerable amount of time. Specimens from Africa and northern South America on the microscope slides showed wide variation in characters, and the method adopted to ascertain any limits to this variation required rearing cultures in the laboratory at different temperatures. This method normally induces wide morphological variation in mealybugs, helping to determine the limits of environmentally induced variation (Cox 1982; Cox and Williams 1981). The knowledge that the species in Africa was pink-bodied and uniparental and the species from northern Brazil and Guyana was yellow-bodied and biparental (later described as *Phenacoccus herreni* Cox and Williams) was obscured initially because the specimens used for this study were dead and had been preserved in spirit, obscuring the body color. When the two species could be identified satisfactorily on the microscope slides, it became apparent that the pink cassava mealybug, *P. manihoti*, was present in Paraguay and Bolivia (Williams et al. 1981); hence, a search for natural enemies could be implemented there. The introduction of the parasitoid *Apoanagyrus lopezi* (De Santis) from South America to Africa and the success of the biological control program against *P. manihoti* were well documented by Neuenschwander and Herren (1988) and Herren and Neuenschwander (1991). Thus, the taxonomic information can be retrieved in case the mealybug introductions originate from this area.

Phenacoccus manihoti remains a threat to the cassava areas of southern Asia, as does the yellow cassava mealybug, *P. herreni*, which still causes problems in South America. Reduction of *P. herreni* populations is now under way, mainly through the introduction of the parasitoids *Apoanagyrus diversicomis* (Howard) and *Acerophagus coccois* Smith (Bento et al. 1999). The most trenchant point concerning the parthenogenetic species *P. manihoti* is that an outbreak could occur in southern Asia with the accidental introduction of just a single immature specimen. Following the introduction of the cassava mealybug into Africa, another introduced mealybug appeared in West Africa in 1981–1982, causing extensive damage to fruit trees including mango. This mealybug was initially identified as an undescribed species already known from India and Pakistan and was later described as *Rastrococcus invadens* Williams (Williams 1986). This species is usually scarce in some parts of India because it is controlled by the natural enemies (Narasimham and Chako 1988); the introduction of the encyrtid *Gyranusoidea tebyi* Noyes from India to West Africa and its swift control of the mealybug are hailed as another biological control success (Neuenschwander et al. 1994).

Another mealybug species was introduced accidentally to the Caribbean area in 1993–94 and has since then spread beyond, eventually reaching USA. This damaging species was rapidly identified by taxonomists as *Maconellicoccus hirsutus* (Green); its biological control was described in detail by Kairo et al. (2000), with discussion of the costs and benefits. *M. hirsutus* is widely distributed throughout the southern Asia, Africa, and other parts of the Old World including Australia, and is still causing damage in some parts of India. The introduced natural enemies, mainly the parasitoids *Anagyrus kamali* Moursi (already known in the Old World) and *Gyranusoidea indica* Shafee, Alam and Agarwal (collected in Egypt), and the predator *Cryptolaemus montrouzieri* Mulsant, have brought the mealybug under control. In response to this outbreak, an identification manual for the area (Watson & Chandler 1999) and a taxonomic study of all the instars of *M. hirsutus* (Miller 2002) were produced.

Yet another mealybug is causing concern in the Caribbean area *Paracoccus marginatus* Williams and Granara de Willink, described from Mexico and parts of Central America as recently as 1992, has become a serious pest in the Caribbean islands, where it attacks numerous

Table 4.2 List of mealybug species, correct identity of which led to a successful biological control

Mealybug species	Country of accidental introduction	Introduced parasitoid for classical biological control
Phenacoccus manihoti Matile-Ferrero	Africa	*Apoanagyrus lopezi* (De Santis)
Phenacoccus herreni Cox and Williams	South America	*Apoanagyrus diversicornis* (Howard)
Rastrococcus invadens Williams	West Africa	*Gyranusoidea tebyi* Noyes
Maconellicoccus hirsutus Green	USA	*Anagyrus kamali* Moursi
Paracoccus marginatus Williams and Granara de Willink	Caribbean islands	*Acerophagus papayae* Noyes and Schauff
		Pseudleptomastix mexicana Noyes and Schauff
		Anagyrus loecki Noyes and Menezes
Paracoccus marginatus Williams and Granara de Willink	India	*Acerophagus papayae* Noyes and Schauff
		Pseudleptomastix mexicana Noyes and Schauff
		Anagyrus loecki Noyes and Menezes

plant species, especially papaya (*Carica papaya*). The mealybug has now reached the southern USA. A search for natural enemies in Mexico (Becker 2000) located three parasitoids that are now in use in controlling the mealybug. An offshoot of the biological control program has been a detailed study of all the instars of *P. marginatus* by Miller et al. (2005). The mealybug had affected *Carica papaya* and several other plants in Guam, Sri Lanka, Palau, India; in all countries, the species was rapidly identified as *P. marginatus* by taxonomists facilitating quick introduction of the parasitoids.

Table 4.2 shows a list of mealybug species, which were introduced in some countries, and the parasitoid, whose correct identity led to a successful classical biological control.

The examples mentioned above show that the new pest species that may have escaped detection at quarantine inspection of imported plant material can be quickly recognized by the taxonomists and accurately identified. The taxonomists can also suggest the correct area of the origin of the pest and report whether any existing specimens in slide collections were parasitized, so that the precise collection localities can be searched for natural enemies for use in classical biological control. This information requires access to important reference collections of insects and to the relevant taxonomic literature. The above field guides and taxonomic information are to be referred for the quick tentative identification up to the species level. If the specimen does not come under the existing keys, it may be named as a new species.

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5 Molecular Identification of Mealybugs

K.B. Rebijith, R. Asokan, and N.K. Krishna Kumar

Insects are the numerous life forms that have captured the attention of human beings since ancient times. In the same context, proper classification and identification of life forms has been a challenge, and a plausible method of classification was established by Carlous Linnaeus, a Swedish botanist who published *Systema Naturae* in 1758. However, the Linnaeus system of classification was not based on evolutionary relationships among the target groups. Later, Darwin's "The Origin of Species" in 1859 changed the way life forms were classified, where the identification, description and explanation of the diversity of the organisms had come to be known as systematics. According to Mayr and Ashlock (1991), systematics is the scientific study of the kinds and diversity of organisms, and any and all relationships among them; taxonomy, on the other hand, was the theory and practice of the classification of organisms. It took 200 years for taxonomists to describe the 1.7 million species on the earth, which is only 10 % of the total number of species estimated. In this context, identification of insects has been a monumental task which calls for the availability of more specialists and funding. But with the dwindling interest in taxonomy and fund availability, the classification and identification of various life forms, particularly insects, has been a major challenge to the scientific community. With the advent of molecular biology and molecular tools, the identification of life forms, including insects, has become quick, precise and easy. The development of species-specific markers enables even a non-specialist to identify insects to the species level.

5.1 Methods of Classification and Identification

5.1.1 Linnaean System

Taxonomists assess the physical characteristics that a set of species shares and selects the most representative species to be the 'type' for each genus, and the most representative genus to be the type of the family and so on. Individual specimens are deposited in museums to serve as a reference for that species and genus. When new species are found with similar traits, they are categorized as part of a known species as a new species, or as a new genus, depending on how closely the new specimens resemble the type. The reliance of types results in dramatic changes if a taxonomist re-evaluates a group and decides that

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some members do not belong and suggest that the group name must be changed.

5.1.2 Cladistics

During the 1980s, another classification method called cladistics, which is based on the evolutionary histories of organisms, was proposed. This method is based on phylogeny, whereas the Linnaean system is not.

5.1.3 Phylocode

In this system, the genus name is removed, and species name is shortened and hyphenated with their former genus name or given numeric identification.

5.2 Shortfalls in Morphological Identification

Mealybugs (Hemiptera: Pseudococcidae) are the major pests in a wide range of agricultural crops as well as ornamental plants worldwide (Millar 2002; Miller et al. 2002, 2005). These sap-sucking insects have been studied intensively for decades because of the economic losses they cause to agriculture through direct physical damage to crop plants, as well as by vectoring many plant pathogenic viruses, which in turn decreases yield quality (Meyer et al. 2008 and Nakaune et al. 2008). The family Pseudococcidae consists of more than 2000 described species in 270 genera (Downie and Gullan 2004). Current estimates suggest that the earth may have anywhere from 10 to more than 40 million species of organisms, but only about 1.7 million of them have actually been described. It includes over 7,50,000 insects, and it took 250 years for taxonomists to categorize all 1.7 million species, which comprise only 10 % of the total species on earth (Hebert and Gregory 2005). Classifying the remaining 90 % of the unidentified organisms will require more time and expertise of taxonomists to complete this monumental task. Economic development and increased international commerce are leading to higher extinction rates and the introduction of invasive species of pests. Therefore, there is a need for faster species identification and information about their biodiversity for conserving them before they vanish from the face of the earth. Undoubtedly, the contribution of morphological taxonomy is enormous, but it also has some drawbacks, such as the following:

- Incorrect identification due to phenotypic plasticity and genetic variability between different taxa of mealybugs
- There are many morphologically cryptic taxa which are common in many groups
- Morphological examination is time consuming and is often effective only for a particular life stage or gender (mostly in adult females in case of mealybugs). As a result, many cannot be identified
- Although modern interactive versions represent a major advance, the use of keys require high level of expertise that often lead to misidentification (Hebert et al. 2003a)
- Taxonomists have always looked for discontinuous character variations that could signal divergence between species. The debate on threshold values employing molecular identification for interspecific divergence is also true in the case of morphology-based identification.
- Early identification of new invasions is an important aspect in preventing the spread. Rapid and accurate identification of mealybugs is not easily accomplished with conventional taxonomy. Taxonomy separation of many species occurring together can be difficult, particularly for the nymphal stages that are primarily involved

Hence, there is a need for an adjunct tool that facilitates rapid identification of species where molecular identification, popularly called 'DNA barcoding', becomes handy. The concept of DNA barcoding was proposed by Hebert et al. (2003b, c) as a rapid and precise way for species discrimination of a broad range of biological specimens using a selected 658-bp fragment of the 5′ end of the mitochondrial cytochrome oxidase-I (mtCO-I) gene (Fig. 5.1).

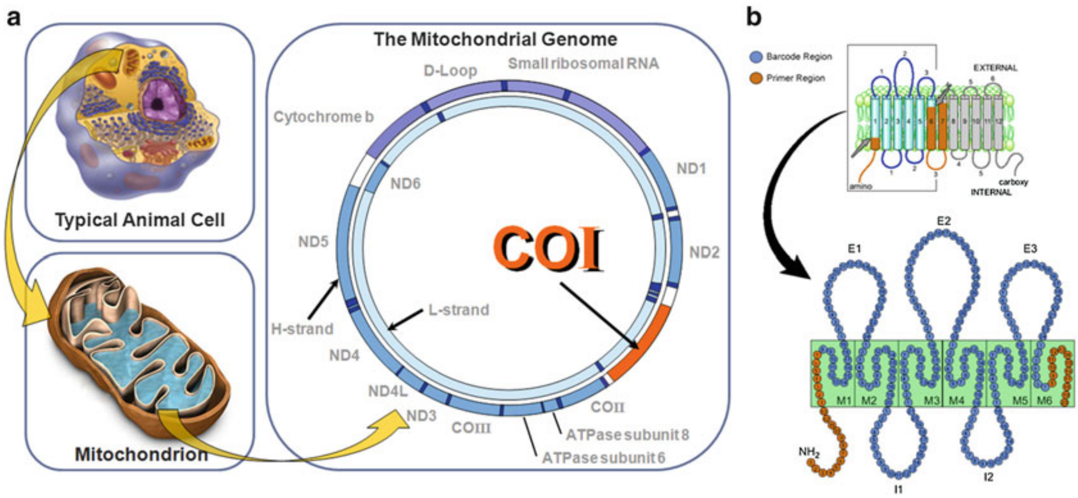

Fig. 5.1 (**a**) Organization of genes in mitochondrial genome. (**b**) Arrangements of barcode region with mitochondrial membrane with barcode region (*blue* in colour) and primer region (*brown*) with amino- and carboxy-terminal spanning inside

5.2.1 Uses of DNA Barcoding

- *Works with fragments*: Barcoding can identify a species from bits and pieces. When established, barcoding will quickly identify undesirable animal or plant material in processed foodstuffs and detect commercial products derived from regulated species (Stoeckle et al. 2004).
- *Works for all stages of life*: Barcoding can identify a species in its many forms, from eggs and seed, through larvae and seedlings, to adults and flowers (Rebijith et al. 2012).
- *Unmasks look-alikes*: Barcoding can distinguish among species that look alike, uncovering dangerous organisms masquerading as harmless ones, and enabling a more accurate view of biodiversity (Asokan et al. 2011).
- *Reduces ambiguity*: Written as a sequence of four discrete nucleotides – CATG – along a uniform locality on genomes, a barcode of life provides a digital identifying feature, supplementing the more analog gradations of words, shapes and colours (Stoeckle et al. 2004).
- *Democratizes access*: A standardized library of barcodes will empower many more people to call by name the species around them. It will make possible the identification of species whether abundant or rare, native or invasive, engendering appreciation of biodiversity, locally and globally (Stoeckle et al. 2004).
- *Opens the way for an electronic hand-held field guide, the Life Barcoder*: Barcoding links biological identification to advancing frontiers in DNA sequencing, miniaturization in electronics, and computerized information storage (Stoeckle et al. 2004).
- *Demonstrates value of collections*: Compiling the library of barcodes begins with the multimillion specimens in museums, herbaria, zoos and gardens and other biological repositories (Stoeckle et al. 2004).
- *Speeds up writing the encyclopaedia of life*: Compiling a library of barcodes linked to the vouchered specimens and their binomial names will enhance public access to biological knowledge, helping to create an on-line encyclopaedia of life on earth, with a webpage for every species of plant and animal (Stoeckle et al. 2004).

The core idea of barcoding is based on the fact that short pieces of DNA vary only to very a minor degree within the species, and that the variation is much less between different species. Therefore, a threshold value of variation could be characterized for each taxonomic group (2–12 %), above which groups of individuals do not belong to the same species, but form supra-species taxon. Therefore, unknown individuals could be assigned to a species level.

5.3 Targets for Molecular Identification

5.3.1 Mitochondrial DNA

Mitochondrial (mt) DNA (Fig. 5.2) has a long history of use at the species level; recent analyses suggest that the use of a single gene, particularly mitochondrial, is unlikely to yield data that are balanced, universally acceptable, or sufficient in taxonomic scope to recognize many species lineages (Rubinoff 2006). Mitochondrial cytochrome *c* oxidase subunit I (mtCO-I) gene sequence is suitable for this role because its mutation rate is often fast enough to distinguish closely related species, and also because its sequence is conserved among conspecifics and a lack of recombination. mtCO-I sequence differences are too small to be detected between closely related species; more than 2 % sequence divergence has been detected between such organisms, proving the barcode effective. However, the rate of evolution of *cox1* is very slow.

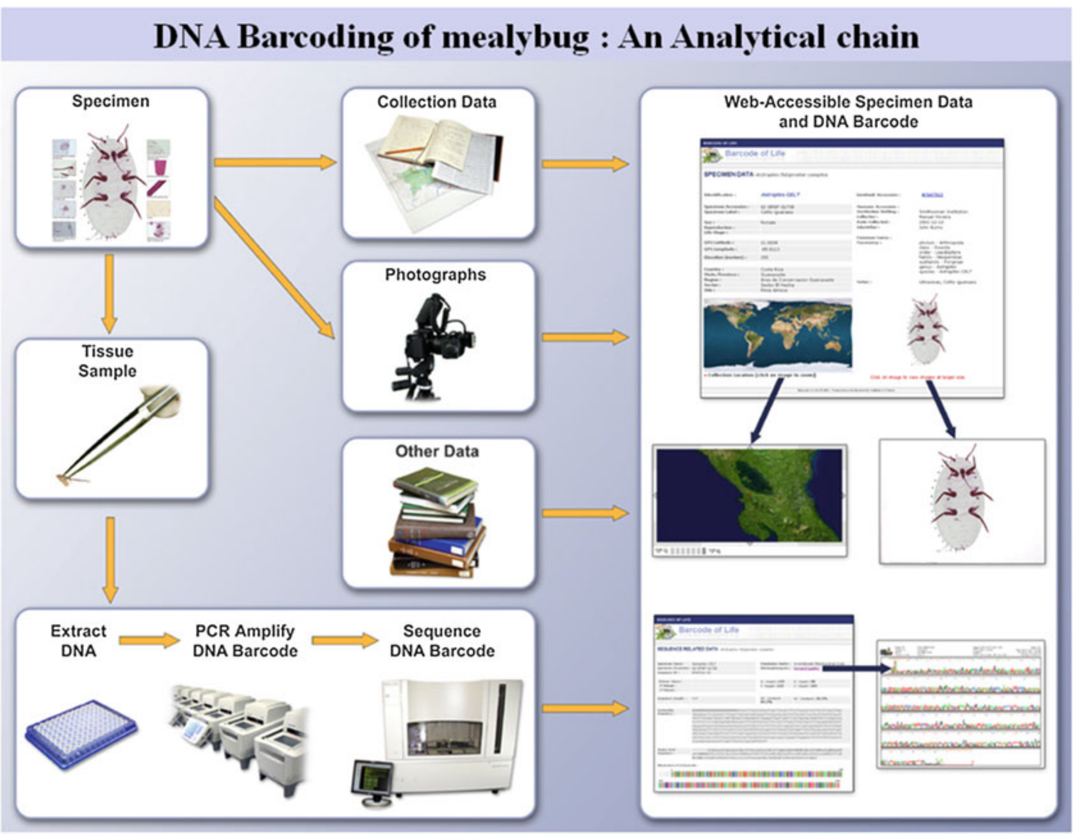

Fig. 5.2 Flowchart showing steps in DNA barcoding of mealybugs, from collection to sequence deposition in iBOL

5.4 Advantages of Using Mitochondrial Genome

- Haploid mode of inheritance, and it supports less recombination
- Mitochondrial genome does not have introns
- Universal primers are robust, which can amplify 5′ end in most of the animals, including insects
- Rapid evolution allows the discrimination of not only closely related species but also phylographic groups within a single species
- In animal mitochondrial genome, the 13 protein coding genes are better targets because of rare insertions and deletions (indels)
- By identifying amino acid substitution patterns of mtCO1, it is possible to assign any undefined organisms to a higher taxonomic group before examining nucleotide substitutions to determine its species identity

5.5 Collection and Morphological Identification

Mealybug specimens can be collected in 95 % ethanol and kept at −80 °C (deep freezer) until further work. Morphological identification can be carried out by a taxonomist. Whenever possible, it is better to analyse at least three specimens collected from each of the host/locality for reproducibility.

5.5.1 Genomic DNA Isolation

Total genomic DNA can be extracted from individual mealybugs using a non-destructive method (Hajibabaei et al. 2006), while voucher specimens are required to be mounted on glass slides and deposited with any of the National Insect Repository such as the National Pusa Collection (NPC) or the Indian Agricultural Research Institute (IARI), Delhi. Various DNA isolation protocols are available, namely (a) direct TNES buffer method, (b) spot-PCR method, (c) phenol:chloroform method and (d) salting out method.

5.5.1.1 Direct Buffer Method

A single insect can be crushed in 50–200 μL YNES (50 mM Tris–HCI, pH 7.5, 0.4 M NaCI, 20 mM EDTA, 0.5 % SDS), STE (0.1 M NaCI, 10 mM Tris, pH 8.61 mM EDTA), GES (0.1 M glycine, pH 9, 50 mM NaCI, 1 mM EDTA, 1 % β-mercaptoethanol, 0.5 % Triton X-100) or CTAB (100 mM Tris–HCL, pH8,1.4 M NaCI, 20 mM EDTA, 2%CTAB, 0.2 % β-mercaptoethanol) buffer. The sample is to be incubated at 94 °C for 12 min, with the cell debris to be precipitated by spinning it at 13,000 rpm for 1 min. The extracted DNA is to be stored at −20 °C.

5.5.1.2 Spot-PCR Method

A single insect should be crushed on a positively charged nylon membrane soaked in a 50-mM NaOH and 2.5-mM EDTA solution, and then allowed to dry. A small portion (ca. 3 mm^2) of the spotted membrane is to be cut out and placed in 10–50 μL TNES, STE, GES or CTAB buffer (described above). The sample can then be incubated at 95 °C for 10 min and cooled on ice. Extracted DNA can be stored at −20 °C.

5.5.1.3 Phenol/Chloroform Method

DNA from a single insect can be extracted using the modification of a general procedure for extraction with phenol (Sambrook et al. 1989; Sambrook and Russell 2001). The insect is to be crushed and incubated at 40 °C in 0.6 mg/mL Proteinase K and 300 μL TNES buffer for 4–18 h. DNA can then be purified by washing with organic solvents: once with a chloroform:isoamyl mix (24:1 v/v); once with a chloroform:phenol mix (1:1 v/v) and once with chloroform only. DNA can then be precipitated with absolute ethanol. Extracted DNA can be stored at −20 °C.

5.5.1.4 Salting-Out Method

DNA from a single whole insect can be extracted using the protocol of Sunnucks and Hales (1996) with minor adjustments, including the following: the insect can be incubated at 40 °C in 0.6 mg/mL

Proteinase K and TNES buffer; and the samples can be left for at least 1 h at −20 °C during precipitation of the DNA with absolute ethanol. Extracted DNA can be stored at −20 °C.

5.5.2 Polymerase Chain Reaction

Polymerase chain reaction (PCR) was developed by Kary B. Mullis (Mullis and Faloona 1987) and has radically changed molecular research and diagnostics (Caterino et al. 2000). PCR involves the *in vitro* synthesis of large amounts of DNA copies from a single starting molecule and employs short single strands of DNA (18–30 nucleotides) called oligomers or primers (Table 5.1) to select a region of specific interest from the DNA. Once the primers are annealed to the DNA, Taq DNA polymerase builds a complementary strand extending from the primer by incorporating free deoxynucleoside triphosphate (dNTP: base + deoxyribose sugar + phosphate) molecules in the reaction mix. Two primers that anneal on complementary strands are used, with the Taq extending the region between them. The reaction mixture is cycled between different temperature optima for the different stages of reaction of denaturation, annealing and elongation. This process is repeated in a number of cycles (usually 30–40), and the DNA thus produced increases exponentially (Saccaggi 2006).

5.5.3 Sequence Analyses and Submission

The amplified products can be eluted using an extraction kit according to the manufacturer's protocol, and the sequencing can be done in an automated sequencer (ABI prism® 3730 XL DNA Analyzer; Applied Biosystems, USA) using PCR specific primers, both in forward and reverse directions. Homology search and sequence alignment can be performed employing the NCBI-BLAST (http://blast.ncbi.nlm.nih.gov/) and BioEdit version 7.0.9.0 (Hall 1999), respectively. All the sequences generated in the respective studies need to be deposited in the NCBI-GenBank and the Barcode of Life Data systems (BOLD) (Table 5.2).

5.6 Nuclear Copies of Mitochondrial Genes

There is a possibility that a pseudogene is being amplified if the study encounters the following anomalies (Zhang and Hewitt 1996):

- More than one bands, or different bands, are constantly produced during PCR amplification.
- Background peaks or sequence ambiguities are constantly found when sequencing.
- The DNA sequence contains data which will unexpectedly change the polymerase translation of the sequence, such as unusual frameshifts, insertion/deletion or stop codons.
- The DNA sequence is particularly more divergent than expected.
- Phylogenetic analysis results in unusual, unexplained or contradictory tree topology.

In the recent past, DNA barcoding has gained importance in the species diagnosis of animal species, but has some difficulty with certain insects. This is probably due to its inconsistency in amplifying the 5′- mtCOI region; however, a total of 178 mtCOI sequences for 29 mealybug species are available with the NCBI-GenBank.

Table 5.1 Primers employed in DNA barcoding of mealybugs

mtCO-I	Sequence	Amplicon Size (bp)	Reference
LCO-1490	5′-GGTCAACAAATCATAAAGATATTGG-3′	658 bp	Folmer et al. (1994)
HCO-2198	5′-TAAACTTCAGGGTGACCAAAAAATCA-3′		
PcoF1	5′- CCTTCAACTAATCATAAAAATATYAG-3′	649 bp	Park et al. (2010a)
LepR1	5′- TAAACTTCTGGATGTCCAAAAAATCA-3′		

Table 5.2 Maximum composite likelihood estimate of the pattern of nucleotide substitution from 29 species of mealybugs

	A	T	C	G
A	-	*10.58*	*2.19*	**2.4**
T	*8.03*	–	**6.15**	*1.07*
C	*8.03*	**29.68**	–	*1.07*
G	**18.04**	*10.58*	*2.19*	–

The nucleotide frequencies are 0.367 (A), 0.484 (T/U), 0.1 (C) and 0.049 (G). The transition/transversion rate ratios are $k_1=2.247$ (purines) and $k_2=2.805$ (pyrimidines). The overall transition/transversion bias is $R=0.443$, where $R=[A*G*k_1+T*C*k_2]/[(A+G)*(T+C)]$. Codon positions included were 1st+2nd+3rd+Noncoding

All the above species could be clearly differentiated on the basis of the 5′- mtCOI barcode (Fig. 5.3), which is a valuable tool for the identification of these serious insect pests, an approach complementing classical taxonomy. An insight into the sequence analyses revealed that the G.C content in the barcode region is very low (14.9 %) and is the lowest from any insect species, which is in total contrast to other lineages (33–53 %) (Min and Hickey 2007; Park et al. 2011). Interestingly, the low G.C frequency is more predominant at the third codon (wobble position), than the first and second position. Among various life forms, the G.C content (12.6 %) for *Atrococcus paludinus* is the lowest value, which is even lower than bacterial genomes whose G.C content is in the range of 17–75 %. The lowest G.C content (17–33 %) occurs in bacterial species with small genome sizes, especially the endosymbionts of insects, such as aphids (Andersson and Kurland 1998; Moran et al. 2008). The lower G.C content in insects such as scales and mealybugs, feeding on plant sap, a diet which is very deficient in organic nitrogen, possibly can be explained as an evolutionary adaptation to less nitrogen and relatively less nitrogen is required for A.T than G.C pair.

DNA barcoding can be used as an acceptable system for molecular identification of species in its distinct life stages and forms (Foottit et al. 2010; Rebijith et al. 2012), host-associated genetic differences (Brunner et al. 2004), discrimination of cryptic species (Smith et al. 2006) and biotypes (Shufran et al. 2000). In this regard, sequence analyses revealed that the specimen of a single species, namely *Planococcus ficus, Crisicoccus matsumotoi, Phenacoccus solani* and *P. aceris*, from various geographic regions and hosts often showed substantial genetic difference, possibly reflecting cryptic species overlooked by current taxonomy classification (Park et al. 2011). However, further studies are required in this direction to clarify these potential cases of cryptic mealybug species (Fig. 5.4).

5.7 Limitations of DNA Barcoding Employing mtCOI

Following are the limitations of DNA barcoding employing mtCOI:

- Limitations in resolving species at species boundaries in some groups where nuclear ribosomal regions are suitable.
- mtCOI does not show much variation in plants, except for some algae.
- Introgression: mtCOI is largely maternally inherited, and usually as a single copy. Hence, it has one fourth the population size of other nuclear genes, has a different inheritance pattern and is more sensitive than nuclear genes to population bottlenecks. mtDNA introgression confounds the boundaries between otherwise distinct lineages; such introgression between species could lead to inaccurate identifications.
- Maternal inheritance: The full effect of maternal inheritance on rates of molecular divergence in mtDNA is not predictable, and therefore the failure rate of DNA barcoding is also unpredictable. mtDNA is inherited maternally, but not in bivalve molluscs which display double unpatented mtDNA inheritance. It is also evident in a wide range of the taxa infrequent paternal inheritance.
- Low recombination: The general absence of recombination will lead to the persistence of population structure long after the barriers which created the structures are removed and gene flow is restored. Therefore, it is not pos-

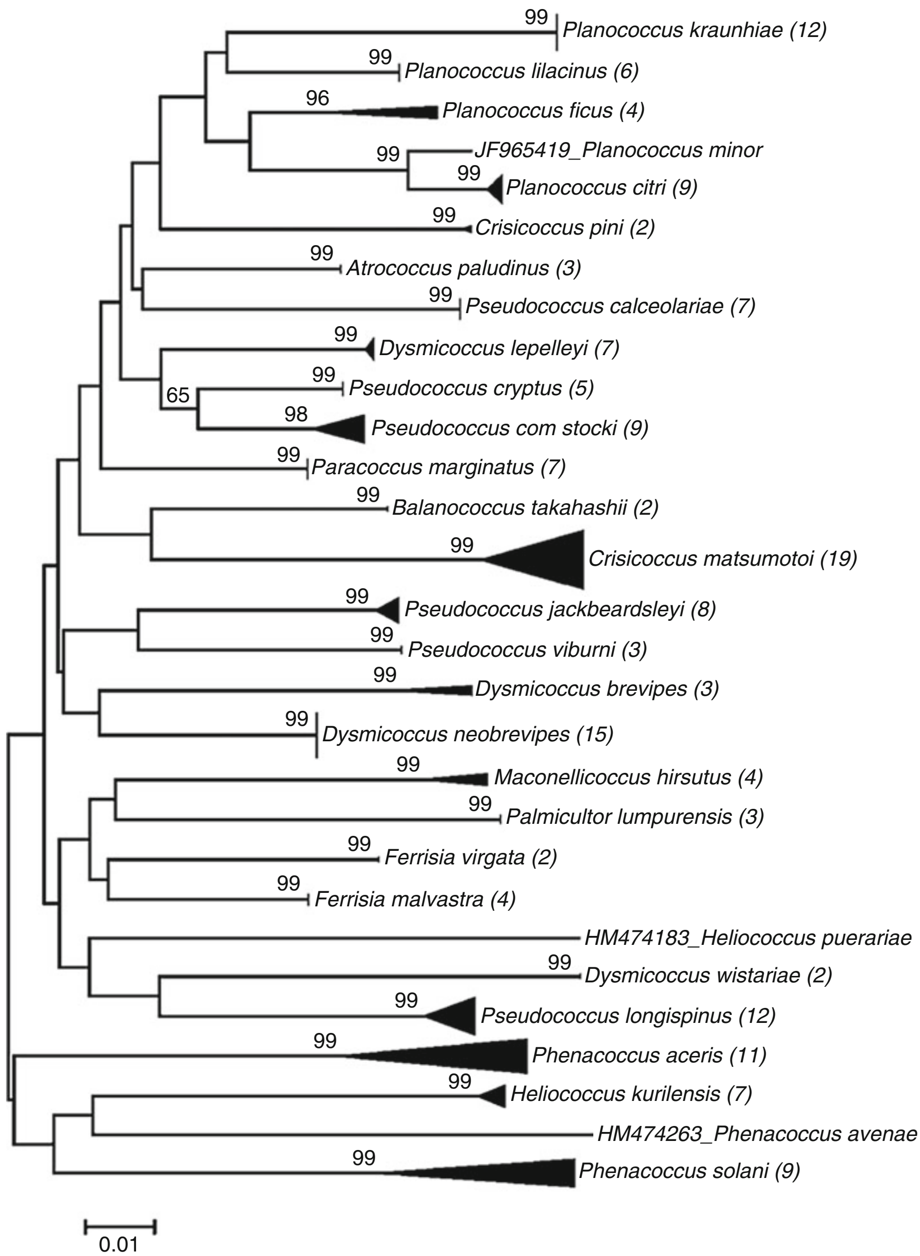

Fig. 5.3 NJ tree with bootstrap support (1000 replicates) showing clusters of species for mtCOI sequences. Distinct clades for 29 species of aphids can be seen in the figure, in which four species, namely *Planococcus ficus, Crisicoccus matsumotoi, Phenacoccus solani* and *P. aceris* showing two distinct groups with >90 % bootstrap support. The numbers indicated in brackets represent the individuals analysed in the corresponding species

sible to estimate species boundaries which would have been estimated from a broader data set.

- Mutation rate: For the DNA barcode to be used as standalone, there should be a consistent mutation rate, such as the proposed 2–3 % divergence to correlate with species limit on a consistent basis. Speciation, uniquely driven by changes in mtDNA or speciation event, necessarily alters the mtDNA haplotypes.

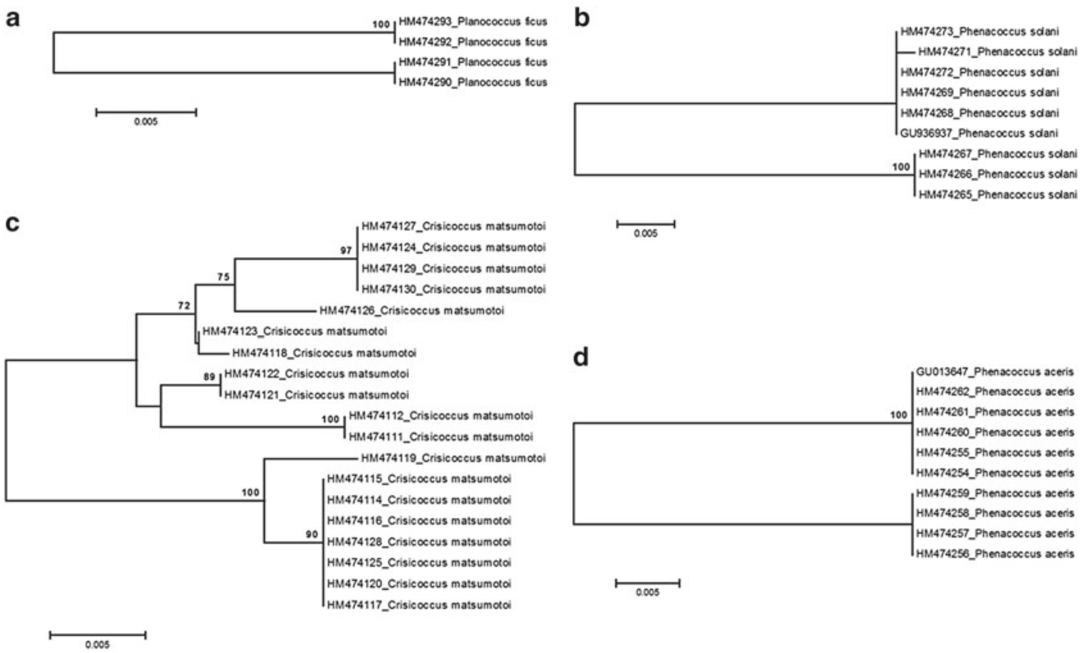

Fig. 5.4 Neighbour joining (NJ) showing intra-specific variation in the barcode region for four species of mealybugs, namely *Planococcus ficus* (**a**), *Phenacoccus solani* (**b**), *Crisicoccus matsumotoi* (**c**) and *P. aceris* (**d**)

- Heteroplasmy: This refers to the classical view of mitochondria functionally haploid with multiple identical copies. However, single nucleotide differences are common in some species and are also abundant in some, especially at the restriction sites.
- Compounding genetic factors: Coinheritance factors that bias single mitochondrial inheritance and most obvious are (a) mitochondrial selection either on the barcoding gene itself or on the other linked genes; (b) cytoplasmically inherited bacteria like *Wolbachia* and some *Rickettsia* which alter the inheritance factors (Rubinoff et al. 2006).
- Identification depends on the intra- and inter-specific genetic variations.
- Difficult to resolve, recently diverged species that arose through hybridization.
- No single gene is conserved in all domains of life and exhibit enough sequence divergence for species discrimination.

There are about 52 million sequence records available currently, and it is expected that the barcoding initiative of the animal kingdom will produce about 100 million sequences and will be available through GenBank.

An international database called BOLD (Barcode of Life Data system) organizes the sequence data on species identification, which was initially developed as an informatics work bench for a single, high-volume DNA barcode facility. Later, the same has been selected by the Canadian Barcode of Life Network (www.bolnet.ca) to barcode all the eukaryotic life of Canada, and subsequently, it has been adopted by major barcode communities like birds, fishes, lepidoptera, etc. BOLD provides an integrated bioinformatics platform that supports all phases of analytical pathway from specimen collection to a tightly validated barcode library. It also provides a vehicle for collaboration across research communities by coupling flexible security and data entry features with web based delivery. A copy of all sequences in BOLD is also sent to NCBI, DDBJ, and EMBL as soon as the results are ready for public release.

5.8 Other Targets for Molecular Identification of Insects

5.8.1 Ribosomal DNA

Ribosomes are the major components of cells that are involved in translating the mRNA into proteins. Ribosomes consist of both proteins and RNAs. The ribosomal RNA (rRNA) regions that are conserved and more variable regions can serve as both slow and fast clocks in identifying and unravelling the molecular phylogeny. In eukaryotes (including insects), the genes encoding both 18S and 28S rRNA are clustered as tandem repeats in the nucleolus; in most animals, there are 100–500 copies of rDNA in the nuclear genome in tandemly repeated transcription units. The repeated transcription unit is composed of a leader promoter region known as external transcribed spacer region (ETS), 18S rDNA coding region, internal transcribed spacer region (ITS), 28S rDNA coding region and an internal non-coding transcribed spacer region (IGS). In addition to the above, R1 and R2 retro transposable elements are found in specific locations (Fig. 5.5).

Different portions of the repeated transcription units evolve at different rates in the nuclear genome; a higher degree of polymorphism is found in the non-coding segments (IGS, ITS, ETS), and the most variable part of the repeated unit is IGS, which contains reiterated sub-repeats ranging from 50 to several hundred base pairs in length. The coding regions of the repeated unit change relatively less and can be used for systematic studies of higher taxa or for ancient lineages. Ribosomal RNA genes undergo concerted evolution so that the sequence similarity of the members of an RNA family is expected to be greater within species than between species.

In addition to the above reterotransposons, R1 and R2 have been in the 28S rRNA genes of most insects, are associated with arthropods, and are usually precisely located at the same nucleotide position within the 28S rRNA gene. Most of the R2 elements are located about 74 bp upstream from the site of R1 insertions. R1 and R2 do not have long terminal repeats and block the production of functional rRNA, since there are many rRNA genes, and R2 are kept from invading by miRNA/siRNA. Usually, R1 and R2 do not have accumulated mutations that would make them inactive.

5.8.2 Satellite DNA

Satellite DNA may consist of a large fraction of the total DNA in an insect. Microsatellites are usually species specific, and evolve at very high rates. Satellite DNA can also be used for species identification and analysis of populations.

5.8.3 Nuclear Protein Coding Genes

A variety of protein coding loci have been used in molecular systematics, and some of them are listed below:

1. alpha amylase 2. acetyl choline esterase 3. actin 4. alcohol dehydrogenase 5. arylphorin 6. cecropin 7. chorin 8. dopa carbaxylase 9. elongation factor 1 alpha 10. esterase 11. glycerol 3 phosphate 12. glycerol 6 phosphate dehydrogenase 13. guanylate cyclase 14. globin family genes 15. histones 1 and 4 16. hunch back 17. kruppel 18. luciferase 19. lysozyme intron 20. myosin alkali light chain intron 21. nullo 22. opsin 23. period 24.

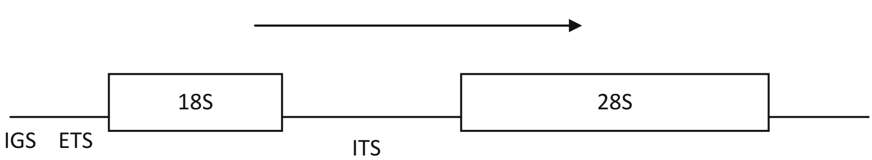

Fig. 5.5 Gene organization of ribosomal genes

phosphogluco isomerase 25. phosphoenol pyruate carboxy kinase 26. prune 27. copper, zinc superoxide dismutase 28. sodium channel para locus I 29. snail 30. timeless 31. triose-phosphate isomerase 32. vestigial 33. white 34. wingless 35. xanthine dehydrogenase 36. yolk protein 1 and 2 37. zeste.

5.9 Limitations

- May be heterozygous and present in low copy numbers.
- Many genes contain large introns that makes it difficult to amplify more than one exon.
- Many single-copy loci are actually are present in more than one copy.
- Pseudogenes may create problem if comparisons are made inadvertently.

Even with all the limitations, the molecular identification of insects employing mtCOI is gaining momentum, and as of now it can be an effective adjunct tool for the integrated taxonomy. Many barcoding initiatives are beginning to take shape, such as the recent initiative on *Barcoding of butterflies of India* funded by the Department of Biotechnology. With the increase in international trade on agricultural produces where the danger of introduction of invasive species looms large, DNA barcoding is going to play a vital role in the quick identification of insect-pests at the port of entry. As ambitiously envisaged, the development and deployment of the hand-held sequencer, which is supported by the global networked database, is going to revolutionize the way we identify insects that are already described, along with the new ones.

5.10 Applications

1. The relationship of six mealybug species (*Pl. citri, Pl.ficus, P.ovae, Ps.longispinus, Ps.vibruni*, *Ph.aceris*) was studied using randomly amplified polymorphic DNA-polymerase chain reaction (RAPD-PCR) in Turkey. Cluster analyses of RAPD data clearly separated the species into two groups (Serce et al. 2007).
2. Seven species of mealybugs (*Ps maritimus*, *Ps.vibruni. Ps.longispinus, Ps.calceolariae, Pl.ficus, Pl.citri, Ferrisia gilli* Gullan) were identified using a Multiplex PCR based on the mitochondrial cytochrome oxidase subunit gene (Daane et al. 2011).
3. There was a slight difference in morphological characters in the populations of *Planococcus ficus*, indicating that there are two different populations of the same species in Tunisian vineyards. Likewise, in the molecular analyses, two separate clades were revealed in the neighbour-joining phylogenetic tree, supporting the morphological studies and suggesting there are two distinct populations of grape vine in Tunisia, which might be two different biotypes (Mansour et al. 2012).

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Biology

6

M. Mani and C. Shivaraju

A few generalizations on the biology of mealybugs are derived primarily from the detailed studies of the work previously done on common mealybug species. There are slight variations in the biology of mealybugs among the species.

6.1 Reproduction

The mature or gravid adult female begins to grow in size as the ovaries develop, ending at about 4–5 mm in length and far less dorso-ventrally flattened. The adult male is about 1.5 mm in length, with long wings, a brown-coloured body and two multi-segmented antennae that are about half the length of the body. Mealybugs have the lecanoid type of the paternal genome elimination system, where both sexes develop from fertilized eggs (i.e., diploidy), but during the early stage of development of the male, the paternal half is deactivated through heterochromatinization. This system suggests that the females would produce a male-biased sex ratio when alone and a more female-biased sex ratio when grouped with other females. Mealybug reproduction can be quite variable. For some mealybugs, mating is probably necessary, although facultative parthenogenesis has been reported for *Planococcus citri* (Risso). To attract adult males, the females emit a sex pheromone. Female mealybugs mate multiple times and the number of times they mate also affects the egg production. Parthenogenetic reproduction is also observed in many mealybug species, while in some others, reproduction is by both sexual and parthenogenetic means.

Most mealybug species reproduce sexually, as well as lay eggs. However, some species such as *Phenacoccus solani* Ferris, *Phenacoccus parvus* Morrison and *Ferrisia malvastra* (McDaniel) reproduce parthenogenically and others, for example, *Pseudococcus longispinus* (Targioni Tozzetti) and *Antonina graminis* (Maskell) are ovoviviparous. Two different genetic systems may be found in mealybugs; the more common corresponds to a particular type of haplodiploidy known as paternal genome elimination in which both males and females develop from fertilized eggs. The male develops from a zygote containing one haploid genome from his mother and one haploid genome from his father, but only the maternal genome is transmitted to the offspring via the sperm, because the set of chromosomes of paternal origin becomes heterochromatic and genetically inactive. Male mealybugs are thus functionally haploid, owing to heterochromatization (parahaploidy). The other genetic system is thelytokous parthenogenesis, in which there are no males and therefore no mating occurs. There are no sex chromosomes in mealybugs; sex is probably determined by a functional haploidy/diploidy mechanism, which seems to be

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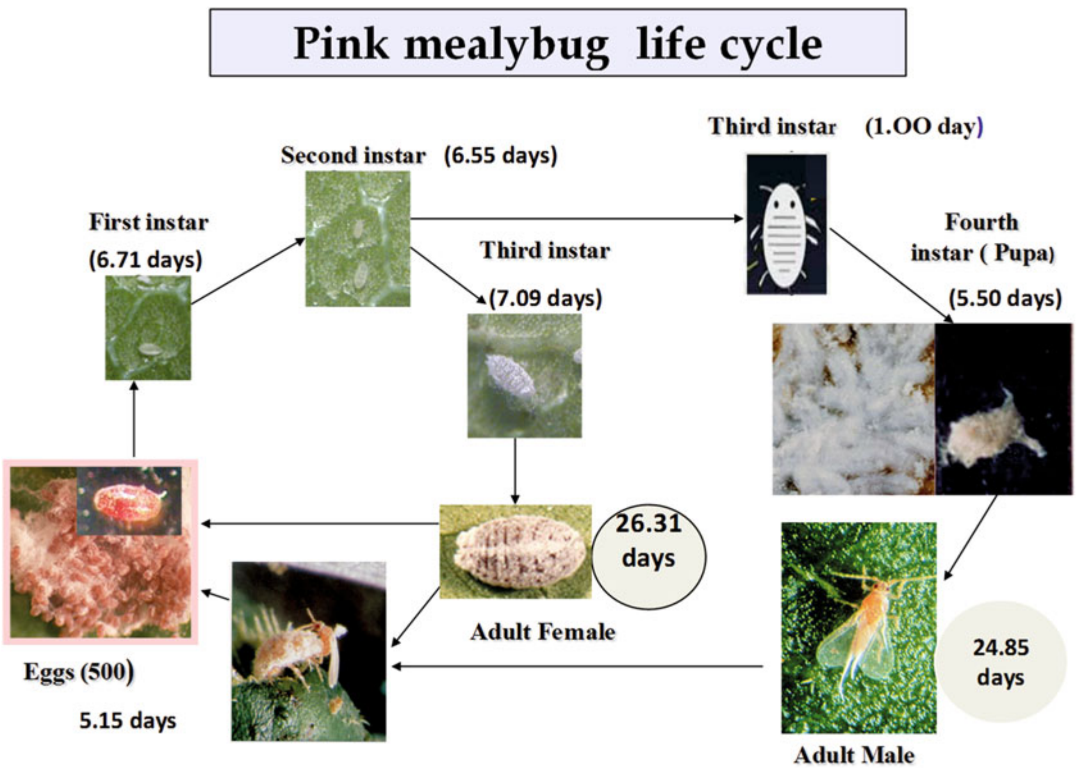
dependent on the behaviour of a set of chromosomes and not on a single chromosome. If heterochromatization of an entire set of chromosomes takes place during the cleavage stage of embryogenesis, the embryo will develop into a male, or otherwise into a female. Spermatogenesis is characterized by inverse meiosis and the absence of chromosome pairing and genetic recombination where the genome of the mother determines the heterochromatization of the inherited paternal chromosomes in mealybug embryos. According to this model, heterochromatization is controlled by a maternal factor, with the maternally derived chromosomes imprinted so that they do not suffer the fate of the male chromosome. Sex determination in mealybugs, and consequently the sex ratio, is known to be influenced by temperature and the age of the mother. The effect of the temperature or the age of the mother on the sex ratio of the offspring is attributed to a change in the ratio between the numbers of oocytes with and without the maternal factor.

The male is holometabolic and develops through four stages, egg, larva (two nymphal instars), pupa and adult, while the female is hemimetabolic and develops through three stages, egg, larva (three nymphal instars) and adult.

6.1.1 Oviposition

Mealybugs may be oviparous, viviparous or ovoviparous. Although variable, the pre-oviposition period is 4–5 days in general. In most of the mealybugs like *Pseudococcus longispinus*, *Ferrisia gilli* Gullan, *Dysmicoccus brevipes* (Cockerell) and *Heliococcus bohemicus* Sulc., eggs are laid by the adult female among the filamentous secretion of the ovisac formed by the pores on the adult's body. Wax secreted by the numerous pores and ducts around the ovipositional opening plays an important role in forming a waxy sac around the laid eggs. The



ovisacs are somewhat variable in their structure, depending upon the species of the mealybug. Several types of ovisacs have been recorded, varying from one covering the entire female body, to one covering only half or perhaps the last two abdominal segments, to one which is entirely ventral. These ovisacs are normally deposited on the shoots, fruits, flowers, leaves, underneath the bark and the cracks and crevices of the plant stem and arms.

The eggs are oval and can be seen with the naked eye, while the colour of the eggs varies with the species. The normal oviposition period of female mealybugs is 6–8 days, but it differs depending upon the species and climatic conditions. They are in close proximity in the ovisac. Female mealybugs are capable of mating multiple times on the same day and the female reproductive output is unaffected by multiple copulations. As many as 600 eggs can be laid by one female, but the number of eggs varies according to the mealybug and the host species. Freshly laid eggs vary in colour in different species, for example, the eggs are orange in case of *Maconellicoccus hirsutus* (Green), violet in case of *Nipaecoccus viridis* (Newstead), yellow in case of most of the mealybugs like *Planococcus citri* (Risso). However, the colour changes slightly before hatching, and the size also varies in different species. In the case of *M. hirsutus,* the eggs are 0.34–0.38 mm in length and the width ranges from 0.17 to 0.20 mm. Most of the mealybugs are oviparous and they lay eggs in the ovisac. But some mealybugs are ovoviviparous (depositing live first instars); for example, *Dysmicoccus brevipes* (Cockerell) bears live young, producing as many as 908 crawlers. These ovoviviparous females produce little or no ovisac and apparently shield their young for a short time by covering them with their abdomen. This character is particularly true of *Puto,* a genus which, for the most part, is ovoviviparous. *Planococcus lilacinus* (Cockerell) also lays the crawlers directly, while *Ferrisia virgata* (Cockerell) lays eggs which hatch immediately after laying. The number of offspring produced per female varies depending on the species, environmental conditions and food supply. It has been reported ranging from about 50 to over 800. In the absence of adult males, the virgin females of *Planococcus minor* (Maskell) do not produce eggs.

6.1.2 Incubation

The eggs hatch between 4 and 10 days, depending on the temperature and humidity. Hatching percentage ranges from 80 to 90 %.

6.1.3 Nymph

Mealybugs generally have three larval instars for females and four for males. Each of these stages resembles the previous one, except for an increase in size and the amount of wax secreted. Usually, immature males are slightly longer and more slender than females.

6.1.4 First-Instar Nymph (Both Sexes)

The eggs hatch into first-instar nymphs or crawlers and are vulnerable to insecticidal applications. This stage usually has proportionally very large legs and antennae compared with other instars and often there are fewer antennal segments than in the adult. This crawler is often quite mobile and usually migrates to other hosts, or at least to diverse areas of the parent host. There is no reliable character to distinguish between the male and female at this stage. The mean duration of the first instar is about 6–7 days; there is not much variation between male and female instars, but it can vary under different conditions of temperature and humidity. When viewed from above, it seems elongate oval in shape, but is extremely flat from the side. The first-instar nymph is often free from the waxy coating which usually develops at the later stages of growth.

6.1.5 Second-Instar Nymph (Both Sexes)

The second-instar nymph emerges through a slit in the medio-dorsum of the head and thorax of the first-instar skin. The legs and antennae are still proportionally larger compared to the adult body and often there are fewer antennal segments than in the adult. During this stage, it is possible to differentiate between the sexes, for by the end of this instar, the males produce a filamentous sac or cocoon over their bodies. The rostrum of the male is lost after the first moult, making the recognition of the second-instar male quite simple. The second nymphal stage of the female is characterized by the presence of six jointed antennae, four pairs of cerarii in the abdominal segments VI–IX and the oral rim ducts are restricted to the dorsum. In the second stage, the male only has one pair of, rarely two pairs of, cerarii and tubular ducts of oral collar type both on the dorsum and the venter. Mean duration of the second instar is about 6–7 days, but not much variation is seen between male and female instars, though it can be variable under different conditions of temperature and humidity.

6.1.6 Third-Instar Nymph (Both Sexes)

The second-instar skin is shed in the same manner as the first, producing the third-instar nymph. In female specimens, these instars begin to take the normal shape of the adult. Legs and antennae are approximately in proportion to the body size, when compared with the adult and the antennal segments are normally, but not always, the same in number as in the mature forms. The duration of the third instar in females is usually about 8 days, but it can vary under different conditions of temperature and humidity. In the male, the second skin is shoved to the posterior portion of the cocoon; the third-instar male is called the prepupa and is usually much smaller and more elongated than the third instar female. It also differs because it has wing pads, no rostellum and more antennal segments. The duration of the third-instar male is about 1 day, but it again varies according to temperature and humidity conditions for different species.

6.1.7 Fourth-Instar Male

The fourth instar of the male is produced in a cocoon and is known as the pupa. The third skin that is shed is again shoved to the back of the cocoon. This instar differs from the previously mentioned one; it has two longer, backwardly directed wing pads, more antennal segments (ten-jointed, normally the same as the adult) with a few pointed setae and three pairs of eyes. At one point between this instar and the next, a break in the posterior part of the cocoon is formed and the fourth shed skin is pushed outside. The duration of the fourth instar/pupa is about 6 days, but it again varies under different conditions of temperature and humidity.

6.1.8 Adult Female

The adult female is almost similar to the third-instar female nymph. The third-instar female has seven-jointed antennae and five pairs of cerarii in the abdominal segments V–IX, but the adult female has nine-jointed antennae, six pairs of cerarii in the abdominal segments IV–IX., valvular opening and multilocular disc pores in the venter. The fourth-instar female emerges in the usual manner to become an adult. The female nymph can be distinguished from all of the nymphal instars by the presence of a vulva and it is often very large and distorted from the eggs or nymphs which she carries in her abdomen. The female nymph has various types of pores on its body; the circular multilocular and pentagonal quinquelocular pores are believed to function in the production of the filamentous ovisac, whereas the normally more abundant trilocular pores function in the production of the white powdery secretion, characteristic of mealybugs. The exact function of any of these pores has yet to be confirmed and the precise morphological structure of the various types of tubular ducts is still unknown.

In certain mealybug species, such as *Ferrisia virgata*, it is believed that the enlarged tubular ducts produce thin crystalline rods, but the importance of the smaller tubular duct remains a mystery.

The setae of the cerarii are apparently important in supporting the filaments; again, in most adult female mealybugs, two pairs of dorsal cavities or 'ostioles', as they are called, can be located submarginally. The posterior pair is on the seventh abdominal segment and the anterior pair is apparently on the head. As previously mentioned, the ostioles, when irritated, seem to function in the secretion of globules of body fluid, perhaps as a defensive mechanism. It is also believed that these dorsal openings function in the exit of honeydew for consumption by ants. The filaments which may be seen so often on the lateral margins of many mealybugs are apparently produced by the clusters of trilocular pores surrounding the cerarii.

Other structures of the adult female are the antennae, the eyes, mouthparts, legs, spiracles, vulva, circulus, anal ring, anal lobes, body setae and cerarii. The antennae of mealybugs are filiform, with the terminal segments characteristically longer and wider than the preceding ones. There is a slight noticeable tapering of the antennae from the first segment to the last and the antennal segmentation varies in number from two in some species of *Antonina* to nine in certain species of *Phenacoccus*. Antennal shape is important in the field identification of some subterranean mealybugs. The unusually short geniculate antennae of *Rhizoecus, Pygmaeococcus* and *Geococcus* are easily recognized, particularly when compared with the normal, straight antennae of most other genera, which makes their field identification quite simple. There are often some enlarged setae on the apical, two antennal segments, which apparently act as special sensory setae. These setae differ from the other antennal setae, being larger in diameter and more rounded at the tip. The eyes of mealybugs are compound and they function only in distinguishing between light and dark.

The legs of mealybugs have a characteristic colour. For example, the legs of *Rhizoecus* and *Misericoccus* are white, those of many species of *Phenacoccus* and *Spilococcus* are red, while these of *Pula* are very dark brown or almost black in colour. Leg size is also quite variable: *Antoninoides* have very small, reduced legs; *Discococcus* have slightly larger legs; *Phenacoccus, Spilococcus, Chorizococcus* and others bear proportionately normal sized legs; and the numerous *Puto* species bear very enlarged and robust legs. The adult females of *Antonina* are totally without legs (apodous); on each surface of the posterior part of the trochanter, there are normally two, sometimes three, small clear spots which are sensory in function. On the tarsal segments and on the claw, mealybugs normally have a pair of spatulate setae, but these are sometimes absent. The use of these setae is not known, but it seems logical to assume that they, in some way, function in clinging to the substrate. The vulva, which is always present in the adult female, is the genital opening and functions in copulation and egg laying. In some instances, more than one male is able to mate with a single female at one time.

The anal rings are often of various shapes in different mealybugs, but they all function in waste elimination. As previously mentioned, these wastes, which are in many instances detrimental to the mealybug, are propelled long distances from the body by the rapid contraction of the walls of the anal cavity. It is also possible that the anal ring serves as an exit for honeydew intended for ant consumption and that the long setae of the ring serve as standards to hold the honeydew secretion before it is consumed by the ant.

The adult female measures 2.65–2.80 mm in length and 1.75–1.85 mm in width, and the females are wingless and as they mature, become more sessile. The female mealybug has a soft, oval and flattened segmented body, but the division between the thorax and the abdomen is not distinct.

6.1.9 Adult Male

The fifth-instar male refers to the adult which is very complex morphologically and only the easily recognized characteristics are discussed here. There are two or three known primary types of dermal pores occurring on male pseudococcids. The first type is normally clustered in a circular group on the posterior lateral margin of each side of the ninth abdominal segment. In *Phenacoccus gossypii* Townsend and Cockerell, there is, in addition to the pair of pore clusters on the ninth abdominal segment, another pair on the eighth segment. These pore groupings apparently form the wax of the long caudal filaments. The pores which make up these clusters are circular with a five-pointed star-shaped lumen, are called 'stellate pores'. Most of the stellate pore clusters also have long slender setae, which apparently act as central bases for the wax of the caudal filaments. It is felt that the long anal lobe setae of the females might also function in this manner. The male caudal filaments of *Puto arcloslaphyli* Ferris and *Puto decorosus* McKenzie, herein described as new, show a seta in the middle of the long waxy filaments. In *Phenacoccus gossypii* Townsend and Cockerell and *Pseudococcus longispinus* (Targioni Tozzetti), the above characteristic was observed in the females. Other types of pores have also been found on the males and are scattered over the body surface. These are called 'dermal disc pores' and name the number of loculi they contain. These may vary from three to five in number with four being normal, and it is further pointed out that these structures are by no means flat, but rather are recessed into the derm, with several small protrusions from the central part of the loculi.

Body setae are also characteristic in the male. Just as the normal lanceolate setae of the female are present, so also are the 'thick, finger-like digitiform setae' described by Beardsley. The latter are normally the most common of the two types; they predominate on both the surfaces of the body, the legs and especially the antennae. The 'digitiform' setae, which are presumably sensory in function, are very similar to those on the last two segments of the female mealybugs' antenna.

One pair of dorsal ostioles is present on the submarginal portion of the seventh abdominal segment and corresponds to the posterior pair of ostioles on the female. The antennae of the adult male normally have ten segments, but occasionally there are species which have nine-segmented antennae, such as *Palmicola palmarum* (Ehrhorn). The male has six eyes – a ventral pair, a lateral pair and a dorsal pair. The eyes of most males are dark red, with the smaller lateral pair protruding more than the other two. The mouthparts of the male are almost nonexistent and are completely non-functional. All that remains of the mouth is a small circular opening found at the posterior margin of the ventral part of the head. Normally, there is one pair of wings which develope from the mesothorax; these wings possess two longitudinal veins, the anterior one being the radius and the posterior one being the media. There is also a complex of minute basal veins called the 'costal complex of wing veins'. There are three forms of males, the first form has fully developed wings (macropterous); the second form has wings, but they are reduced and nonfunctional (brachypterous); and the third form is wingless (apterous). Examples of the first form are *Phenacoccus gossypii* Townsend and Cockerell, *Planococcus cilri* (Risso), *Puto lalicribellum* Mc- Kenzie *Saccharicoccus sacchari* (Cockerell); of the second form is *Palmicola palmarum* (Ehrhorn); and of the third form are *Puto ambiguus* (Fullaway), *P. echinalus* McKenzie and *P. pacificus* McKenzie. A pair of halteres is present on the metathorax; they are slender projections adorned with one or more setae at their tips. The normal number of apical setae is one, but four have been on each haltere in *Puto yuccae* (Coquillett). The apical setae, whether four or more in number, are re-curved in such a manner so as to hook into a circular pocket in the posterior part of the forewing.

There are two pairs of spiracles in the male, just as in the female, but in the case of the male there is often a much more strongly developed peritreme. The legs of most males are quite similar to those of the females, although they are usually proportionately much longer and more slender. The tarsus of the male has two segments rather than the normal single segment of the female, although in most cases the additional segment is quite small and appears as a slightly sclerotized ring. The digitules of the tarsal claws of most males differ from the spatulate type of the female in being slender and setiform. The claw is normally without a denticle. The external genitalia in male is relatively simple, consisting of a large penile sheath, a conspicuous vertical slit and the penis or aedeagus. The penile sheath is normally large and sclerotized with a posterior apical projection; this projection maybe of various shapes, but is usually broadly oval. On the ventral surface of the sheath, there is a noticeable slit from which the aedeagus often protrudes, is normally tube-shaped and curves downward. The penile sheath is apically of various shapes, from broad as in *Pseudococcus fragilis* Brain, to very sharp and pointed as in *P. longispinus* (Targioni-Tozzetti). The male of *Puto yuccae* (Coquillett), as well as many others of the *Puto* group, is quite different from the 'normal' Pseudococcid male. The primary differences noted were eight pairs of eyes, four setae on each halter, a toothed and bifurcate aedeagus and a denticle on the claw.

The adult male has a brown-coloured body, bears two white, anal filaments and is about 1.5 mm in length. The development of the egg to an adult male or female mealybug takes about 24–26 days, but this can vary for different species under different climatic factors in different host plants. The population of the male mealybug is generally very low, compared to the females; the male to female ratio varies from 1:5 to 1:8, but again, this is highly variable for different species.

The biology of the mealybug varies with different temperature conditions. The number of generations is quite variable in the Pseudococcidae; there are eight life cycles in approximately 1 year. In most of the *Puto* species, however, only one generation occurs annually and in *Puto sandini* Washburn, a high-altitude species, there is one generation every 4 years.

6.2 Biology of Important Mealybug Species

6.2.1 *Antonina graminis*

The mealybug *A. graminis* (Maskell) reproduces unisexually and up to five generations are produced each year. Eggs hatch within the body and the young ones are produced over a period of up to 2 months. On average, there are 170 offspring per female during the spring and about 150 in the summer. The first-instar nymphs are motile, but the succeeding instars are sessile and produce the felted wax covering from which a characteristic excretory tube protrudes. A generation may take 4–6 weeks, depending upon temperature and location.

6.2.2 *Brevennia rehi*

Reproduction of *B. rehi* Lindinger is mainly by thelyotokous parthenogenesis, viviparous parthenogenesis and, to some extent, by oviparous sexual reproduction. The oviposition period has been reported to be 2–4 days and the total number of eggs laid by a female varies from 42 to 144, although up to 350 eggs has also been recorded. The eggs are hyaline to yellowish-white or pinkish-white and are elongate oval in shape. They are laid in groups in between the leaf sheath under the 'mealy' covering; the incubation period ranges from a few minutes to 39 h, with the hatchability of the eggs varying from 41.7 to 93.5 %. The newly hatched nymphs are crowded within the waxy threads for 6–10 h before they disperse to various parts of the same plant. The pale yellowish nymph is active and the body gets covered with the waxy material on the second day. The nymphal period varies from 3 to 4 weeks, where the mature females lay eggs for about the same duration. The male nymphs gradually develop wings after the first few moults and emerge as small, active, flying insects; they are rarely seen and generally mate with females before dying a day or two after their emergence. Adult females are wingless, robust, pink and oval.

6.2.3 *Cataenococcus ensete*

Ensete root mealybug *C. ensete* Williams and Matile-Ferrero is a serious pest in southern Ethiopia. The females are viviparous and produce 253 nymphs/females. The average duration of the first-, second- and third-instar nymphs was 16.2, 18.1 and 19.7 days, respectively. The average lifespan of the adult female is 49.9 days. The body length and width of the adult female mealybugs ranged between 2.9–4 mm and 2.5–3.5 mm, respectively, when measured inclusive of the wax covering. Adult female mealybugs could not survive more than 3 weeks in the soil in the absence of plant materials.

6.2.4 *Coccidohystrix insolita*

The adult female has very little dorsal wax and secretes a white, waxy ovisac up to 6 times as long as its own body, which is more typical of some Coccidae. The immature stages do not secrete a thick layer of mealy wax, the body being shiny yellow-green with submedian grey spots on two abdominal segments and one thoracic segment. The female and male nymphs of *C. insolita*, reared in mass on sprouted potato tubers, at 22 and 33 °Cand 60–96 % RH, completed ecdysis at the age of 13.92 and 14.60 days, respectively. The ratio of female:male was 3.24:1. Starvation of impregnated females had no adverse effect on their oviposition. The increase in age of impregnation from 5 to 40 days in females had little effect on the preoviposition and oviposition periods and the incubation period of eggs. Fecundity is about 261 days and the longevity varies from 17.66 to 51.6 days. Thirty- to forty-day-old females showed 77–88 % and 96–99 % reduction in oviposition period and fecundity, respectively.

6.2.5 *Dysmicoccus spp.*

There are two separate species of *Dysmicoccus* found on pineapple plants. The pink mealybug *Dysmicoccus brevipes* (Cockerell) which reproduced non-sexually and the gray mealybug *Dysmicoccus neobrevipes* Beardsley which was bisexual. *D. brevipes* reproduces non-sexually through a process called parthenogenesis in which females birth female larvae without fertilization by males in Hawaii. In areas such as Brazil, where males are present, both sexual and non-sexual reproduction occurs. In summer, both the species produce living young over a 3–4-week period, with the *Dysmicoccus neobrevipes* produces 346 offspring per individual and *D. brevipes* produces 246. The first, second and third instars or larval stages last for 10–26 days, 6–22 days and 7–24 days, respectively. Thus, the total nymphal period varies from 26 to 55 days, with the average being about 34 days. The pink form starts reproducing parthenogenetically about 25 days after the third moult, whereas the gray form produces males in about a 1:1 ratio and mating is necessary for reproduction. Unmated females may live for nearly 4 months awaiting fertilization. There are multiple overlapping generations, with the life cycle of some being at least twice as long as that of others, reared under similar conditions. Adult females are plump and have a convex body, and are pinkish in colour. Lateral wax filaments are usually less than one fourth as long as the breadth of the body and those towards the back of the insect are half as long as the body. The fecundity of the female was 658.58 nymphs/ovisac and the prelarviposition period for adult females lasts for about 27 days. The larviposition (giving birth to larvae) period lasts for an average of 25 days, they give birth to about 234 progeny, but may produce up to 1000 crawlers. It may then live for another 5 days before dying. The duration of the adult female life varies from 31 to 80 days, averaging about 56 days. Male pineapple mealybugs do not exist in Hawaii; they are observed from Brazil. Male pineapple mealybug males are distinguished from the gray pineapple mealybug males by the difference in the number of antennal segments. The pineapple mealybug has eight antennal segments and the gray pineappple mealybug has ten. In addition, the pineapple mealybug has short clavate setae on its body and appendages instead of the digitiform setae that is found on gray pineapple mealybugs. The duration of the adult female life varies from 31 to 80 days, averaging about 56 days, where, the prelarviposition, larviposition and post-larviposition periods last for an average of 27, 25 and 5 days, respectively. They give birth to about 234 progeny, but may produce up to 1000 crawlers.

Another species *Dysmicoccus boninensis* (Kuawana) is oviparous. The eggs are laid in a cottony ovisac and hatch in about 10 days. The nymphal period ranges from 18 to 26 days and the males are necessary for reproduction. *Dysmicoccus carens* Williams was viviparous with four nymphal instars preceding the adult stage. The life cycle of the mealybug ranges from 48.2 to 63.8 days when reared on CoC 671 or Co 740. The mean fecundity is the lowest (117.6 crawlers/adult female) when reared on Co 6907 and the highest (230.6 crawlers/adult female) on C 740. The longevity of males is 3–4 days. The longevity of females is the greatest (32.3 days) on Co 740 and the shortest (18.0 days) on CoC 671. The mean duration of the first instar varies from 4.8 days on CoC 671 to 6.1 days on Co 6806. The duration of the second instar is the shortest (4.1 days) on CoC 671 and the longest (5.8 days) on Co 7704. The duration of the third instar was the shortest (5.1 days) on CoC 671 and the longest (6.1 days) on Co 6806. The duration of the fourth instar ranged from 13.5 days on Co 6907 to 15 days on Co 7704.

6.2.6 *Ferrisia virgata*

Reproduction in *F. virgata* (CklI.) is by both sexual and parthenogenetic means, but the latter is more common in this species. The courtship lasts for 1–30 min and the copulation time ranges from 15 to 20 min. The males prefer young adult females and mating occurs only once during the lifespan of the female. The longevity of the female is about 50 days and the fecundity ranges from 300 to 700 eggs per female. The eggs are deposited in groups, rarely singly and are usually concealed under the body. They are oval and buff to light yellow in colour. Since the eggs are laid in an advanced stage of embryonic development, they hatch soon after the oviposition in a very short time and are therefore seldom seen. Under normal conditions, the egg hatching percentage is about 95 %. The egg period lasts about 28.14 min. Pre-oviposition, oviposition and post-oviposition periods are 6.4, 8.1 and 1.5 days, respectively. Upon hatching, the crawlers (0.34 mm long and light yellow) remain motionless for 10–15 min before moving to the tender parts of the plant to fix themselves for feeding. The average duration of the first instar is 6.7 days and it takes about 4.4 days from first moult to cocoon formation in March–April. In the cocoon, males moult three times and their development inside the cocoon takes about 9 days. The total nymphal period is about 20 days in males. Thus, an adult male emerges from the cocoon after the fourth moult and is ready for copulation a little after emergence. The male adults live for 1–3 days. Females undergo three nymphal instars and pass through incomplete metamorphosis. The duration of the first, second and third instar was 7, 6 and 6 days, respectively. Total duration of the nymphal stage in females averages between 43.2 and 92.6 days at 28.9 and 16.6 deg °C, respectively, while in males it averages to 25.4 days at 26.5 °C. The total lifespan, from the egg stage to the end of the adult stage, averages about 76.2–154.6 days in females as opposed to 19–47 days in males. The male:female sex ratio is 1:1.87. Adult females are apterous with two long prominent waxy filaments at the posterior end and with a lot of waxy or glossy hair over the body which is covered with white waxy powder. They have fairly long, dark stripes on the dorsum of the posterior end of the body.

6.2.7 *Ferrisicoccus psidii*

In *F. psidii* Mukhopadhyay and Ghose, the duration of the first nymphal stage ranges from 4 to 11 days. The second- and third-instar female nymphs complete their moulting at the age of 15.5 and 21.35 days, being 66.8 and 60.0 % at the age of 13–17 and 19–22 days, respectively. In he second, third and fourth instars, males moult at the age of 13.28, 14.71 and 18.69 days and are around 69.4, 62.4 and 68.5 % developed at the age of 11–14, 13–16 and 17–20 days, respectively. The colour of the crawlers and all the nymphal instars of females are rosy, creamy pink, pinkish chocolate and chocolate; waxy dusts are found on their dorsum, the quantity progressively increasing with the progress of their development and the stage. Nymphal instars of females secrete 7–8 pairs and 13 pairs of marginally waxy tassels, mostly abdominal. All the instars of females and the second instar of males secrete a tubular and waxy anal process.

6.2.8 *Kiritshenkella sacchari*

The eggs of *K. Sacchari* (Green) are laid in a chain containing nearly 120 smooth eggs beneath the abdomen of the female. The incubation period is 14 h when the average temperature is 27.8 °C and humidity is 63 %. Freshly emerged nymphs remain beneath the abdomen of the mother for a short while, after which they turn restive and move about to settle in the vicinity of the mother. The total life cycle is completed in 18.6 days during April.

6.2.9 *Maconellicoccus hirsutus*

Parthenogenesis was the main mode of reproduction in *M. hirsutus* (Green), but sexual reproduction was also observed. Freshly laid eggs are translucent and yellowish or light orange in colour. They are elongated and oval in shape. As the incubation period advances, the translucent eggs become pinkish in colour before hatching. The incubation period varies from 5 to 7 days; and the hatching percentage of the eggs is about 90 %. The first-instar nymphs are usually yellow to orange in colour with reddish compound eyes. The neonate larvae are oval in shape and are highly mobile; during this stage, males and females are indistinguishable. The duration of the first-instar nymph lasts for 7–9 days. The body is pinkish in colour with white, thin and waxy secretions on the body. The duration of the second-instar nymph lasts for 6–8 days; at the end of second instar, the female nymphs moult as usual, like the previous instars, but the males secrete a cottony puparia around their body. The duration of the last instar of the female nymph lasts for 8–10 days. The third-instar male nymphs are recognized by denuding the puparia, distinguished by the presence of two small wing buds. This instar lasts for 1–2 days, with an average of 1.4 days. The last instar male nymph is characterized by well-developed wing pads and lasts for about 5–7 days. The duration of development, from egg to adult in case of the female and the male, is 30.3 and 28.7 days, respectively. The pre-ovipositional period ranges from 6 to 7 days and the ovipositional period ranges from 7 to 9 days, while the fecundity ranges from 426 to 573 eggs. Adult males are orange coloured, minute and very active. The longevity of adult females range between 13 and 16 days and for males between 3 and 5 days.

6.2.10 *Nipaecoccus viridis*

Adult females of *N. viridis* (Newstead) are rather large and have black or purplish bodies. They appear to be flat, having short filaments around the margin, whereas the males are winged with long antennae. The eggs are laid in clusters and enclosed in a protective, cottony mass. A female lays about 300–500 eggs in its life time; the eggs are purple in colour and hatch in 10–20 days and soon envelope themselves in the fluffy material. The nymphs are amber coloured with whitish, waxy coating around the margins. Female nymphs moult thrice and complete their life cycle in 6–8 weeks, while the males moult four times and after passing through a pre-pupal stage, emerge as winged adults. The average developmental periods of males and females are 18.19 and 16.19 days, respectively. The average pre-oviposition, oviposition and fecundity are 7.33 days, 8.33 days and 176.33 eggs, respectively.

6.2.11 *Paracoccus marginatus*

A single female of *Pa. marginatus* Williams and Granara de Willink is known to lay about 230–400 eggs in an ovisac. The ovisac, developed ventrally, is three to four times the length of the body and is entirely covered with white wax. Egg laying usually occurs over a period of 1–2 weeks. The eggs are greenish-yellow and egg hatching occurs in about 10 days. The males have four instars; the first-instar nymphs are called crawlers and the duration of the first-, second-, third- and fourth- instar in the male nymph at 25 °C was 6.5, 6.6, 2.4 and 41 days, respectively. The fourth instar is produced in a cocoon and is referred to as the pupa. Adult males tend to be pink in colour, especially during the pre-pupal and pupal stages, but appear yellow in the first and second instar. The duration of the first-, second- and third-instar of the female nymph in the mealybug was 6.5, 5.5 and 5.2 days, respectively at 25 °C. The species is known to reproduce both sexually and parthenogenetically. Males have longer development time (27–30 days) than females (24–26 days). The mean longevity of adult males and females was 2.3 and 21.2 days respectively. The adult female body is greenish-yellow, dusted with mealywax and not thick enough to hide the body colour without discrete bare areas on the dorsum and with many short waxy filaments around the margin of the body.

6.2.12 *Phenacoccus aceris*

Female *Ph. aceris* Signoret starts laying 200–500 eggs in a cottony ovisac during a 2-week period. The eggs are oval and lemon-yellow in colour. The ovisacs contain up to several hundred eggs. The first instar nymph is lemon-yellow, but with bright red eyes. The nymphs gradually disperse to nearby plant tissues. Soon after they begin feeding, they develop a granular white waxy covering with filaments at the caudal end, which is typical of mealybugs. The adult female has a sage green body, which is visible through the white, waxy coating. The 'tails' on the caudal end of the mealybug are shorter and the colour of the body ranges from greenish to pale purple.

6.2.13 *Phenacoccus bengalensis*

At 28.8–32 °C and 88–96 % RH, the nymphs of *P. bengalensis* Pramanik and Ghose complete their ecdysis at the age of 20.01 days and all of them become adult females. The females start oviposition at the age of 31–42 days. The pre-oviposition and oviposition period, fecundity and incubation period of eggs are 14.20 days, 9.08 days, 67.42 eggs per female and 4.57 days, respectively. The longevity of the adult females range from 47 to 55 days and the species reproduces parthenogenetically.

6.2.14 *Phenacoccus herreni*

Phenacoccus herreni Cox and Williams is a sexually reproducing mealybug. The first instar nymphs (crawlers) complete their development in an average of 7.7 days, the second instar averages to 5.1 days and the third averages to 5.6 days. Adult females live for an average of 24.8 days, with the oviposition period averaging about 18.4 days. The males passed through two nymphal instars, a pre-pupal stage and a pupal stage before becoming adults; these average at around 7.5, 6, 2.8 and 3.1 days, respectively. The ratio of females:males was 3:1. Reproduction was exclusively sexual; oviposition begins 3 days after pairing and the females deposit an average of 773.6 eggs each. Initially, the crawlers are found mainly on the growing point of the plant, from which they disperse down the stalk, settling finally on the lower surface of the leaves.

6.2.15 *Phenacoccus madeirensis*

The total duration of development of the female *Phenacoccus madeirensis* Green is 30 days at 25 °C, 46 days at 20 °C and 66 days at 15 °C. The developmental time of males was 3–9 days longer than females. Adult longevity at 25 °C for males and ovipositing females was 3 and 20 days, respectively. Females at 20 °C produced the highest number of eggs (500 eggs/female).

6.2.16 *Phenacoccus manihoti*

In the case of *Ph. manihoti* Matile-Ferrero, no males are observed and reproduction is by thelytokous parthenogenetic means. The eggs are enclosed in an ovisac of felted waxen threads and about 700 eggs are laid by one female. The adult females' mean longevity is 34.3 days. The duration of the egg stage, first instar (crawler), second–fourth instars and the adult stage averages about 8.0, 4.5, 4.1, 4.2, 5.2 and 20.2 days, respectively. The mean generation time is 28.48 days.

6.2.17 *Phenacoccus peruvianus*

Adult females are elongate oval in shape, are greyish with a green tinge and covered in a thin layer of white mealy wax. They lack marginal and caudal wax filaments, which are well developed in other mealybug species. No males are observed in the case of *Ph. peruvianus* Granara de Willink and they reproduce parthenogenetically. Eggs are laid in the highly conspicuous white, waxy and elongate ovisacs that form dense groups on the undersides of the foliage and on the stems. The nymphal instars are pale orange in colour.

6.2.18 *Phenacoccus saccharifolii*

The female *Ph. saccharifolii* Williams secretes the ovisac probably from the accessory glands one or two days prior to oviposition. The gravid female lays about 700 eggs in a single ovisac in batches. By the time the last batch of eggs is laid, the body of the female is raised to a vertical position with the anterior end attached to the substratum by the oral bristles. The female dies soon after oviposition. The incubation period lasts for 5–6 days. The total life cycle is completed in 25–28 days.

6.2.19 *Phenacoccus solenopsis*

Phenacoccus solenopsis (Tinsley) is observed to be ovoviviparous; the adult female is capable of reproducing only if she mates with a male. *P. solenopsis* lays about 500 eggs in the ovisac; they are minute, oval in shape and light yellow in colour. The eggs are smooth, translucent oblong in shape with tapering ends. It retains its eggs in the body until they are ready to hatch. It produces a sac with a cottony covering protruding from the anal end of the body. The incubation period of the eggs is 6.6 days; the female nymphs moult three times, while the males moult four times. The freshly emerged first instar nymphs are oblong in shape. The average duration of the first-, second- and third-instar nymphs is 4.8, 5.6 and 6.4 days, respectively, with the total nymphal duration being 16.8 days in females. The first- and second-instar nymphs are pale yellow in colour and oblong-shaped. During the third instar, a white waxy substance covers the dorsal body surface. The adult female is oblong in shape, light to dark yellow in appearance and is wingless. The pre-oviposition, oviposition and post-oviposition periods are recorded as 4.3, 8.0 and 2.7 days, respectively. The female adult survives for 15.5 days and the entire lifespan lasts about 31 days. A pair of dark spots on the thorax and three pairs on the abdomen forming two longitudinal stripes are noticed. Male mealybugs have two nymphal instars. The mean duration of the first and second instar is 4.0 and 5.3 days, respectively. At the end of the second nymphal instar, the males construct the puparia. The pupal duration ranges from 6 to 7 days. The total development of the female is complete in about 26 days, while that of male takes about 18.33 days. The sex ratio is 1:1.29.

6.2.20 *Planococcoides njalensis*

This mealybug, *Pl. njalensis* (Laing) is biologically variable. Some of the forms exhibit a strong parthenogenetic habit, so that males are not necessary, whereas the others require males for reproduction. Fecundity is very low, averaging only about 36 young ones per female over a 20-day adult lifespan. The eggs hatch within a few moments of being laid. There is no ovisac, only a few thin filaments being provided by the female for temporary protection of the young. The life cycle is completed in about 42 days and there are about eight generations in a year.

6.2.21 *Planococcus citri*

The female *Pl. citri* (Risso) lays yellowish-white eggs within the ovisac. There may be 300–800 eggs in one mass and the eggs are oval and glossy. They hatch within 6–10 days; the nymphs are yellow, oval-shaped with red eyes and covered with white waxy particles. The female nymphs have four instars, while the males have three instars and a pre-pupal stage. Only the males can produce a cottony cocoon and pupate. The male nymphs are elongated and narrower in appearance than females and often occur in a loose cocoon. A female nymph is full grown in 6–8 weeks with three moults. The male is winged, greyish in colour and midge-like with long antennae. The male nymphs spin cotton-like cocoons, 2–3 weeks after hatching and pupate before transforming themselves into winged adults with four moults, completing many overlapping generations in a year. The total life cycle of this mealybug is completed in 30–35 days. Citrus mealybug populations are generally composed of equal numbers of males and females. The females are wingless, white to light brown in colour, with brown legs and antennae. The body of adult females is coated with white wax and bears a characteristic faint gray stripe along the dorsal side. Short waxy filaments can be seen around the margins of their oval body, with a slightly longer pair of filaments present at the rear end. The females live for up to 29 days, depending on the host plant. The males are similar in colour to females and have two long backward-projecting white wax threads. The adult males are winged and thus capable of flying to new host plants for the purpose of mating. Following their emergence, males live for 1–2 days, during which they are incapable of feeding. The males are short-lived, ranging from 2 to 4 days after the final nymphal moult. The females, however, live for 30–40 days.

6.2.22 *Planococcus ficus*

Life table analyses were conducted for *Planococcus ficus* (Signoret) and its parasitoid *Coccidoxenoides perminutus* Girault at five temperatures between 18 and 30 °C. The intrinsic rates of increase (r_m) for both species were similar, reaching maxima at 25 °C (r_m = 0.169 for *P. ficus*; r_m = 0.149 for *C. perminutus*). The net replacement rate (R_o) of *P. ficus* was higher than that of *C. perminutus* at all five temperatures tested. The R_o of *P. ficus* reached a maximum at 21 °C (308.87 days) and that of *C. perminutus* at 25 °C (69.94 days). The lower and upper threshold temperatures for development of *P. ficus* are estimated at 16.59 and 35.61 °C, respectively. The lower threshold for the development of *C. perminutus* was 8.85 °C, but the upper threshold could not be determined as there was no turning point on the graph. Both the insects were well adapted to the temperatures. An average of 360 eggs per female was recorded.

6.2.23 *Planococcus kenyae*

An adult female of *P. kenyae* (LePelley) produces more 150 progeny. The eggs are laid in a small, light ovisac and hatch in about 1.5 days, but this period varies with climatic conditions from 1 h to 4–5 days. The development from the egg to the adult stage requires about 36 days for the female and 33 days for the male.

6.2.24 *Planococcus krunhiae*

In the case of *Planococcus krunhiae* Kuwana, the duration of development from the egg to the adult stage takes 35 days at 28.7 °C and 80 % RH. The duration of the egg and the nymphal stage is 4 and 20 days, respectively. Female lays about 150 eggs per female. Male mealybug takes 25 days to complete life cycle. Egg hatchability is about 95 %.

6.2.25 *Planococcus minor*

The eggs of passionvine mealybug *Pl. minor* (Maskell) are yellow, minute and are protected in an ovisac. At 29 °C, the eggs hatch in 5.7 days.

The duration of the first and second instar(female), the second instar (male), the third instar(female), the third instar (m) and the fourth instar(M) are 6.6, 7.2, 6.4, 6.9, 2.6, 5.9 days, respectively. The females take 30.8 and males take 27.5 days, respectively, to complete the development cycle. Fecundity is about 180 eggs and the male:female ratio ranges from 1:1.54 to 1:2.75.

6.2.26 *Pseudococcus comstocki*

Pseudococcus comstocki (Kuwana) is known as a pest of pome and stone fruits and certain ornamental plants. There are two, three, or even four generations per year, depending to some extent on climate. Generally, there is little overlapping of broods until late in the season. Overwintering is in the egg stage within the cottony ovisac. Overwintering eggs are laid as early as October, even in the milder climates, such as that of central California. The overwintering eggs generally start hatching in late spring; they are elliptical and bright orange-yellow in colour. They are laid in jumbled masses along with the waxy filamentous secretions in protected places such as underbark crevices, near pruning cuts and occasionally in the calyx of fruits. The summer-generation eggs are laid from mid-June through late July and the overwintering ones from mid-August to October. The summer-generation eggs have an incubation period of about 11 days; the females produce an average of 200–300 eggs, although some individuals produce up to 700. The young females develop through three instars, after which they are capable of being fertilized and oviposition follows after 10–15 days. The first- and second-larval instars of the female and the male mealybug are virtually indistinguishable. They appear similar to adult females, except that they are smaller, more oval-shaped, lack the long body filaments and are more orange-yellowish because they have a lesser amount of wax covering them. The first-instar female crawler is flat and pale yellow but become darker over time. The second and third instar females are similar in appearance, but become progressively browner and redder. The third instar of the immature male, called a 'pre-pupa', is contained in a cocoon that begins forming toward the end of the second instar. The fourth stage of the immature male is the pupa; it is elongated and light reddish-brown. At 30 °C, a generation may be produced in 27–29 days.

Adult females and males emerge at the same time, from late June to mid-July for the first (overwintering) generation and late August to mid-September for the second (summer) generation. Adult females are present for a total of 4–6 weeks and oviposit for about 1 week after mating. The males survive for only a few days after emerging. The overwintered eggs hatch from mid-April through May and the nymphs (crawlers) migrate from the oviposition sites to their feeding sites on terminal growth and to the undersides of the leaves of trees and shrubs. This hatch is completed by the petal-fall stage of pears. The nymphs that hatch from these overwintered eggs are active from roughly early May to early July. As the nymphs approach the adult stage, they tend to congregate on older branches at a pruning scar, a node, or at a branch base, as well as inside the calyx of pears. The second (summer) generation nymphs are present from about mid-July to mid-September.

6.2.27 *Pseudococcus cryptus*

Egg development time in *Ps. cryptus* (*Ps.citriculus*) Hempel decreases with increasing temperature and ranges from 2.4 days at 16 °C to 1.0 days at 28 °C. The total development time of nymphs decreases from 54.9 days at 16 °C to 17.4 days at 28 °C and 19.3 days at 32 °C. *P. cryptus* shows an ovoviviparous reproductive behaviour and hence the egg period is combined with the first-instar nymph. By fitting linear models to the data, the lower developmental threshold temperatures for the egg to the first nymphs, second nymphs, third nymphs and from the egg to the third nymphs are calculated as 8.7, 12.8, 13.1 and 12.1 °C, respectively. The thermal constants are 198.6, 84.7, 69.8 and 296.3 degree-days, respectively, for each of the above stages. The non-linear model based on a Gaussian equation, used to predict the relationship between development rate and temperature, is well described for all the stages. In addition, the adult longevity decreases from 80.4 days at 16 °C to 31.3 days at 32.0 °C. Furthermore, the pre-oviposition and oviposition periods show a pattern similar to that of longevity. Overall, *P. cryptus* has a maximum fecundity of 111 eggs per female at 28 °C, which declines to 102.7 eggs per female at 32 °C.

6.2.28 *Pseudococcus jackbeardsleyi*

The Jack Beardley mealybug *Ps. jackbeardsleyi* Gimpel and Miller is oviparous and lays yellowish eggs. The eggs are laid in a mass within a loose, thin and waxy sac behind their abdomen. The ovisac is a little elongated and the number of eggs laid by a single mealybug ranges from 650 to 900 with a mean of 775.60. They are in close proximity within the white ovisac. Freshly laid eggs were yellowish, smooth and oval with slightly tapering ends, but they turn a darkish yellow before they hatch. The incubation period is 5–8 days, with a mean of 5.37 days at 25 ± 1.8 °C and 70–85 % RH. The nymphs remain in the egg sac for a day or two after hatching, before crawling about the plant in search of food. Newly hatched mealybugs (crawlers) are quite active. The crawlers, once they begin feeding, secrete a white, waxy material that covers their body and produces approximately 34 leg-like filaments around the perimeter of the body. The nymphs are light yellow and six-legged with oval, flattened and smooth bodies. The females change only slightly in appearance, except for growing in size to about one sixth or one fourth of an inch when fully grown. The females of this species have three larval stages (or instars); similar to the other mealybugs, the male and female nymphs are indistinguishable in the first instar, but by the end of the second instar, it is possible to differentiate between the sexes. Female mealybug nymphs are similar to that of adult female mealybugs, except the latter are larger in size. The females become adults after the last moult; the female nymphal period ranges from 18 to 21 days with a mean of 20.82 days. The males have four nymphal instars, similar to that of the other mealybugs. At the end of the second instar, the males produce cocoons (pupa) over their bodies. The third moulting takes place within the cocoon; the fourth instar, also known as pupa, is characterized by well-developed wing pads. Only males pupate and develop into adult males. The male development, including the nymphal and pupal stages, ranges from 18 to 20 days with a mean of 19.10 days. The adult female mealybugs are very sluggish and are similar to the nymphs. The male mealybugs are rare, tiny and active. They have a pair of wings and two long waxy caudal filaments at the posterior end of the abdomen, similar to the other mealybugs. They are fly-like insects, do not feed and die soon after they mate. The females complete the life cycle in 25–29 days, with a mean of 26.20 days and while the males complete their development in 23–26 days, with a mean of 24.40 days. There is a variation in the developmental period from eggs to adults in the mealybugs, depending on the weather and host plants.

6.2.29 *Pseudococcus longispinus*

The female *Ps. longispinus* (Targioni-Tozzetti) produces around 200 live young (which she deposits under her body) over a 2–3-week period. During summer, the life cycle is completed in around 6 weeks and in about 12 weeks in winter. Long-tailed mealybugs produce live young, but do not produce an ovisac. The eggs are straw yellow at first, but deepen in colour before hatching. The eggs (20–240) may hatch as soon as they are laid, giving the impression that the young are born, rather than hatched. The crawlers are flat, oval, light yellow in colour and six-legged insects with smooth bodies. Soon after beginning to feed, they exude a white, waxy covering over their bodies. The differentiation between the male and the female begins only after moulting. The male nymphs stop feeding near the end of the second stage and migrate towards a protected place where they secrete waxy cocoons in which they complete their development. The females go through three stages to adulthood, but change little in appearance.

6.2.30 *Pseudococcus mandio*

At 25 °C, 80 % RH and constant light, the female *Ps. mandio* Williams has three nymphal instars, with average durations of 9.2, 5.7 and 6.5 days, respectively and their average lifespan is 17.8 days. The males have two instars, which last an average of 8.9 and 5.2 days, with the average pre-pupal and pupal periods of 12.5 days, and an average adult lifespan of 2.1 days. The pre-oviposition period lasts 4.7 days and each female lays an average of 302.2 eggs. The average incubation period is 3.8 days, with 99.4 % eclosion. The life cycle from oviposition to adult emergence is 25.2 days for females and 30.4 days for males.

6.2.31 *Pseudococcus maritimus*

Both sexes of *Ps. maritimus* (Ehrhorn) are capable of mating multiple times on the same day and on sequential days. Median times between copulations are short (<10 min) on the first day that the males are presented with the females, but tend to increase with sequential copulation events. Unmated females live for up to 19 weeks, as mating and oviposition result in reduced longevity. The eggs that are laid are yellow to orange in colour and are within an egg sac. The crawlers are yellow to orange-brown in colour. There is a stronger winter dormancy in the egg and crawler stages, so that the seasonal development is attuned to a deciduous host. Overwintering usually takes places ordinarily in crawlers and unhatched eggs in the loose cottony ovisac. With the first warm weather of early spring, these nymphs move to the swelling buds and feed on the tender shoots; on reaching maturity, they begin to oviposition around June or July. The mature females tend to move to the trunks or protected crevices of the rough bark to oviposition. It is this brood which, by feeding on the leaves and the fruits, causes the damage.

6.2.32 *Pseudococcus saccharicola*

Parthenogenesis and sexual reproduction are the common modes of reproduction in this species. While the female undergoes four instars, the male has five. The pre-oviposition period is 12 days and the eggs laid by the gravid females are observed on the underside of their abdomens. Fecundity ranges from 200 to 300 eggs per female; they are creamy yellow and covered with mealy powder. The first-instar nymph is cream-coloured and after the first moult, the cream-yellow colour changes to light pink. The nymphs feed together for some time and a few days before the second moult, the nymphs developing as males spin a cocoon. Such 'male nymphs' descend from the stalk of young plants and pupate in the leaf sheaths, while the female nymphs remain feeding on the leaves. This stage lasts for 6–7 days. The pre-pupa appears pink in colour and lasts for 2 days. In the case of males, the pupa is distinguished from the pre-pupa by the presence of wing pads. The pupa moults once again to attain the adult form; the adult male is a small, delicate and alate insect with a reddish-pink body. The lifespan of the male is only days. In the case of females, the light pink second-instar nymph is covered by mealy secretion and this stage lasts for 6 days. Third instar nymph is light pink and covered with copious secretions of wax. The yellowish-brown adult female is densely covered with wax, very sluggish and seldom moves away from the spot of feeding. The lifespan of the adult female, including the pre and post-gestational period, is 25–27 days.

6.2.33 *Pseudococcus viburni*

Pseudococcus viburni (Signoret) (=*Pseudococcus obscurus* Essig; *Ps. affinis* (Maskell)) has four or five generations per year on citrus, depending on the climate. It overwinters in all stages, with moderate retardation from cold weather. Each female deposits up to 500 eggs during the first 1–2 weeks, which accumulate in a loose caudal egg sac. They hatch in about 8 days under summer conditions and maturity is attained in about 42 days, followed by oviposition after several weeks.

6.2.34 *Rastrococus iceryoides*

The female *R. iceryoides* Green lays eggs only after fertilization. The pre-oviposition period lasts for 7–9 days and the oviposition lasts for

7 days. About 500 eggs are laid in the white ovisac and the fecundity averages to about 800 eggs. The incubation period is 6 days. Females moult three times, while males moult four times to become adults. The females take 20–30 days and males 18–25 days to complete the life cycle.

6.2.35 *Rastrococcus invadens*

The mealybug, *R. invadens* Williams completes eight generations in a year. The female and male nymphs complete development in 34.67 and 38.16 days, respectively, during winter at 15–21 °C and in 24.63–32.67 days or 27.63–36.18 days at 18–33 °C during February to November, the optimum being during June–July at 27–31 °C in females and during May–June at 27–33 °C in males. The male:female ratio ranges from 2.13:1 to 3.3:1. The maximum pre-reproductive period and oviposition period and minimum fecundity are 20–29 days, 34–45 days and 165 (145–175) in nymphs, respectively, in winter. The minimum pre-reproductive period and the maximum fecundity are 14–18 days and 204 (180–235) days in nymphs, respectively, in September and the minimum oviposition period (28–35 days) occurs in April.

6.2.36 *Saccharicoccus sacchari*

In the largely parthenogenetic mode of reproduction, alate males are not uncommon, though apterous forms are also observed in the case of *Sa. sacchari* (Cockerell). With a pre-oviposition period of 13.83 days, a single female is capable of depositing nearly 1,000 eggs. The eggs are smooth, yellowish, cylindrical, with both ends rounded. A single such batch may contain a maximum of 262 eggs. The nymphs hatch within 3–4.15 h and before hatching, the eggs become soft and elongated. Sometimes, no eggs may be noticed and only orange coloured tiny crawlers may be found swarming from below the mother, which tend to give an impression that the mealybug is viviparous. The crawler extricates itself from one end of the egg, the eggshell sticking on its posterior end. The first-instar nymphs are tiny, transparent and pink in colour and very active. This stage lasts for 5.3 days. During the second-instar nymphal period, the body grows in size and the antennal length increases to 0.36 mm due to the addition of a segment. The stage is completed in 4.83 days. The duration of the third-instar nymph is 17.2 days. Ovarian development is completed in 13.8 days while one generation is completed in 54.7 days.

6.2.37 *Trionymus haancheni*

The adult female *Trionymus haancheni* McKenzie is quite small, but is visible to the eye without magnification, reaching a length of approximately one fifth of an inch (5 mm). The eggs are laid in loose, cottony wax. These cottony egg sacs are usually laid on the lower part of the plant, close to the roots and were also observed under the leaf sheaths of the plant. A single female can lay as many as 256 eggs in a single ovisac during a week. Reproduction occurs asexually in the absence of males. The eggs are pink-red and not visible to the naked eye. Eggs hatch producing the crawlers (the most mobile nymphal stage, which disperse to find suitable sites for feeding on plant sap). The crawlers can also be transported to other plants by wind, people, or animals; they develop through several successive nymphal instars that resemble small adults, each of which have legs and can actively move, until the mature adult stage is reached and the cycle repeats. The number of generations in Idaho is still unknown but all the instars can be found at a single time on a plant host. The number of generations is not known, but all the stages have been found co-existing on infested plants. Coupled with a short generation time, the ability to reproduce asexually can allow mealybug infestations to increase quickly to damaging levels.

6.3 Biology of Root Mealybugs

6.3.1 *Geococcus citrinus* Kuwana

This is a bisexual species. The females lay the eggs in masses or chains. These eggs are pearly white, translucent and elongate oval in shape. The average incubation period is 12.20 days. In *Gococcus citrinus*, a single female is known to lay about 113–188 eggs, with an average of 128.2 eggs. There are three nymphal instars for the females; the nymphs are elongate oval, white in colour and cluster on the roots to feed. The duration of the first-, second- and third-instar nymphs lasts for an average of 7.3, 5.6 and 5.8 days, respectively. The size of the nymphs increases with the instars. In males, the pupal stage lasts for 5 days. The adult females are elongate oval, white and wingless with a segmented body. The females live for about 12.78 days. The adult males are light brown in colour and have only one pair of narrow, elongated and opaque wings with a round outer margin. The males live for a maximum of 5 days. Unlike other mealybugs, *G.citrinus* nymphs and adults do not produce honeydew; hence usually these are not associated with ants. The total life cycle of *G. citrinus* and *Geococcus coffeae* Green are 28.8 days and 33.8 days, respectively.

In case of *Rhizoecus hibisci* Kawai and Takagi, the eggs are laid in white, loose, waxy, elongate ovisacs which are about 2 mm long and can easily disintegrate when disturbed. Each ovisac contains up to 80 eggs, which usually hatch within 24 h. Nymphs (immature stages) are creamy-white. They closely resemble the adults, but are significantly smaller. Adult females are creamy-white, elongate and covered in a powdery wax that is deposited on the roots and the soil; these deposits are often the first sign of infestation. Adults and nymphs feed on the roots of the host plants, but may also be found within the root ball and on the inner surface of the plant container. The males are extremely rare and are unlikely to be seen. There can be several overlapping generations throughout the year and their numbers can multiply rapidly under favourable conditions.

6.3.2 *Paraputo* sp.

They are bisexual and can be ovoviviparous or viviparous. The favourable period for their reproduction is around August–October, with 30 nymphs per female mealybug. The nymphs develop into both male and female adults. The males are characterized by one pair of wings, are shorter in size than the females and occur in very few numbers. The females are plump, convex in shape and covered with white waxy mealy substances. They develop by undergoing three nymphal instars, while the males undergo four growth stages. The life cycle of the females takes 33.5–43.7 days, while that of the males take 29.3–39.5 days.

6.3.3 *Cataenococcus ensete*

Adults of enset root mealybug *C. ensete* (Williams and Matile-Ferrero) are viviparous and produce 156–383 nymphs, and their total lifespan is 94–113 days. This species has three nymphal stages; the development of the nymph to the adult mealybug takes 54 days on average and the lifespan of the adult root mealybug is 50 days. The average duration of the first-, second- and third-instar nymphs is 16.2, 18 and 20 days, respectively. The average lifespan of the adult female is 50 days.

6.3.4 *Rhizoecus amorphophalli*

Rhizoecus amorphophalli is the noxious pest infesting the stored tubers of elephant foot yam, taro and tannia. The ovoid, pale white eggs are laid in clusters inside the egg sac and turn light brown on hatching. The average length and breadth of the eggs are 187.80 μm and 102.50 μm, respectively. After eclosion, the first-instar larvae (crawlers) moved out of their ovisac, actively searching for suitable feeding sites on the tubers. The crawlers are oval and semi-translucent with three pairs of legs and paired eyes, measuring 183 μm in length and 98 μm in width. They prefer to hide out in the crevices or depressions of the tubers and on settlement produce mealy substance to create waxy filaments over their body. The first instar lasts for

4–7 days. The second-instar larva is 270 μm long and 124.74 μm wide and is semi-translucent with a shiny body. The second-instar larva lasts for an average of 4.82 days and before undergoing next moulting, they settle either on the previous site or on another suitable site on the tuber and cover themselves with mealy filaments. The third instar is relatively larger, measuring 429.47 μm in length, 193.2 μm in width, and the duration of this instar is 4–6 days and the sex differentiation is obvious at the end of this stage. The female nymphs moult normally, but the male instar produces a cottony puparium around its body.. The pupal stage lasts for an average of 2.50 days and the males transform into winged adult forms. They undergo a radical change during their life cycle – the wingless nymphs transform into winged adults. The adult female body is oval, whitish, wingless and sparsely covered with white mealy substance. The length and width of adult females are 867.19 μm and 368.88.78 μm, respectively. After mating, the adult females secrete an ovisac of white waxy substance in about 7–14 h and egg laying begins 3–7 h after this process. The eggs are laid in a bead-shaped pattern, but later they are found in a disarrayed and scattered manner under mealy covering. Oviposition is completed in about 3–8 h with a maximum fecundity of 79 eggs and the females are not able to survive more than 4 h after egg laying. At 32.22–35.10 °C and 55–65 % humidity, all the eggs hatch after about 6–9 days of incubation.

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7 Culturing of Mealybugs

M. Mani and C. Shivaraju

Culturing of mealybugs is essential to rear the natural enemies, particularly parasitoids and predators for use in the field. Biological control programmes of mealybug species have relied on sprouting potatoes, pumpkins and butternut for rearing of both mealybugs and their natural enemies. The ability to mass-rear the mealybugs is a vital step towards the culturing and colonisation of its natural enemies. An inexpensive mass-rearing technique and a nutritionally efficient but simple diet have to be developed for the mealybugs. The nutritional regime should be capable of producing and supporting great numbers of mealybugs at low cost. An important requirement for mass-rearing substrate is a long shelf life, which obviates the regular provision of fresh food. In this regard, butternut, pumpkins and sprout in potatoes have been found as suitable substrates for the mass-rearing of mealybugs (Johnson and Giliomee 2011).

In the large-scale production of mealybugs, potato sprouts or ripe pumpkins have been used in several countries. For mass rearing, a pure culture of *Planococcus citrii* (Risso) must be maintained in an isolated room solely for infesting work (Finney and Fisher 1964). Species of mealybugs have been satisfactorily reared in the laboratory in different countries on potato tubers and cucurbit fruits for the purpose of mass breeding of their parasites and predators (Ahmad and Ghani 1970). Large-scale multiplication of the mealybug for mass production of natural enemies was done on potato sprouts and pumpkin (Ahmad and Ghani 1970. The rearing of *Ferrisia virgata* (Cockrell) on brinjal has been reported by Rawat and Modi in India.

7.1 Potato Sprouts

The use of potato sprouts as an insectary host for the mealybugs culture was discovered by H. S. Smith and E. J. Branigan of the State insectary of USA (Branigan 1916). It was later modified by Smith and Armitage (1920), who found that white sprouts which developed in subdued light and at temperatures of 21.1–22.2 °C were highly acceptable to the mealybugs (Fig. 7.1).

The production method of *P. citri* on potato sprouts is described in detail, as given by Fisher (1963). The variety Red Bliss Triumph is preferred to Bounty or White Rose because it produces sturdy sprouts highly acceptable to the mealybug and its natural enemies.

Potatoes after harvest should be stored for more than 3 months at 2.2 °C. Fans have to be provided to facilitate the circulation of air, which reduces the temperature fluctuation throughout the storeroom, and also reduces the decay

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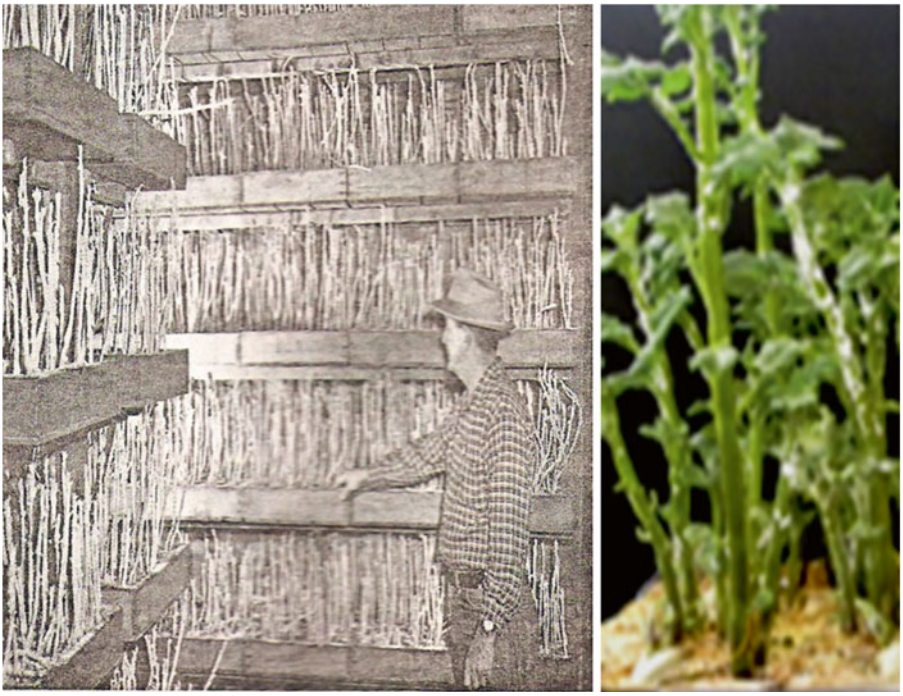

Fig. 7.1 Culturing of mealybugs on potato sprouts (Fisher 1963)

fostered by humidity. Planting trays are made of redwood and their outside dimensions are 18”×4”. Soil used is sandy silt, obtained from riverbed. Trays and soil can be sterilised prior to re-use. Approximately 3 months after harvest or when ½” sprouts begin to appear, the tubers are ready for planting. Medium to large-size sound whole potatoes are used, and 25–26 tubers are placed about ½” apart and on a ½” layer of soil in the tray. They are covered with slightly dampened soil. Immediately after planting, trays are placed on the racks of a thoroughly cleaned room and watered. Trays should be filled with brimful of water every 4 or 5 days and watering should be discontinued after the sprouts have been infested. Temperatures of 21.1–23.3 °C appear to be optimum for facilitating sprout growth and relative humidity of 60–84 % have given good results, provided there is proper airflow through the culture room. Control of light intensity in order to minimise leaf growth and chlorophyll development is a critical factor in the production of optimum (properly bleached) potato sprouts. Continuous weak light causes sprouts to become excessively etiolated and too much light causes excessive leaf growth. Excessive long sprouts are pruned to 12” lengths. The time from planting until infesting with mealybugs is usually 21 days in summer and 30 days in winter and in early spring (Fig. 7.2).

Crawlers are removed from producing trays by allowing them to crawl into freshly cut short leafy terminals of ‘Switches’ of *Pittosporus undulatum* placed among the sprouts. *Schinus molle* (California pepper) is also used in autumn. Approximately 6 h after placing them on the trays of mealybugs, the switches are removed from the food room and placed on the fresh sprouts in the production from where the mealybug crawlers move on to the sprouts as the switches dry out. During the transfer periods, trays are not watered; light intensity is increased and temperature is adjusted to 26.6 °C. Another method is to remove every third tray in the row

Fig. 7.2 Mass production of mealybugs on potato sprouts

and replace it with a tray containing long sprouts that can be carefully bent over to interlace with the over-producing sprouts of adjoining trays. Stock from one mealybug tray will infest from 20 to 25 trays. The optimum temperature for continuous culture of mealybugs lies between 20 and 23.8 °C (Fisher 1963). Sprouting potatoes are the preferred host for the mass rearing of Oleander mealybug *Paracoccus burnerae* (Brain) (Johnson and Giliomee 2011).

In India, the rearing of mealybugs on potato sprouts has been standardised by Joshi. The following are the steps involved: (1) Procurement of medium-sized potatoes with well-developed eyes. (2) Cleaning with tap water and keeping in a basin filled with sterilised sand. (3) Covering potatoes with sand and water moderately. (4) Within a week or two, the sprouts grow to a length of 3–4 in.. (5) Removing the potatoes from sand and washing them with tap water. (6) Keeping them in sunlight for a day so that the sprouts turn green. (7) Infesting one sprout with five gravid females of mealybug. (8) Keeping infested potatoes at 27 °C and 50–60 % relative humidity (R.H.).

7.2 Pumpkin

The rearing of *P. citri* on cucurbits in USSR was first reported by Sysoev (1953). In Sicily (Italy), the mealybug *P. citri* was reared on pumpkin, *Cucurbita maxima* Gil. (Mineo 1967). The propagation of citrus mealybugs on ripe pumpkins, *C. moschata* D., has been outlined by Chacko et al. (1978) and Singh (1978). The pumpkins with ridges and grooves and a small stalk are selected, which makes the handling easy. To prevent rotting, the pumpkins are treated with 0.1 % benomyl (1 g/L). The wounds, if any on the pumpkin, are plugged with melted paraffin wax. Ovisacs on *P. citri /M. hirsutus* are distributed over the pumpkin fruits or crawlers are dusted on the fruits. In due course, the crawlers settle on all sides of the pumpkin. The infested pumpkins are kept on small tripod stands, which can be arranged in the racks. In about a month, the mealybug population covers the whole pumpkin. A temperature of 25 °C is to be maintained in the rearing room (Chacko et al. 1978; Singh 1978) (Fig. 7.3).

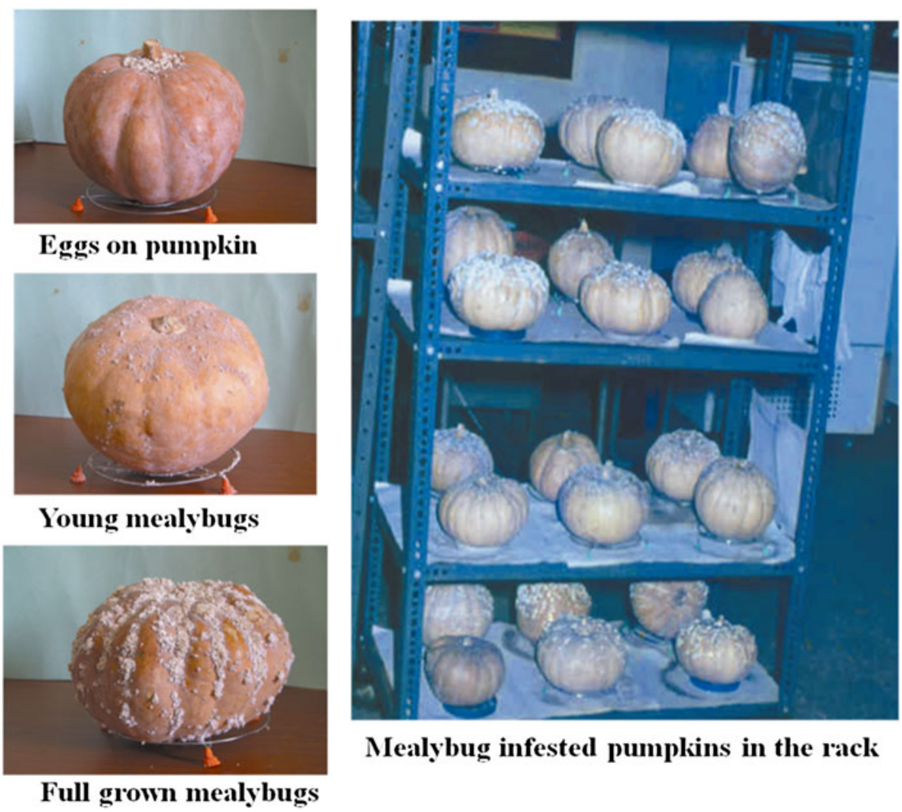

Fig. 7.3 Rearing of mealybugs on pumpkins

7.3 Host Plants

The mealybugs are cultured on host plants. Initial culturing is always done on natural host plants. Sometimes mass culturing is also done on the host plants. A mass production protocol is available for the production of papaya mealybug *Paracoccus marginatus* Williams and Granara de Willink on potato sprouts. However, it was very difficult to maintain potato plants in high-temperature areas where spoilage of potatoes is a concern. Alternatively, a mass production technique has been developed using *Hibiscus cannabinus* for mass production of the papaya mealybug. Seeds were procured locally. Before sowing, the seeds were spread on paper and allowed to dry under sunlight for 1–3 h. Trays of 45 cm × 30 cm × 13 cm (l × w × h) with four to six holes in the bottom to drain out excess water were filled with a mixture of sand, soil and farmyard manure (1:1:1) up to 9 cm and *H. cannabinus* seeds were sown for culturing the plants under laboratory conditions. The seeds started to sprout within 2 days and attained a height of 40 cm within 20–25 days, which is the suitable stage for infestation with papaya mealybug for mass production purposes. *Paracoccus marginatus*, placed on 20–25-day-old seedlings, was allowed to develop to the second instar, at which time the plant was cut and transferred to plastic containers having one thin layer of absorbent cotton covered with one layer of tissue paper. Based on the number of 2nd-instar mealybugs present, parasitoids were released at a ratio of 2:1 (parasitoid to mealybug) into each container after which the cage was covered with muslin cloth. For production of 20,000 parasitoids on the mealybug using potatoes, the approximate cost was Rs. 8700, whereas culturing done on *H. cannabinus* would require about Rs. 6700. It is concluded that culturing of papaya mealybugs on *H. cannabinus* is easy, economical and suitable for tropical conditions and allows more effective mass production of the mealybug and its parasitoids (Helen et al. 2013).

7.4 Diets

Attempts were also made to rear the mealybugs on artificial diet. Rearing the cassava mealybug, *Phenacoccus manihoti*, was done on a defined diet (Calatayud et al. 1998).

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Mode of Spread of Mealybugs

8

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Mealybugs spread through various means. Local and short-distance dispersal of mealybugs is facilitated by air currents, ant movements, farm labourers and farm implements. Long-range dispersal/movement of mealybugs is usually accomplished by transport of infested plant material. Cotton mealybugs have the propensity to spread through natural carriers such as raw cotton, linted cotton seeds, wind, water, rain, birds, human beings, ants and farm animals. They have immense potential to emerge as crop pests, thereby causing severe economic damage to a wide range of crops and pose a grave threat to agriculture in the new area.

8.1 Planting Material

Infestations often begin with the purchase of infested plant material. The mealybug is passively dispersed with the infested planting material. Mealybugs are not noticed as they hide in protected sites, such as cracks and crevices in bark, leaf axils, root crowns, stems, under the leaves and so on, when the population is very low. The dispersal mechanism of rhizome-feeding root mealybugs is facilitated by the movement of infested suckers.

8.2 Trade and Commerce

Dispersal is likely to occur more rapidly over longer distances with the movement of infested plants in trade. The rapid spread from one country to another is most likely to be due to movement of mealybugs in trade. Both the obscure mealybug *Pseudococcus viburni* (Signoret) and the parasitoid are the new world species that coevolved in Chile and transported to Europe before the nineteenth century, arriving on the roots and foliage of new world potatoes. The spread of the papaya mealybug *Paracoccus marginatus* Williams and Granara de Willink was also aided by the transport of the papaya fruits infested with mealybugs from one state to another in India. Most of the invasive pests like *Phenacoccus manihotti* (Matile-Ferrero), *Rastrococcus invadens* Williams, *Paracoccus marginatus* etc. spread through the sale of planting material, fruits or plants to other countries.

8.3 Personnel

Plants with their associated insects must have been carried to new areas by people for many centuries, and people still carry the infested plant material, as seen by numerous quarantine interception records.

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8.4 Irrigation Water

Root mealybugs spread through irrigation water from one spot to another. Besides, flood irrigation carries fallen leaves and other debris infested with mealybugs from one spot to another.

8.5 Air Currents

Some of the crawlers may be dispersed over longer distances by air currents. Sticky trap collections revealed that *Dysmicoccus neobrevipes* Beardsley and *D. brevipes* (Cockerell) are dispersed by wind. In India, *Paracoccus marginatus* had spread very fast by wind dispersal of crawlers from the state of Tamil Nadu to others. Aerial dispersal could be important in the colonization of mealybugs of new areas.

8.6 Animals

Mealybugs are known to cling to wild and domestic animals. They get transported by the movement of animals.

8.7 Transport

The mealybugs clinging to the vehicles entering from the infested orchards get transported to the other orchards.

8.8 Implements/Equipment

The dispersal of mealybugs is facilitated by farm implements/equipment during farm operations. Harvesting equipment from the infested orchard carries the mealybugs from one place to another.

8.9 Farm Labourers

Farm labourers move from one orchard to another, especially at harvest time. Mealybugs are transported through their clothes, disposable wares and shoes.

8.10 Ants

Among the arthropods, ants have also been reported to disperse many mealybug species. Ants are likely to carry the young mealybugs called as crawlers. Ants are known to transport the mealybugs from plant to plant, between and within fields, thus facilitating mealybug dispersal. In California, it is often possible to see ant *Camponotus* actually carrying the mealybugs from its host plant, directly into the ants nest. Ants are the primary or sole means of mealybug dispersal in pineapple. *Pheidole megacephala* (F.) are seen carrying mealybugs from one pineapple plant to another. The big-headed ant (*P. megacephala.*), Argentine ant (*Linepithema humile* (Mayr)) and fire ant (*Solenopsis geminata* (F.)) are commonly found in the Hawaiian pineapple agroecosystem, where they tend the mealybugs for honeydew. These ants, especially *P. megacephala*, have been blamed for dispersing mealybugs.

8.11 Stage of the Mealybugs and Dispersal

The female mealybugs being wingless and some even legless, are not highly vagile and always have restricted distribution. Adult males and newly emerged first-instar nymphs of most mealybug species display active dispersal. Adult male mealybugs are winged. First-instar nymphs (crawlers) have been found to possess numerous characteristics that are considered as adaptations for dispersal behaviour, including long legs and antennae. After hatching, crawlers are very active and move to the upper leaves and tips of the plant, and also from one plant to another. They move at a speed of 1.525 in. per minute. Other instars remained immobile for the greater part of their lives, infesting mainly the midrib, lateral veins and growing points of the food plant. Only males of this insect have a winged life stage. First- and second-instar nymphs of *Pseudococcus longispinus* (Targioni-Tozzetti) were found in sticky plate traps erected around a commercial Josephine pear block in Victoria, Australia. Of those trapped, 89 % were first instars and 11 % second instars. Adult males are winged and capable of weak flight, but were caught on only 2 of the 76 days of trapping. It is unlikely that the winged males use the wind to assist them in dispersing to new locations. Numbers of instars found in the traps were positively related ($p < 0.05$) to the wind speed and to the square of the daily maximum temperatures.

8.12 Availability of Host Plant

Most of the mealybug species like *Maconellicoccus hirsutus* (Green), *Paracoccus marginatus, Planococcus citri* (Risso), *Nipaecoccus viridis* (Newstead), *Ferrisia virgata* (Cockerell), *Phenacoccus solenopsis* Tinsley, *Pseudococcus longispinus* and *Planococcus lilacinus* are highly polyphagous and known to attack hundreds of host plants aiding the spread of the mealybugs easily within the country. However, oligophagous cassava mealybug *Phenacoccus manihotti* first reported in 1973 from Congo had become established in the whole cassava belt area by 1986, mainly due to the availability of cassava plants cultivated contiguously over a vast area in Africa.

8.13 Absence of Natural Enemies

There were several outbreaks of mealybugs. Mealybugs are usually well regulated by natural enemies. Absence of natural enemies, particularly in the case of invasive mealybugs, aids in the build-up of mealybugs and their spread rapidly within the country. Most of the mealybugs establish themselves easily in the new area and spread to the adjoining areas, in the absence of naturally occurring predators, parasitoids and pathogens. Presence of natural enemies of *M. hirsutus* has essentially stopped the natural spread of the mealybug from the isolated desert region to other areas of California. In 1999, millions of crawlers were produced per tree subject to an array of methods of transport, including being windblown or mechanically transferred by vehicles, trees, shrub pruning equipment, etc. By reducing the abundance of *M. hirsutus* with the natural enemies, it would appear that many such avenues for dispersal became ineffective. Presently, the spread of *M. hirsutus* is largely limited to the transfer of mealybug life stages on plants that are moved or especially ovisacs or adult females on equipment. The cotton mealybug *Ph. solenopsis* was observed in 2006 and has spread like wildfire covering entire India within a short time. Initially, hardly any parasitism was reported, but the absence of the parasitoid like *Aenasius bombawalei* (later reported) aided in spread of the mealybugs.

8.14 Phoretic Method

Reproductive females of the ant *Acropyga ependana* Snelling participating in the flights are known to carry the mealybug *Rhizoecus colombiensis* (Hambleton) between mandibles indicating vertical transfer of mealybugs with their ant hosts. Mealybugs and other scaled insects are known to cling to other insects like locusts and get dispersed during swarming. In another phoretic method, eggs and nymphs of *Maconellicoccus hirsutus* were being transported by nymphs and adult females of another mealybug, *Ferrisia virgata* (Cockerell), in India.

8.15 Root Mealybugs

Under moist conditions, young root-mealybugs or nymphs are active. They move short distances to adjacent plants. They may crawl from pot to pot via drainage holes. They are slow moving in irrigation water, thereby facilitating the spread. However, their dispersal potential is usually limited. Infestations often begin with the purchase of infested plant material.

8.16 Accidental Introduction

The vine mealybug *Planococcus ficus* (Signoret) is an old world species that was accidentally introduced into California in the early 1990s and then it quickly spread to all major grape-growing areas. The mango mealybug *Rastrococcus invadens* Williams was accidentally introduced in Africa in the early 1980s from South East Asia into Ghana and later spread to most of the African countries, causing severe damage. Since its accidental introduction into the island of Grenada in 1994, *Maconellicoccus hirsutus*, native of South Asia, has been inexorably spreading throughout several Caribbean islands.

9 Damage

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Mealybugs throughout the world cause a variety of economic problems. The most obvious damage is caused by the sucking habits of these insects. The damage caused by the mealybugs is linked to sap intake. Heavy infestations often cause stunting or death of the plant host. At times, mealybugs have toxins and act as vectors of certain viruses detrimental to plant life.

9.1 Feeding Process and Endosymbionts

Mealybugs are phloem feeders. As they feed, they produce a sugary excretion (honeydew) that supports the growth of sooty mould. Mealybugs feed by inserting their stylets through the plant tissue to suck up sap from either phloem or mesophyll, or both. Males terminate their feeding towards the end of the second nymphal stage. Generally, stylet penetration is accomplished by the secretion of solidified saliva that forms a sheath around the stylets. Similarly to other members of the suborder Sternorrhyncha, which includes scale insects, aphids, psyllids and whiteflies, mealybugs consume a diet containing mainly carbohydrates as well as limited amounts of free amino acids and other nitrogen compounds (Franco et al. 2000; Gullan and Martin 2003; Silva and Mexia 1999; Tonkyn and Whitcomb 1987). Thus, except for sucrose hydrolysis, food digestion is hardly necessary. However, organic compounds in phloem sap need to be concentrated before they can be absorbed, and this occurs in the filter chamber, a specialized component of the digestive system, which enables the direct passage of water from the anterior midgut to the Malpighian tubules, thereby concentrating food in the midgut (Terra and Ferreira 2003). The residue of ingested phloem sap, after digestion and assimilation in the insect gut, is released from the anus as a sugar-rich material, the honeydew. Up to 90 % of the ingested sugars may be egested in this way (Mittler and Douglas 2003).

Mealybugs have an obligatory association with prokaryotic endosymbionts, probably because of the suboptimal nutrition furnished by phloem sap, which lacks essential nutrients.

These endosymbionts are believed to be important for the nitrogen and sterol requirements of their hosts and may play a role in resistance to microbial pathogens or in detoxification of plant secondary compounds (Baumann 2005; Gullan and Kosztarab 1997). Within their body cavities, mealybugs have a structure, the bacteriome, which comprises specialized cells, the bacteriocytes, which harbour the primary endosymbionts, that is, the P-endosymbionts

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(Kono et al. 2008; Thao et al. 2002). The P-endosymbionts have the unusual property of containing prokaryotic secondary endosymbionts, the S-endosymbionts, within their cytoplasm (von Dohlen et al. 2001). During male development, the bacteriome progressively degenerates in the prepupa and pupa, and became almost unrecognizable in the adult male (Kono et al. 2008).

9.1.1 Host Plants

The various species of plants and animals have characteristic climatic requirements for growth, survival and reproduction, requirements that limit their geographic distribution, abundance and interactions with other species (Gutierrez et al. 1993). Mealybugs feed on a variety of herbaceous and woody plants, including the angiosperm, gymnosperm and fern families. However, most of the species with known hosts develop on herbaceous plants, especially grasses (Poaceae) and composites (Asteraceae) (Ben-Dov 2006; Kosztarab and Kozár 1988). As expected, information on the host ranges of mealybugs is mainly derived from observations of species of economic importance. Most species are apparently oligophagous or stenophagous or monophagous, and some are polyphagous (Ben-Dov 2006; Kosztarab and Kozár 1988). However, such a characterization is problematic. Most of the economically important species are known to be associated with long lists of hosts, and their performance varies widely, ranging from development of high population density, which eventually would kill the host plant, to poor development that renders the survival of the population for several generations questionable. Plant growth conditions may strongly affect the success of the population: under irrigation and fertilization, plant species become favourable hosts of mealybugs, whereas in different environments the performance is usually poor. During laboratory studies, many of the mealybug pest species could be easily reared on alternative hosts, such as potato sprouts or squashes, which are not colonized by mealybugs in the field. For example, the citrus mealybug has been found on plants from 70 botanical families, 60 % of which are characterized as non-woody plants, whereas on the international scale, this mealybug is a pest of subtropical and tropical crops, such as citrus, persimmon, banana and custard apple, or it damages various types of plant species in interior landscapes, greenhouses in particular. Another example of the apparent contradiction between the long lists of host plants and the narrow ranges of damaged crops is the case of *Pseudococcus cryptus* Hempel; although this mealybug is known from 35 host plant families (Ben-Dov 2006), in Israel it causes damage only to citrus trees. Under low pressure of natural enemies, for example, when they spread in new environments, mealybugs are observed on relatively large numbers of host plants, in contrast with the situation when there is effective biological control.

9.1.1.1 Direct Damage

Mealybugs are phloem feeders that use long, slender mouthparts to suck out plant fluids. Most of the mealybugs can feed on the trunk, stem, leaves, flowers or fruits, and some on roots. However, differences in the amount of damage caused by each species are often related to those factors that determine population size (e.g., number of annual generations and female fecundity), preferred feeding locations and temperature tolerances. As the mealybugs feed, they excrete carbohydrate-rich honeydew, which can accumulate on the leaves and in the grape clusters, especially in late summer and early fall. The mealybug ‘flicks’ honeydew away from its location, but it still accumulates on the plant. It has long been noted that honeydew serves as a substrate for the development of sooty mould fungi that can result in further plant damage. For table-fruit growers, any live or dead mealybugs and the honeydew or sooty moulds will cause cosmetic damage to fruit cluster and reduce its marketability. In most dried fruits, juice and wine grapes, the contamination from a small mealybug population, and the resultant honeydew droplets, will not cause economic damage. Although honeydew can be dissolved by light rain and will dry in warm temperatures, when mealybug populations are severe, honeydew can accumulate to form a hard, wax-like layer that covers the infested plant. A copious amount of honeydew gives the bark of the plant a water-soaked appearance.

Feeding damage can result in defoliation and, after repeated annual infestations, cause vine death. There are morpho-histological changes in the plants due to the infestation of mealybugs on plants like ramie (*Boehmeria nivea*), mulberry (*Morus alba*), roselle (*Hibiscus sabdariffa* var. *altissima*) and mesta (*Hibiscus cannabinus*) infested with nymphs of *Maconellicoccus hirsutu*s (Green). Morphologically, linear growth of the stem and petiole was arrested and their thickness was increased. The leaf lamina was markedly reduced and distorted. Histologically, the cells were enlarged and suffered reduced lignification. There was an increase in the number of stomata, which varied in the different plants.

Mealybug (*Rastrococcus invadens* Williams) infestation of fruits caused a significant reduction in weight and size of mango fruits, and also ash content, crude fibre and reducing sugars in Sri Lanka (Tobih et al. 2002).

9.1.1.2 Indirect Damage

In most of the regions, the transmission of viruses, rather than mealybug feeding or contamination, is the primary concern. Several species of mealybugs are vector-virus disease in crops like banana, blackpepper, grapevine, cocoa, pineapple, sugarcane etc. Severe infestations can result in defoliation, cluster infestation and rot, as shown for a *Planococcus ficus* (Signoret) infestation. There is a slight leaf chlorosis and phloem disruption. Grapevine leafroll virus infections impact the berry development and growth by delaying budbreak, flowering and berry maturation, including changes in colour, reduced sugar content and increased acidity in fruit juice. Mealybug toxins are rather important in some areas. The pineapple wilt in the Hawaiian Islands involves the pineapple mealybug, *Dysmicoccus brevipes* (Cockerell), which is a serious economic problem to pineapple. Perhaps one of the most important of these diseases is swollen shoot of cacao, transmitted by several mealybug vectors, including *Planococcoides njalensis* (Laing) and *Ferrisia virgala* (Cockerell). This virus causes excessive damage to cacao trees each year.

9.2 The Origin of Mealybug Pest Status

Similarly to other insect pests, mealybugs have diverse origins, including endemics, immigrants and mutants (Kim 1993). An indigenous species may become a serious pest: when a susceptible crop species is introduced into the area, following environmental disturbance or as a result of stress conditions. Invasive mealybug species may attain pest status as soon as they successfully colonize a new territory, and affect negatively crop yield, which may happen when they encounter a susceptible host, either local or exotic. *Planococcus citri* (Risso) is an introduced pest in most citrus-growing areas of the globe. It may weaken young citrus saplings, but barely affects the growth of fruit-bearing trees; the damage is mainly due to fruit infestation. Two mealybug population trends were shown to occur in citrus orchards in the Mediterranean region (Franco et al. 2004): (1) outbreak dynamics, whereby the percentage of infested fruits (mainly by *Pl. citri*) typically increases exponentially, with maximal values higher than 30 % being recorded during mid- to late summer, and (2) non-outbreak dynamics, whereby the percentage of infested fruits does not increase significantly or, alternatively, exhibits only a small, relatively linear increase, with maximal values lower than 30 %. Three major causes may lead to mealybug outbreaks: (1) a recent invasion by an exotic mealybug species, (2) the application of non-selective pesticides, which disrupt the biological balance, and (3) the effect of environmental factors that might influence the tritrophic interactions among host-plant/mealybug/natural enemies.

These were subdivided by Franco et al. (2004) as follows:

1. Recent invasion by exotic mealybug species
   (a) Lack of control by natural enemies
2. Application of non-selective pesticides
   (a) Mortality differences between pests and their natural enemies
   (b) Indirect effects of pesticides on natural enemies, for example, elimination of their prey
   (c) Effects on predator and parasitoid host interactions
   (d) *Trophobiosis* – positive indirect effects of pesticides on pests, mediated through changes in the host plant
   (e) *Hormoligosis* – positive direct effects of pesticides on pests
   (f) Effects of pesticides on insect behavior
   (g) Effects of pesticides on interspecific competition among phytophagous species of different taxa
3. Effect of environmental factors (tritrophic interactions: host-plant/mealybug/natural enemy)
   (a) Host-plant susceptibility and/or host-plant characteristics
   (b) Water stress
   (c) Nitrogen fertilization
   (d) Weather
   (e) Mealybug defences, for example, encapsulation
   (f) Mealybug refuges from natural enemies
   - Spatial refuge (cryptic behavior), for example, under the bark and on roots
   - Temporal refuge: ant interactions
   - Other factors that may affect natural enemies, for example, intraguild predation and interference, hyperparasitoids

Cause 1 is well documented with regard to mealybug outbreaks and is mainly driven by the combination of host susceptibility and absence of natural enemies in the invaded region (Ben-Dov 1994; Blumberg et al. 1999; Muniappan et al. 2006; Nakahira and Arakawa 2006; Roltsch et al. 2006; Williams and Granara de Willink 1992).

The use of non-selective pesticides (Cause 2) may lead to resurgence and secondary outbreaks. The mechanisms involved in these two types of outbreaks were discussed by Hardin et al. (1995), and studied by Franco et al. (2004) with regard to the mealybug pests of citrus. Environmental factors (Cause 3) may also directly and indirectly affect the tritrophic interactions that develop between mealybugs, their host plants and their natural enemies, thereby initiating mealybug outbreaks. Several mechanisms may be involved. Host-plant characteristics may favour or be detrimental to the development, reproduction and survival of mealybugs (Boavida and Neuenschwander 1995; Calatayud et al. 1994b; Leru and Tertuliano 1993; Nassar 2007; Tertuliano et al. 1993; Wysoki et al. 1977; Yang and Sadof 1995). The resistance mechanisms of the host plant may become involved in both the fixation (antixenosis) and the development of the mealybug (antibiosis) (Tertuliano et al. 1993). Tertuliano and Leru (1992) concluded that the different levels of resistance to the cassava mealybug, *P. manhioti*, which were observed in different varieties of cassava, were not associated with the concentrations of amino acids or sugars, with the ratios between these concentrations, or with the compositions of amino acids obtained from leaf extracts. The identification and assay of cyanogenic and phenolic compounds in the phloem sap of cassava and the honeydew of the cassava mealybug were carried out by Calatayud et al. (1994a). Yang and Sadof (1995) showed that variegation in *Coleus blumei* could increase the abundance of the citrus mealybug, *P. citri*. Sadof et al. (2003) found that the life-history characteristics of *P. citri* on *Coleus blumei* were not correlated with total amino acids and sucrose contents in stem exudates, but were correlated negatively with the proportions of shikimic acid precursors and positively with those of other nonessential amino acids. Host-plant characteristics can also influence the performance of the natural enemies of mealybugs (Serrano and Lapointe 2002; Souissi and Leru 1997; Yang and Sadof 1997). Water-stressed plants may favour the population increases of mealybugs (Calatayud et al. 2002; Gutierrez et al. 1993; Lunderstadt 1998).

Mealybug life-history parameters/damage may also be influenced by the levels of nitrogen fertilization and leaf nitrogen concentration; high nitrogen concentrations were shown to lead to enhanced performance of the citrus mealybug, *P. citri* (Hogendorp et al. 2006). The antibiotic resistance of two varieties of cassava mealybug increased with the addition of nitrogen (Leru et al. 1994). Survival of immature sugarcane mealybugs, *S. sacchari,* increased to a maximum at a soluble nitrogen concentration of 320 mg L^{-1} in sugarcane, and decreased at higher levels, whereas mealybug size increased with increasing nitrogen concentration over the whole tested range (Rae and Jones 1992). Weather conditions, especially temperature and relative humidity, are major ecological factors that affect both mealybugs and their natural enemies (Chong and Oetting 2007; Gutierrez et al. 1993, 2008a; Nakahira and Arakawa 2006). Encapsulation may adversely affect the degree of biological control exerted by mealybug parasitoids, as it may either prevent the establishment of exotic parasitoids in new regions or reduce parasitoid efficacy (Blumberg 1997). The cryptic behavior and tending of mealybugs by ants may, respectively, originate spatial and temporal refuges from natural enemies. Several other factors may affect mealybugs' natural enemies, which include intraguild predation and interference (Chong and Oetting 2007), and hyperparasitoids (Moore and Cross 1992).

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10 Mealybugs as Vectors

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Mealybugs are well-known sap-sucking insects which transmit plant viruses. They are omnipresent, polyphagous, can cause more damage as pests and are less uncommon as virus vectors. The feeding behavior of these vectors has profound ecological and evolutionary implications for the viruses they transmit, as the acquisition and inoculation of viruses occurs during vector feeding. In most cases, there is an intimate relationship between the virus and its vector, and no transmissions occur without the insects feeding in a specific manner. This feeding behavior often causes considerable economic loss to agriculture through direct damage to crops and via virus transmission (Golino et al. 2002; Miiler et al. 2002). They are considered pests as they feed on the plant juices of economically important crop plants, and also act as vectors for several plant viral diseases. The transmission of the plant virus species belonging to *Caulimoviridae* and *Closteroviridae* by different species of mealybugs is furnished in detail in this chapter.

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10.1 Feeding Behaviour of Mealybugs

Mealybugs are found in moist and warm climates. They are less mobile on plants than other groups of vectors, such as aphids and leaf hoppers, a feature that makes them relatively inefficient as virus vectors. They spread from one plant to another when in contact with them, and crawling nymphs move more readily than adults. Adult females can be extremely polyphagous and feed by sucking on plant sap. The stylet pathway to the phloem is intercellular and contains several intracellular punctures (Calatayud et al. 1994). These bugs have less control over fine stylet movements than aphids and produce fewer (8–20/h) and longer intracellular punctures (20 s) along the entire route to the phloem (Calatayud et al. 1994; Cid and Fereres 2010). Mealybugs rarely produce brief probes; they often reach the phloem after a single probe, and it takes a relatively long time to reach the phloem. Some mealy bugs are unable to tap into the phloem sieve elements even after a period of 20 h, but most are able to reach the phloem in 1–6 h (Calatayud et al. 1994; Cid and Fereres 2010). Mealybug stylets are exceedingly long and are coiled within their body when they are not feeding.

This unique morphology of their mouth may explain the propensity of mealybugs to make a single stylet insertion and their inability to reach the phloem quickly, as is seen with other hemipterans. Once in the phloem, the mealybugs

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may continue to feed from the same sieve tube for several days. Xylem ingestion is also a predominant feeding behavior for some mealybug species (Calatayud et al. 1994; Cid and Fereres 2010).

10.2 Types of Transmission

Mealybugs are phloem feeders, and a minimum inoculation time of 15 min is needed for successful transmission. The virus persists through the moult, and for 2–3 days in starved or feeding vectors. All mealybug-transmitted viruses appear to have a semi-persistent mode of transmission based on retention times; however, the Grapevine leafroll-associated virus 3 (GLRaV-3) was found in the salivary glands of its mealybug vector, suggesting a circulative mode of transmission (Cid et al. 2007). Mealybug-transmitted viruses appear to have a high rate of acquisition and a low rate of inoculation (Cid and Fereres 2010). Ants that tend to carry the mealybugs may move them from one plant to another (Sether et al. 1998), and occasionally, long-distance dispersal by wind may also occur. An important factor contributing to the slow rate of spread is that newly infected trees are not infective for some weeks, or even months, and the virus may not become fully systemic in large trees for at least 1 year. Temperature-mediated mealybug activity may be an important variable in transmission efficiency, and the virus spread can occur through the airborne dispersal of young, GLRaV-3-infected crawlers (Cabaleiro and Segura 1997). Cacao swollen shoot virus (CSSV) is transmitted in a semi-persistent mode, meaning that the virus is taken up into the vector's circulatory system but does not replicate within it (Dzahini-Obiatey et al. 2010). The feeding period required for the acquisition of the virus is a minimum of 20 min, but optimally 2–4 days (Posnette and Robertson 1950). Once acquired, the virus can be transmitted within 15 min, but optimal transmission occurs 2–10 h after acquisition. No transmission of the virus occurs through the mealybug eggs. The relationship between the CSSV and mealybugs has some similarities to the non- persistent aphid transmitted viruses; apparently, the virus is carried on or near the stylets of the mealybug.

10.3 Plant Viruses Transmitted by Mealybugs

10.3.1 Viruses of Caulimoviridae

Nineteen species of mealybugs belonging to 13 genera are known to occur on Musaceae (Watson and Kubiriba 2005). The *Banana streak virus* (BSVs) (Fig. 10.1a) is transmitted by *Planococcus citri* (Risso) and *Saccharicoccus sacchari* (Cockerell), both of which colonize bananas (Lockhart et al. 1992). *Sugarcane bacilliform virus* (SCBV) is serologically related to BSVs (Lockhart and Autrey 1988), and is reported to be transmitted from sugarcane to banana by *Saccharicoccus sacchari* (Cockerell) (Lockhart and Olszewski 1993). Experimental transmission of BSV's has also been demonstrated with the pink pineapple mealybug *Dysmicoccus brevipes* (Cockerell) (Kubiriba et al. 2001) and *Pseudococcus comstocki* (Kuwana) (Su 1998). *Ferrisia virgata* (striped mealybug) (Fig. 10.1b) has been found to be able to transmit the *Banana streak Mysore Virus* (BSMYV) from banana to banana (Selvarajan et al. 2006). Meyer et al. (2008) reported that the transmission of activated episomal *Banana streak* OL *virus* (BSOLV) to cv. Williams banana (*Musa* sp.) by three mealy bug species, viz. *Dysmicoccus brevipes, Planococcus citri* and *P. ficus.*

Planococcus citri transmitted episomal BSOLV and the *Banana streak* GF *virus* (BSGFV) from tissue-culture derived plants of FHIA-4 to cv. Williams plants. Using FHIA-TC 10 as the donor plant for transmission, the vector transmitted a 100 % episomal BSOLV to Williams's plants after 3 months, and the numbers of mealybugs feeding on individual recipient plants during the inoculation access period (IAP) ranged from 2 to 25 (Meyer et al. 2008). Episomal BSVs were transmitted by *D. brevipes*. At 3 months post transmission, the virus was detected and symptoms had appeared. Due to the reluctance of the mealybugs to move to Musa spp.,

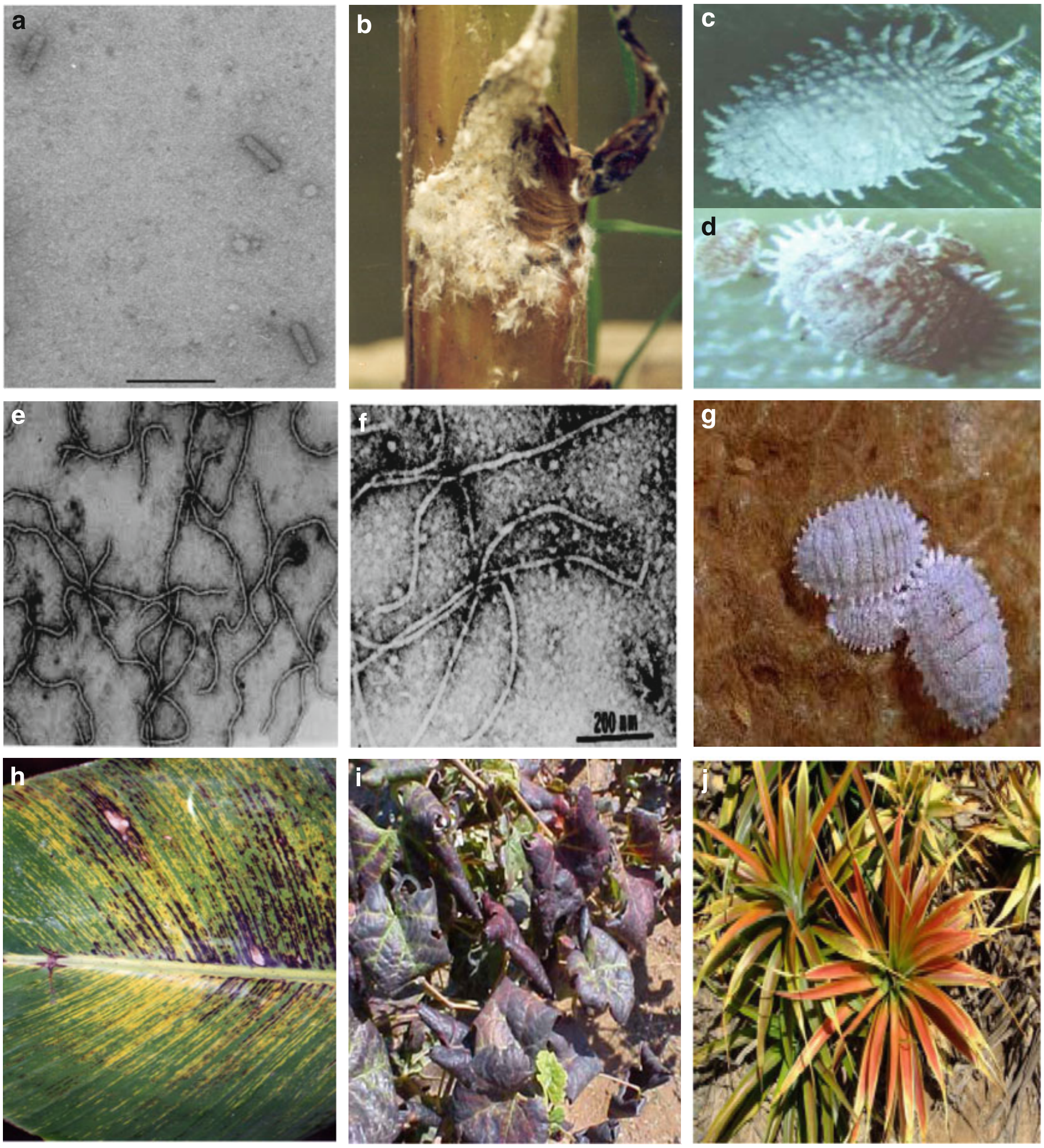

Fig. 10.1 (**a**) Electron micrograph of BSV; (**b**) *Ferrisia virgata* feeding on banana; (**c**) Pink pineapple mealybug, *Dysmicoccus brevipes*; (**d**) Gray pineapple mealybug, *D. neobrevipes*; (**e**) Electron micrograph of GLRaV; (**f**) Electron micrograph of GVB; (**g**) Vine mealybug; (**h**) Symptoms of BSV in banana; (**i**) GLRaV infected grapevine; (**j**) Symptoms of mealybug wilt of pineapple

the low numbers survived the inoculation access period; the virus was transmitted from the TC-5 to the William banana. However, no episomal BSGFV could be transmitted by *D. brevipes* from the FH-4 donor to the recipient plants (Meyer et al. 2008). The fact that none of the mealybug species were able to transmit integrated BSOLV from the FHIA-4 to Williams proves that the integrated form of BSV is not likely to be transmitted by mealybugs; even highly efficient mealybugs such as *P. citri* were unable to transfer any integrated viral sequences to the receptor plants. Episomal BSV in tissue culture-derived tetraploids is highly transmissible by efficient mealybug vectors to Cavendish varieties.

Cocoa swollen shoot virus (CSSV), a badnavirus, is transmitted by at least 14 species of mealybugs of the family *Pseudococcidae* within the *Coccoidae* (Roivainen 1976), but *Planococcoides njalensis* and *Planococcus citri* are the most important vectors (Dongo and Orisajo 2007). *Piper Yellow Mottle Virus* (PYMV) is transmitted by the citrus mealybug, *Planococcus citri* (Lockhart et al. 1997). Bhat et al. (2003) reported that PYMV could easily be transmitted by the mealybugs (*Ferrisia virgata*) from naturally diseased black pepper to healthy seedlings of black pepper. The initial symptoms of the disease, like vein clearing and chlorotic mottle, could be seen in 14 of the 20 test plants in 5 weeks after inoculation. Macanawai et al. (2005) reported that the *Taro bacilliform virus* (TaBV) is transmitted by *Pseudococcus solomonensis.*

10.4 Viruses Belonging to Closteroviridae

Mealybug-vectored viruses often exist as a complex of viruses, such as the mealybug wilt of pineapple complex, which is made up of three pineapple mealybug wilt-associated viruses (PMWaV) (Sether et al. 1998, 2005; Sether and Hu 2002a, b) and Grapevine leafroll-associated viruses. Mealybug wilt of pineapple is a major constraint in the global production of pineapple (Carter 1934, 1942; Rohrbach et al. 1988; Wakman et al. 1995). Carter (1934, 1942, 1949, 1962) found an association between mealybugs, particularly the pink pineapple mealybug, *Dysmicoccus brevipes* (Cockerell), (Fig. 10.1c) and the gray pineapple mealybug, *D. neobrevipes* (Beardsley) (Fig. 10.1d), and wilt throughout the pineapple-growing regions of the world. PMWaV-1 infections are correlated with growth reductions of the plant crop (Sether and Hu 1998), and yield reductions in the ratoon crop. PMWaV-2 infection and mealybug feeding are necessary for the development of mealybug wilt disease (Hu and Sether 1999a, b; Sether and Hu 2002a, b). All pineapple plants with wilt disease have PMWaV-2 infections, but not necessarily PMWaV-1 infections (Hu et al. 1997; Sether and Hu 2002a). Several species of ants are associated with mealybugs (Beardsley et al. 1982; Carter 1963). These ants assist in the establishment of mealybug colonies, consuming the honeydew produced by the mealybugs (Petty and Tustin 1993), and can have a suppressive effect on the natural enemies of mealybugs (Jahn 1992). Sether et al. (1998) reported that presence of ants was correlated with an increased rate of virus spread when caged with *D. brevipes*. All stages of *D. neobrevipes* acquire PMWaV, although vector efficiency decreased significantly in older adult females; the probability of a single third-instar immature transmitting the virus was 0.04. Both the species of the mealybugs acquired and transmitted the PMWaV from infected pineapple material.

The Grapevine leafroll disease is caused by grapevine leafroll-associated viruses (GLRaVs) (Fig. 10.1e). These viruses are common in vineyards worldwide, and are often associated with vitiviruses that are involved in the rugose wood complex of grapevines. Ten mealybug species are known as vectors of one or several of these grapevine viruses, including the apple mealybug *Phenacoccus aceris*, which is widespread, and is able to transmit the Grapevine leafroll-associated virus-1 and -3 (GLRaV-1 and -3). Vitiviruses, namely *Grapevine virus A* (GVA), *Grapevine virus B* (GVB) (Fig. 10.1f), *Grapevine virus D* (GVD) and *Grapevine virus E* (GVD), infect grape vines, and these are transmitted by the members of several insect genera (*Pseudococcus, Planococcus, Phenacoccus, Heliococcus, Neopulvinaria, Parthenolecanium, Cavariella* and *Ovatus*) in a semi-persistent manner (La Notte et al. 1997; Rosciglione et al. 1983; Garau et al. 1995). Tsai et al. (2010; Le Maguet et al. 2012) studied the virus–vector specificity analysis for mealybug transmission of GLRaVs. Plants infected with several GLRaVs virus species were screened for vector transmission by the mealybug

Table 10.1 Mealybug transmitted plant viruses

Virus, genus and family	Vector species	Mode of transmission	Reference
Banana streak virus sps, *Badnavirus*, *Caulimoviridae*	*Dysmicoccus brevipes, Planococcus citri, Pl. ficus, Pseudococcus longispinus, Ferrisia virgata*	Semi-persistent	Meyer et al. (2008), Kubiriba et al. (2001), Selvarajan et al. (2006)
Sugarcane bacilliform virus sp. Badnavirus, *Caulimoviridae*	*Saccharicoccus sacchari*	Semi-persistent	Lockhart et al. (1997)
Piper yellow mottle virus; Badnavirus, Caulimoviridae	*Planococcus citri*	Semi-persistent	Lockhart et al. (1997), Bhat et al. (2003)
	Pseudococcus elisae		
	F. virgata		
Taro bacilliform Badnavirus, Caulimoviridae	*Pseudococcus solomonensis*	Semi-persistent	Macanawai et al. (2005)
Schefflera ringspot virus (SRV)	*Planococcus citri*	Semi-persistent	Lockhart and Olszewski (1996)
Cacoa swollen shoot virus, Badnavirus, Caulimoviridae	*Planococcoides njalensis, Pl. citri, F. virgata*	Semi persistent	Roivainen (1976)
Pineapple mealybug wilt associated virus-1–3; *Closterovirus*; *Closteroviridae*	*Dysmicoccus brevipes* (Cockerell)	Semi-persistent	Sether et al. (1998)
	D. neobrevipes		
GLRaV-1, 3–9; *Ampelovirus, Closteroviridae*	*Heliococcus bohemicus, Phenacoccus aceris* Signoret, *Planococcus ficus Pseudococcus longispinus, Pseudococcus viburni, Pseudococcus calceolariae, Pseudococcus maritimus, Pl. citri*	Semi-persistent	Tsai et al. (2012)
Grapevine virus A, B, D and *E, Vitivirus, Betaflexiviridae,*	*Pseudococcus, Planococcus, Phenacoccus, Heliococcus*	Semi-persistent	Garau et al. (1995), Le Maguet et al. (2012)
Little Cherry Virus 2 Closterovirus, Closteroviridae	*Phenacoccus aceris*	Semi-persistent	Raine et al. (1986)

species *Planococcus ficus* and *Pseudococoucus longispinus*. The results revealed that *P. longispinus* had transmitted the GLRaV-9 to the inoculated plants, and showed that 18 % of the inoculated plats were positive for GLRaV-9, but none of the inoculated plants were found positive for GLRaV-5, tested 9 months after the inoculation. *Planococcus ficus* transmitted the GLRaV-1,3,4,5,9 and GVA. This study showed that there was no evidence of mealybug–GLRaV specificity. Tsai et al. (2008) reported that the vine mealybug (*Planococcus ficus*) (Fig. 10.1g) transmits GLRaV- 3 in a semi-persistent manner. First instars were more efficient vectors than adult mealybugs, but the GLRaV-3 transmission lacked a latent period in the vector. Virus transmission occurred with a 1-h acquisition access period (AAP) and peaked with a 24-h AAP, after which the transmission rate remained constant. In addition, the GLRaV-3 was found not to have been transovarially transmitted from infected females to their progeny (Table 10.1).

Mealybugs are less mobile on the plant compared with groups of vectors such as aphids and leaf hoppers, a feature that makes them relatively inefficient as virus vectors. Mostly, the mealybug-transmitted viruses appear to have a semi-persistent mode of transmission based on retention times. Mealybug-transmitted viruses appear to have a high rate of acquisition and low rate of inoculation. Mealybug-vectored viruses often exist as a complex of viruses, such as the mealybug-associated viruses. Badnaviruses such as PYMV, BSV's TaBV and CSSV have been shown to transmit by different mealybug species. In all of these studies, the interaction of the mealybug vector with the virus and the host is lacking; hence it is necessary to generate fundamental knowledge about the interaction of the vector, the host and the virus system to develop effective disease management strategies for viral diseases. Epidemiological studies are also required to predict the spread of the plant viruses through mealybugs, and the changing climatic conditions need to be considered while developing forecasting models of disease spread.

10.5 Loss Due to Mealybug-Transmitted Virus Diseases

Comprehensive analysis of yield loss due to mealybug infection has not been carried out in many of the crops, however, the infection of mealybug-transmitted viruses leads to drastic yield losses have been reported. Estimated yield losses of between 7 % and 90 % have been attributed to the banana streak disease in different parts of the world (Harper et al. 2004; Lockhart et al. 1998; Davis et al. 2000; Daniells et al. 2001). In India, a yield loss of 49.48 % has been recorded in cv. Poovan (Mysore, AAB) due to BSV (Fig. 10.1h) (Thangavelu et al. 2000). In banana, the yield loss due to BSV is influenced by the cultivar, the virus species infecting, and environmental conditions. Grapevine leafroll disease occurs in all the major grape-growing regions of the world, causing reductions in productivity and quality of both wine and table grapes.

Infected grapevines (Fig. 10.1i) result in reduced berry yields, delayed maturity and poor pigmentation. Estimated yield losses of as much as 30–40 % due to Grapevine leafroll disease has been recorded (Maree et al. 2013). In addition, the disease agent has been implicated in certain types of graft incompatibility and young vine failure. Cacao swollen-shoot virus (CSSV) infects cacao trees and has a major effect on crop yields. Within 1 year of infection by CSSV, the yield decreases by 25 % and by 50 % within 2 years. The infected trees are usually killed within 3–4 years (Fig. 10.1j) (Crowdy and Posnette 1947). The impact of mealybug feeding and Pineapple mealybug wilt associated virus-1 (PMWaV-1), PMWaV-2 infection on pineapple yield and the spread of PMWaV-1 and mealybug wilt of pineapple (MWP) were evaluated under field conditions; the results showed a 35 % reduction in yield when compared with PMWaV-free plants (Sether and Hu 2002b). If MWP develops during the first 3 months of the plant crop, it can lead to a 55 % reduction in average fruit weight, compared with fruits from PMWaV-free plants.

10.6 Management

The best way to manage the virus diseases transmitted by mealybugs is to ensure that purchase of planting material is from virus-tested and virus-free mother plants, and the control of vectors – mealybugs.

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11 Economic Importance

M. Mani and C. Shivaraju

Mealybugs are widely distributed phytophagous insects, often with broad host ranges. There are approximately 2000 described mealybug species worldwide. According to Millar et al. (2002), 158 species of mealybugs are recognized as pests. Mealybug is a pest, which can have a considerable negative economic impact on a wide range of crops and ornamentals. In the last 30 years, there have been several major outbreaks of mealybugs causing alarming damage to crops, as a result of invasion/accidental introductions. Losses and costs of controlling mealybugs in Georgia (USA) in 1996 were estimated at about \$9.8 million. Damage and costs of controlling the pink hibiscus mealybug in the United States were recently estimated at \$700 million annually. In South Africa, costs for control of vine mealybug in vineyards were estimated at around \$100 per hectare per season. Most notorious mealybug species are polyphagous, and have become serious pests of different crops under different environments.

Economic damage can happen in four ways:

1. A high population of mealybug can lead to fruit, flower/leaf drop, fruit/flower deformation ('high shoulders') and development of discoloured welts on the rind of the fruit, flower, etc.
2. Mealybugs excrete copious quantities of honeydew, which is a substrate for the fungus, sooty mould. Sooty mould is black in colour and may stain the fruit/flower decreasing the packout percentage as well as causing a delay in fruit colour development. Photosynthetic potential, especially of young trees, may be negatively affected if sooty mould infection is severe.
3. Mealybug is a phytosanitary pest in some export markets (USA, Japan) and if found on fruit/flower destined for these markets can result in rejection of the consignment and could place these important markets at risk for the future.
4. Mealybugs act as vectors of plant virus disease causing heavy losses. Several mealybugs are responsible for transmission of Grapevine-leafroll-associated virus (GLRaV), and the virus infection was predicted to spread with the economic impact of Grapevine-leafroll-associated virus-3 (GLRaV-3) infection exceeding 10,000 dollars per ha, annually in South Africa.

Mealybugs spread between continents through international trade. In the United States, there are 350 species of mealybugs. Approximately 70 % of the 66 mealybug species that are considered as

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pests are invasive. Invasive mealybugs in California are serious pests of several economically important crops. There are several other mealybugs that reveal the extent of damage and economic losses. In New Zealand, most of the known 114 species of mealybugs are found only on native plants. Three cosmopolitan and invasive *Pseudococcus* species are frequently occurring pests of horticultural crops in the country, where they account for more than 99 % of the mealybug fauna in orchards and vineyards (Charles 1993). In France, scale insects, including mealybugs, represent 31 % (Streito and Martinez 2005) of the newly introduced species in recent years, although all mealybug pests on grapevine are native (Sforza 2008). Likewise, in many countries, there were serious economic losses caused by mealybugs.

Rhodesgrass mealybug, *Antonina graminis* (Maskell), has been a major pest of many pasture grasses and lawns, and to some extent on bamboos in various parts of the world. It had completely destroyed thousands of acres of good pasture land. Injury is first indicated by the stunting and reduction in the overall size of individual grass clumps, with darkening of the leaves and eventual death of the host plant. Death of seedling plants is known to occur in about 3 weeks. Conventional control is difficult because of the position of the mealybug on its host. The success in controlling this mealybug in Texas is by the introduction of the parasitoid *Neodusmetia sangwani* (Subba Rao) from India (Dean et al. 1979). The cost of the control programme was estimated at that time at $0.2 million, resulting in the savings of about US$200 dollars per annum. Subsequently, colonies of the parasitoid have been sent elsewhere in the New World. Heavy infestations of the mealybug *Antonina pretiosa* (Ferris) produce unsightly condition of the bamboo (McKenzie 1967). *Brevennia rehi* (Lindinger) is an important pest of rice in India, Pakistan, Burma, Indonesia, Bangladesh and some other countries causing severe loss of the crop especially in the dry seasons. Grains from mealybug-infested plants did not develop properly and that they tasted bitter, and if present in normal food, they spoilt the flavour after being cooked. It is also known to transmit the virus known as cholorotic streak (Williams 2004). *Birendracoccus saccharifolii* (Green) is a major pest of sugarcane in India and a vector of spike disease (Ali 1962). *Coccidohystrix insolita* (Green) has been a serious pest of brinjal, egg plant/aubergine, in Bihar, West Bengal, Tamil Nadu, Kerala and several other states in India (Williams 2004). Economic damage by mealybugs on brinjal was reported in Pakistan and also in other Asian countries (Arif et al. 2009).

Dysmicoccus boninsis (Kuwana) is a widespread pest of sugarcane causing economic damage (Ben-Dov 1994). *Dysmicoccus brevipes* (Cockerell) is a well-known pest of pineapples worldwide and also coffee. It acts as vector of pineapple wilt in Hawaii and several other countries. It is one of the principal pests of mango in Okinawa. *D. brevipe*s was reported on oilpalm-infesting leaves, inflorescence and ripe fruit bunches in India (Ponnamma 1999). *Dysmicoccus neobrevipes* (Beardsley) is common in Hawaii and also in southern Asia. It has caused severe loss to tube rose growers in India. *Dysmicoccus grassii* (Leonardi) has been reported as a pest of banana in Canary Islands (Beardsley 1964a, b) and heavy infestations on plantain in Nigeria. *Ehrhornia cupressi* (Ehrhorn) is a serious pest, which caused the destruction of cypress hedges in California (Herbert 1920).

Gilli mealybug *Ferrisia gilli* (Gullan) is the primary pest of pistachio covering over 3000 acres of pistachios in California. It is also known to attack and cause huge losses to a wide range of crops such as almonds, grapes, stone fruits.

The striped mealybug *Ferrisia virgata* (Cockrell) has been of some concern to several countries. In the past few years, however, heavy infestations were noticed on many ornamental plants. This has caused some alarm as this species is reported as an important pest, especially to cotton. It is found normally above ground on the foliage where it causes the usual honeydew-sooty mould-type damage. During severe weather conditions, in Africa at least, it may move to the crown and roots of its host. This mealybug is found on a wide range of hosts. It caused economic losses to citrus, guava, custard apple, mango, cotton, pomegranate, pummelo, tuberose, pepper, jackfruit, poinsettia, Acalypha, Caesalpinia, etc. in India (Mani and Krishnamoorthy 1993), as well as pepper in India and jute in Bangladesh. *Formicococcus robustus* (Ezzat and McConnell) is only known from the Indian region but it is sometimes intercepted at port inspection elsewhere. Although a polyphagous species, it is frequently found on mango, and in Pakistan it is reported as a serious pest. *Kiritshenkella sacchari* (Green) is known to cause severe loss to sugarcane growers in India.

Another example that indicates the high economic importance of a polyphagous mealybug is the pink hibiscus mealybug, *Maconellicoccus hirsutus* (Green). This mealybug is indigenous to southern Asia, and actually is considered a potentially serious pest in the United States, because of its extremely broad range of economically important hosts, including citrus, ornamentals, vegetables and the native American flora. It was first reported in the Western Hemisphere in Hawaii in 1984, and later in Grenada in 1994; subsequently it has spread rapidly through the Caribbean islands and to southern California (1999) and Florida (2002). Without control, the economic impact of *M. hirsutus* to U.S. agriculture has been estimated at $750 million per year (Hall et al. 2008). The same pink hibiscus mealybug was introduced accidentally to the Caribbean area in 1993–94, and has since spread beyond, eventually reaching the United States. This damaging species was rapidly identified by taxonomists such as *Maconellicoccus hirsutus* (Green); its biological control was described in detail by Kairo et al. (2000), with discussion of the costs and benefits. *M. hirsutus* is widely distributed throughout southern Asia, Africa and other parts of the Old World including Australia. *M. hirsutus* is reported as a vector of virus disease on cocoa in Zanzibar and other plants in East Africa, which causes growth arrest and branch distortion (De Lotto 1967). *Maconellicoccus hirsutus* gets ranked as one of the most important polyphagous mealybugs in southern Asia, especially in India still causing damage in parts of India (Mani et al. 2011). The pink hibiscus mealybug is a major pest of grapevine in peninsular India causing up to 100 % loss in grapevine and mulberry. It is also known to attack other crop plants, guava, pomegranate, custard apple, acid lime, Phalsa, hibiscus, ber, sapota, okra, etc. in different countries. Introduced natural enemies, mainly the parasitoid *Anagyrus kamali* (Moursi) (already known in the Old World) and *Gyranusoidea indica* (Shafee, Alam and Agarwal) and the predator *Cryptolaemus montrouzieri* (Mulsant), have brought the mealybug under control in Egypt, West Indies, the United States, etc. *Maconelicoccus hirsutus* was detected in teak plantations in 2004 in the Banderas valley in Mexico. A biological control programme was initiated in May 2004 to release 210,000 of the predator *Cryptolaemus montrouzieri* on 150 ha of land. Damage to trees was reduced by 92 % (Villa Castillo 2006). *Mizococcus sacchari* (Takshashi) was very injurious to sugarcane in Taiwan (Takahashi 1928). Its presence in European and Mediterranean Plant Protection Organization (EPPO) countries would probably affect export markets, since it is regulated as a quarantine pest by many countries in other continents.

Nipaecoccus viridis (Maskell) is widespread throughout tropics and subtropics causing economic losses to numerous crop plants including citrus, pomegranate, guava, grapes, ber, jackfruit, mango, custard apple and pummelo in several counties. In India, it is a pest of stored potatoes. Cotton is often attacked, when gall-like swellings appear on terminal shoots, and tea is often heavily infested. On *Artocarpus* spp., large aggregations of the mealybug lead to drying of the shoots. In South Africa, *N. viridis* is a major pest of citrus, and in Okinawa it is one of the principal pests of mango. When first introduced into Jordan in 1993, apparently without natural enemies, infestations sometimes resulted in total loss of the citrus crop. In Egypt, a severe outbreak of *N. viridis* occurred on lebbak trees. *Niapecoccus nipae* (Makell) has become serious pest of avocado and guava in Hawaii (Zimmerman 1948) and Puerto Rico (Martorell 1940). The species is now controlled successfully in Hawaii by the parasitoid *Pseudophycus uitilis* (Timberlake). *Nipaecoccus nipae* was also known to cause serious damage to coconut in Bermuda (Bennet and Hughes 1959).

Palmicultor palmarum (Ehrhorn) is reported to infest 5 % of coconut palms in Bangladesh and India. The species attacks the spear leaves of oil palm in India. It sometimes occurs deep in the fibrous material covering palm stems, where it is difficult for chemical insecticides to penetrate. *Paracoccus marginatus* (Williams and Granara de Willink) causes serious economic losses to the tune of several crores of rupees to more than 90 plant species particularly to the papaya, tapioca and mulberry damage in more than 53 countries including India. *Paracoccus marginatus* has become a serious pest in the Caribbean islands, where it attacks numerous plant species, especially papaya. The mealybug has now reached the southern United States. The mealybug reached Guam and Palau on *C. papaya*; these islands are possible sources for future incursions into the Pacific area and southern Asia. Biological control of *Pa. marginatus* with *Acerophagus papayae* (Noyes and Schauff) saved the silk, papaya and tapioca industry from the loss worth to 2000 crores rupees in India alone (Mani and Shivaraju 2012). Similar economic benefits were realized in several other countries. Hatting (1993) reported *Paracoccus burnerae* (Brain) as the most important pest on citrus in South Africa.

Phenacoccus aceris (Signoret) has become a serious threat to apple, pear, plum and other fruit trees in Miane, British Columbia, Nova Scotia, California and South Africa. The parasitoid *Allotropa utilis* (Muesbeck) was introduced to British Columbia where it became well established. This was considered one of the outstanding successes of classical biological control. *Phenacoccus gossypii* (Townsend and Cockerell) is widely distributed in many countries. It is a pest of numerous flowering plants in nurseries and greenhouses, and in natural environments. This mealybug, which is most often found on the foliage of its host, apparently causes as much damage to its host plants. *Phenacoccus solani* (Ferris) has probably been introduced recently and is now established in southern Asia. There are reports that it is a pest of stored potatoes in North America, and heavy infestations have been found on tobacco in Zimbabwe. Presence of *Phenacoccus graminicola* (Leonardi) under the calyxes of apple and pears grown for export has caused concern in Australia and New Zealand (Ward 1966). *Phenacoccus madeirensis* (Green) is a common polyphagous mealybug in much of the New World, Africa and the Pacific region. This mealybug is injurious to potatoes (*Solanum tuberosum*) in Peru, and the growth of associated sooty moulds causes malformation and damage to leaves of other plants in Japan, where it has been reported recently. It has invaded India recently and found to be severe on tapioca.

Phenacoccus manihoti (Matile-Ferrero) appeared on cassava in Africa in 1973, and soon spread throughout the whole cassava belt. The introduction of the parasitoid *Apoanagyrus lopezi* (De Santis) from South America to Africa and the success of the biological control programme against *P. manihoti* had been well documented by Herren and Neuenschwander (1991). The tremendous success is credited with preventing the malnutrition of millions of Africans and may well be the most important example of classical biological control ever. Zeddies et al. (2001) calculated the total costs and benefits of this biological control programme for 27 African countries over a 40-year period (1974–2013) under different scenarios, such as transport, loss of crop and even the price of maize as a possible substitute. Based on the total cost of biological control at US$ 47 million, the benefits from different scenarios range mainly from 199:1 (or US$ 9.4 billion) to 430:1 (or US$ 202 billion). Although the initial cost of identification of the mealybug was negligible, there was a taxonomic advantage in that the costs included funds set aside for a study of the mealybugs of Central and South America by Williams and Granara de Willink (1992). *Phenacoccus manihoti* remains a threat to the cassava in the areas of southern Asia, as does the yellow cassava mealybug, *P. herreni*, which still causes problems in South America. Reduction of *P. herreni* populations is under way, mainly through the introduction of the parasitoids *Apoanagyrus diversicomis* (Howard) and *Acerophagus coccois* (Smith) (Bento et al. 1999). The most trenchant point concerning the parthenogenetic species *P. manihoti* is that an outbreak could occur in southern Asia with the accidental introduction of just a single immature specimen.

Phenacoccus solani (Ferris) and *Ph. solenopsis* (Tinsley) are examples of invasive pests of annual crops; they cause heavy damage to green pepper in Israel and cotton in the Indian subcontinent (Ben-Dov 2005; Hodgson et al. 2008; Nakahira and Arakawa 2006). The damage caused by mealybugs is linked to sap uptake, honeydew secretion and associated sooty mould development, toxin injection and virus transmission, although the presence of the insects may itself lead to economic losses (Franco et al. 2000; McKenzie 1967; Panis 1969). The cotton mealybug, *Phenacoccus solenopsis*, native of the United States (New Mexico) invaded several countries – Central America, the Caribbean and Ecuador (Argentina, Brazil, Ghana, Colombia, Nigeria, Asia (Pakistan, India and China)). It is a major pest posing a severe threat to the cotton crop in India and vegetable growing areas of Thailand and several ornamental plants in many countries. This mealybug caused economic damage in India and Pakistan reducing the yields up to 4–50 %. *Phenacoccus solenopsis* caused a loss of several lakhs of rupees to cotton growers in India alone. *Phenacoccus gossypii* (Townsend and Cockerell) is widely distributed in many countries. It is a pest of numerous flowering plants in nurseries and greenhouses, and in natural environments. This mealybug, which is most often found on the foliage of its host, apparently causes as much damage to its host as the citrus mealybug, *Planococcus citri* (Risso). Heavy infestations of *Ph. solani* have been recorded on tobacco in Zimbabwe.

Phenacoccus saccharifolii (Green) is known to attack sugarcane in India, Nepal and Pakistan. In Bihar (India), infestation causes leaves and internodes to become drastically reduced so that the cane can resemble a spike. Young sugarcane plants have been severely damaged by this species in West Bengal (India). *Planococcoides nijalensis* (Laing) is the dominant vector of the cocoa swollen shoot virus in African countries. It is also known to attack cashew, Annona, silk cotton, pineapple, Acacia, Albizia, Caesalpinia, Erythrina, coffee, Clerodendron, etc.

Planococcus citri (Risso) is one of the most cosmopolitan mealybugs. It is considered a serious pest of citrus in many parts of the world damaging many other field crops in tropics and subtropics as well as greenhouse in temperate regions. The mealybug is known to attack mainly subtropical fruit trees and also olive under Mediterranean climate conditions and ornamental plants in interior landscapes in cooler zones (Ben-Dov 1994; Franco et al. 2004). The citrus mealybug has become a key pest in the mint and tarragon industry in Israel. This cosmopolitan species was probably the first recorded as pest in southern Asia. Chemical control of this insect is amazingly difficult. *Planococcus citri* is known to cause up to 38– 65 % damage on various citrus species (sweet orange, acid lime and lemon), pummelo, guava, grapes (60 % loss), ber, sapota, pomegranate, custard apple, crossandra, coffee, etc. in India (Manjunath 1986; Mani 2001). Biological control of *P. citri* with natural enemies saved several citrus orchards in India, the United States, Italy, Australia and South Africa. *Planococcus* is also listed as a vector of Ceylon cocoa virus in Sri Lanka and also Grapevine virus (GVA). *Planococcus ficus* (Signoret) is a pest of grapevine in the Mediterranean region, South Africa, Pakistan, Argentina, Georgia and California, causing heavy losses to grape growers. It also transmits the grapevine leafroll virus. *Planococcus kenyae* (Le Pelley) is popularly known as coffee mealybug. It has caused heavy losses to coffee growers in Uganda, Tanzania and Kenya (Bigger 2009).

Planococcus lilacinus (Cockerell) is one of the most common in southern Asia and reports of damage vary. It is known to attack and cause serious economic losses to cocoa, guava, ber, citrus, black pepper, cashew, pomegranate, guava, sapota, coffee, chow chow, mango, etc. (Mani 2001). *Planococcus lilacinus* is known to transmit Ceylon cocoa virus in parts of Sri Lanka. *Planococcus ficus* is a serious pest of grapevine in the Mediterranean region, South Africa, Argentina, Georgia and Pakistan. It is also found transmitting GVA and grape leafroll virus (Ben-Dov 1994; Daane et al. 2006; Zada et al. 2008). *Planococcus minor* (Maskell) is a common species on economically important plats particularly cocoa throughout its geographical range. Trees (*Cupressus* and *Juniferus*) infested with *Planococcus ovae* (Nasonov) suffer from dieback of twigs, heavy accumulation of honey dew and decline of trees in Italy (Ben-Dov 1994). *Planococcus kraunhiae* (Kuwana) is widely spread in California, Taiwan, China, Japan damaging fruit tress such as pears, grapes, persimmons, banana, citrus, figs, etc. *Planococcus minor* Maskell is a common species of many economically important plants including cocoa. *Planococcus ovae* (Nasanov) is widely distributed in Neotropical and Palaearctic regions on Anthurium, Cupress and Juniperus trees. Infested trees suffer from dieback.

Several members of the genus *Pseudococcus*, for example, *Ps. calceolariae* (Maskell), *Ps. longispinus* (Targioni-Tozzetti) and *Ps. viburni* (Signoret), are important pests of apple, pear and vineyards in New Zealand (Charles 1993), whereas around the Mediterranean they are considered mainly as pests of citrus, persimmon and several other subtropical fruits (Franco et al. 2004). *Pseudococcus comstocki* (Kuwana) is a serious pest on apple, mulberry, pears, peach in the United States and Japan. The citriculus mealybug, *Pseudococcus cryptus* (Hempel), is a major pest of citrus in the east Mediterranean region, and it attacks coffee roots in Asia and South America (Ben-Dov 1994; Williams and Granara de Willink 1992). It is widespread and a polyphagous mealybug species and appears to be kept under control by natural enemies in southern Asia. Citrus and coconut are its favourite host plants, and infestations are known to occur on oil palm in India. It is widely distributed in Southeast Asia, Tropical Africa, Middle East Meditrranean and South America. It is particularly a pest of citrus in Israel and the pest was controlled with the introduction of *Clausenia purpurea* (Ishii). *Pseudococcus fragilis* (Brain) was first found in California and rapidly became a serious pest of citrus to the point that it threatened the industry; it also became a serious pest in Abkhazia of USSR.

Pseudococcus longispinus (Targioni Tozzetti) is distributed worldwide. This mealybug is often a pest in greenhouses and nurseries, but is also found out of doors in warmer areas. It has been reported as a pest of avocados, grapes and citrus. Severe infestations have been reported on black pepper in India. The mealybug is a target pest for classical biological control in Australia, and the species has caused damage to avocados in Israel in recent years. It also acts as a vector of grape leafroll virus. The orchid mealybug *Pseudococcus microcirculus* (McKenzie) has caused many problems to orchid growers (McKenzie 1967). It is found primarily on the roots of its host but crawls to the foliage and leaf sheaths when infestations become heavy. The type of damage is the normal form of unsightly contamination with the production of honeydew during heavy infestations. *Pseudococcus maritimus* (Ehrhorn) is another species important primarily to grapes and pears in some countries. The presence of these mealybugs on the ripe marketed grapes results in serious economic loss to the growers. Heavy infestations cause the grapes to crack, allowing mould contamination. *Pseudococcus viburmi* (Signoret) is most common in tropical and temperate areas but it is not widespread in southern Asia. It may have been overlooked, however, owing to its cryptic habit of living on roots. In Australia, it causes damage to lawns and tubers, and is a target species there for classical biological control. It is causing damage to California's coastal vineyards.

Following the introduction of the cassava mealybug into Africa, another introduced mealybug *Rastrococcus invadens* (Williams) appeared in West Africa in 1981–82, causing extensive damage to fruit trees including mango (Williams 1986b). This mealybug was already known from India and Pakistan (Narasimham and Chako 1988). *Rastrococcus invadens* is usually scarce in parts of India because it is controlled by natural enemies. The introduction of the encyrtid *Gyranusoidea tebyi* (Noyes) from India to West Africa, and its swift control of the mealybug there, is hailed as another biological control success (Neuenschwander et al. 1994). *Rastrococcus iceryoides* (Green) is causing serious damage to mango from India, and other fruit trees, and it is also a pest of cotton. At present, it is distributed throughout India and eastwards to Thailand and Malaysia. It has also reached East Africa, where there have been reports of damage in inland parts of Tanzania and Malawi. *Rastrococcus iceryoides* is also known to cause serious damage to Kapok trees in Tanganyika. *Saccharicoccus sacchari* (Cockerell) is distributed wherever sugarcane is grown, particularly Hawaii, Egypt, Somalia, Costa Rica, etc. In southern Asia, it has been rated as one of the most important mealybugs attacking sugarcane, which is the main source of sugar and alcohol. It is also a possible vector of rice diseases in Cuba and India. *Spilococcus mamillariae* (Bouche) is a common pest of ornamental succulent plants.

Trionymus radicicola (Morrison) caused severe damage to sugarcane in Cuba when areas of sugarcane dried out due to heavy population of the mealybug on the roots. *Trionymus townesi* (Beardsley) is also known to attack rice and sorghum. In the Philippines, infested upland rice crops have been reported to show depressed areas; plants in these areas were apparently stunted and yellowish. *Vryburgia rimariae* (Tranfaglia) is a pest of economic importance in greenhouses in Italy.

One of the most common groups of insects attacking ornamental plants is mealybugs. There are about 275 species of mealybugs known to be present in the continental United States. Mealybugs are prevalent pests in greenhouses and interior plantscapes such as shopping malls, conservatories, hotels and office buildings. Mealybugs cost growers and retailers millions of dollars per year in control and crop damage or loss. Damage is caused by mealybugs feeding on host tissues and injecting toxins or plant pathogens into host plants. In addition, mealybugs secrete a waste product, honeydew, which is a syrupy, sugary liquid that falls on the leaves, coating them with a shiny, sticky film. Honeydew serves as a medium for the growth of sooty mould fungus that reduces the plant's photosynthetic abilities and ruins the plant's appearance. Feeding by mealybugs can cause premature leaf drop, dieback and may even kill plants if left unchecked. There is almost no information published on the economic importance of bougainvillea mealybug, but it has caused significant damage to ornamental bougainvillea plants in Britain, ruining their aesthetic appearance and reducing their market value. Large mealybug populations cause necrosis of the foliage, leaf loss, dieback and moulds grow on the excreted honeydew. Mealybug is a pest, which can have a considerable negative economic impact on a wide range of crops and ornamentals.

There are some ground-inhabiting mealybug species of undetermined economic importance belonging to the genus *Rhizoecus* and *Geococcus. Puto pilosellae* (Sulc) is a pest of strawberries (Kosztarab and Kozar 1988). These species are almost impossible to control. They are capable of causing serious economic damage to some crops, namely alfalfa, strawberry, banana, pepper, coffee, etc. *Rhizoecus americanus* (Hambleton) is often a serious pest in Florida nurseries and recently it appeared in Italy, where it infests ornamental plants. *Paraputo leveri* (Green) has been recorded as damaging roots and killing coffee plants in Papua New Guinea (Williams 1986a). *Paraputo theaecola* (Green) is found on tea roots, apparently in large numbers in North India. It is also a severe pest on the roots of *Taraktogenos kurzii*, a plant that produces a valuable oil. *Paraputo banzigeri* sp. lives on the roots causing the death of *Dimopcarpus longan. Paraputo leveri* (Green) is already known from much of the tropical Pacific region and southern Asia. In Papua New Guinea, it is found on the roots of coffee, where it is protected under a layer of the fungus *Diacanthodes philippinensis* and eventually kills the trees.

Rhizoecus cocois (Williams) is a hypogeal species known from India, where it occurs on coconuts, causing roots to dry up and young plants to show loss of vigour. *Rhizoecus dianthi* (Green) is a serious pest of African violets in California (Snetsinger 1966) and a major pest of greenhouse plants in Europe. *Rhizoecus kondonis* (Kuwana) is one of the most widespread and economically important subterranean mealybugs in California, where it is a pest of alfalfa, prune trees and strawberry plants and also caused severe damage to citrus in Japan. *Rhizoecus amorphophalli* (Betrem) was recorded from

Trivandrum, Kerala (India), on the roots of elephant foot yam, *Amorphophallus* sp., ginger, *Dioscorea* and rhizomes of *Curcuma domestica* stored for seed purposes. *Rhizoecus amorphophalli* sucks the cell sap from the tubers, and severely infested deformed tubers of elephant foot yam, taro, tannia find no place in the market, nor do they accept for cooking, causing economic loss in India.

Rhizoecus americanus (Ferris) is a *soft-bodied, sucking insect that attacks the tips of roots.* It is very common in Florida and other southern states. However, if shipped in plants, it continues to thrive indoors and in greenhouses. These creatures are dangerous to plants and are often ignored as insignificant or misidentified as mycorrhiza.

Geococcus coffeae (Green) is found throughout most of southern Asia, often killing plants in several counties, where it has been introduced. Heavy infestations of *Geococcus johorensis* (Williams) in Malaysia cause the yellowing and early dieback of the leaves. *Xenococcus acropygae* (Williams) was found causing damage to the roots of grapes in India.

Several mealybug species are vectors of viral diseases of various crops: banana, black pepper (Bhat et al. 2003), cocoa (Dufour 1991), grapevine (Tsai et al. 2008), pineapple (Sether and Hu 2002), rice (Abo and Sy 1998) and sugarcane (Lockhart et al. 1992). In such cases, mealybugs may be economic pests even at low densities. For example, several mealybug species are responsible for GLRaV-3 transmission to grapevine, which has been shown by the strong positive correlations between mealybug numbers and infection levels in the following season. The virus infection was predicted to spread rapidly within the vineyard, with 50 % infection occurring in years 6, 8 and 11 for high, intermediate and low infection rates, respectively. The economic impact of GLRaV-3 infection in sensitive varieties exceeded $10,000 per ha by years 7, 9 and 12, and profitability was sufficiently affected to justify replanting by year 11 (Walker et al. 2004). Transmission of pineapple wilt by *Dysmicoccus* spp. and cocoa swollen shoot by *Planococcoides njalensis* (Laing) had resulted in heavy crop loss in some countries.

Some mealybug species may be manipulated as beneficial insects in conservation biological control tactics. For example, the cupress mealybug, *Planococcus vovae* (Nasonov), which occurs on cupress trees (*Cupressus* spp.) grown in windbreaks, serves as an alternative host for natural enemies of mealybug pests in surrounding citrus orchards and cocoa plantations (Cox 1989; Ho and Khoo 1997; Franco et al. 2004).

Mealybugs have been also used as beneficial insects in biological control of weeds. For example, *Hypogeococcus pungens* (Granara de Willink) was successfully introduced from Argentina into Queensland (Australia) for the control of *Harrisia cactus* (*Eriocereus martini*) and related plants (Williams and Granara de Willink 1992). In southern Asia, *Trabutina serpentina* (Green) is confined to *Tamarix* spp. in Pakistan and India. Heavy infestations of the mealybug cause withering of the plant, and the mealybug has the potential for biological control of *Tamarix* wherever the plants have gained weed status. The mealybug *Hypogeococcus festerianus* has been used to control *Harrisia cactus*, a major weed in central Queensland.

Mealybugs have also provided food for humans; the biblical manna, one of the food sources consumed by the Israelites during their wandering in the wilderness of Sinai, is believed to have been the honeydew excretion of the manna mealybug *Trabutina mannipara* (Hemprich and Ehrenberg) (Ben-Dov 2006; Miller and Kosztarab 1979).

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12 Ecology

M. Mani and C. Shivaraju

12.1 Macro-environmental Preferences

Mealybugs are much more numerous than might be expected. Most people know of them as common garden and nursery pests, but few realize the enormous native fauna which exist. Mealybugs are found in areas ranging from the low moist coastal regions to the high snow-covered areas. They are found from elevations of −200 ft to altitudes of over 12,000 ft above mean sea level. They are found in salt marshes and hot, dry desert sands. In these different environments, certain types of mealybugs are found more frequently than others. In the very high altitude regions, conifer- and perennial-inhabiting *Puto* and grass sheath-infesting *Trionymus* are most likely to be found. In the moist coastal regions, root- and soil-inhabiting *Rhizoecus* and grass-infested *Trionymus* are common. In the dry, arid deserts, foliage- and root-inhabiting *Phenacoccus* and *Spilococcus* are numerous. These regions are not restricted to the genera mentioned above, nor are the genera restricted to just these regions (McKenzie 1967).

There are some mealybugs which have no particular environmental preference. *Amonosterium lichtensioides* (Cockerell) is a good example of this, for its only restriction is the distribution of its host, *Artemisia* (Compositae). It is found in high mountains at altitudes of 10,000 ft to low coastal regions of 30 ft. It is also commonly found in dry chaparral areas.

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12.2 Microenvironmental Preferences

Do mealybugs show the wide diversity of host plants. The general groups of plants infested are perennial and annual flowering plants (angiosperms), grasses, conifers and some ferns.

12.2.1 Perennial Flowering Plants

Mealybugs are most commonly found in perennial plants. In some regions, every possible niche is utilized on the perennial hosts. In one instance, in San Diego County, an *Artemisia* plant was infested with *Rhizoecus gracilis* McKenzie on the roots, *Phenacoccus antemisiae* Ehrhorn on the crown, *Spilococcus corticosus* McKenzie under the bark and *Amonostherium lichtensioides* (Cockerell) on the foliage. Perennial foliage-infesting mealybugs, although common in the field, are predominately noticed in greenhouses and backyard gardens. On foliage and stems, mealybugs apparently prefer tight, enclosed

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areas, for they are normally found in the leaf or stem axils. Infestations on fruits are usually enclosed in the calyx area. On the foliage, mealybugs such as *Planococcus citri* (Risso), *Pseudococcus longispinus* (Targioni-Tozzetti) and *P. obscures* Essig are common.

Stems and twigs of perennials are also good areas for mealybug colonies. Normally, the mealybugs are found wedged into the cracks and crevices of the bark, again showing a preference for tight areas. Stems and twigs of plants are not nearly as important as roots, crowns and leaf axils, but mealybugs such as *Spilococcus eriogoni* (Ehrhorn), *Phenacoccus delectus* Ferris and *P. alleni* McKenzie are occasionally found restricted to the branches. Most often, branches are an overflow area from the heavily infested leaf axils.

The habitat of the mealybugs may be divided into two parts: the part which is above the ground (arboreal) and that which is below the ground (hypogeal). Very heavy infestations often occur below the ground. Frequently, this area becomes so heavily contaminated with mealybugs that they often overflow onto the roots. It should be noted that only very rarely does this overflow of soil-inhabiting mealybugs move to the plant parts above the soil surface. Many species of mealybugs are entirely restricted to the root region. These mealybugs can be divided into two types: those that inhabit the main, large roots, and those that restrict themselves to the small fleshy roots. Cracks and crevices are the common areas of infestation on the main roots, but on the fleshy roots, infestations may occur in any area where there is a vacant space. Species commonly collected in the large root areas are *Phenacoccus solani* Ferris, *P. artemisiae* Ehrhorn, *Chorizococcus polyporus* McKenzie, *Puto pacificus* McKenzie, *Chnaurococcus trifolii* (Forbes) and many more. Species found in the second group are usually representatives of the genus *Rhizoecus*, with *R. falcifer* Kunckel d'Herculais, *R. gracilis* McKenzie and *R. kondonis* Kuwana as good examples.

Infestations of moderate- to small-sized mealybugs usually occur in cracks and crevices on the bark, whereas large species such as *Puto yuccae* (Coquillett) or *Puto decorosus* McKenzie usually just cling to the bark in any way possible. Mealybugs of the *Phenacoccus* type may also be found encysted in the centre of the trunk of the perennial plant itself. Perhaps these pseudococcids gain entrance into this area through cracks in the bark, but they appear to be completely enclosed by the plant tissue. *Phenacoccus artemisiae* Ehrhorn is an example of this type of mealybug.

Very often, the plant parts, both above and below the ground, are utilized by certain boring insect larvae. Commonly, if these boring tunnels are pulled open, heavy infestations of certain species of mealybugs will be discovered. *Phenacoccus eremicus* Ferris seems to depend upon the cerambycid boring tunnels for its total existence during detrimental weather. When snow is on the ground or temperatures are consistently above 100 °F, these mealybugs are found only in the cerambycid tunnels. Apparently, the tunnels are an ideal setting for this pseudococcid, for the empty cavities surrounding the beetle larva are quite often completely full of mealybugs in all stages of development. During more favourable weather conditions, infestations outside of the tunnels are quite common.

12.2.2 Annual Flowering Plants

Mealybugs infesting annual plants are unique in that their host is present for only a small part of the year. The location of these mealybugs during that part of the year when their host plant is absent is still a question. This is still a mystery. For example, a very heavy infestation of *Phenacoccus eschscholtziae* McKenzie was found in early April on a large variety of annual hosts. But no mealybugs were found on plant parts either above or below the ground after 2 months. Probably the annual-infesting mealybugs, the disappearance of the pseudococcid with its host, are still a mystery. Infestations on annual hosts are localized in the subterranean areas, and there are mealybugs that are commonly found on the foliage of such hosts.

12.2.3 Grasses

Mealybugs are found on grasses in three areas: the foliage, crowns and roots. Most of the mealybugs inhabit the leaf-blade sheath of the grass plant. This type of pseudococcid is especially adapted to its habitat in that it is dorsoventrally flattened, allowing it to fit comfortably in its sheath environment. *Trionymus* is the most common genus of this type, with *T. dolus* Ferris, *T. smithii* (Essig) and *T. festucae* (Kuwana) being good examples. Mealybugs are found on the leaf surfaces of the Gramineae. Again, *Trionymus* is a good example of this type of infestation. Some mealybugs are found in the crown regions of Gramineae, for example, *Discococcus* spp. Some mealybugs are found at the nodes of the grass stems, for example, *Antonina graminis* (Maskell). Some of these mealybugs feed on the tender terminal roots of the grass, where they are exposed to the surrounding soil with little or no waxy protection. *Cryptoripersia*, on the other hand, occurs in the same area on the roots, but is covered by a tough, felted sac. Another root area is inhabited by *Discococcus spectabilis* McKenzie. The mature adult females of this mealybug form their ovisac at the base of the plant just a few millimetres below where the roots were first produced from the culm base.

12.2.4 Conifers

The genus *Puto* contains several species which inhabit various types of conifers. Most of them have been found only in the cracks in the bark or under the rocks and fallen logs. This host position is quite extraordinary because it would seem virtually impossible for the mealybugs to gain any nourishment from such inanimate objects. Some of these pseudococcids have been found on the bark at the base of the trunks of redwood trees well over 150 ft tall. The bark in this area would undoubtedly be over ten times thicker than the length of the mealybug stylets.

Perhaps these late-instar nymphs were able to sustain themselves completely on nutrients gathered in the early parts of their life history. The roots or the foliage of the conifer are the areas of early development and the bark is merely a resting place for later development where no feeding occurs. In the case of *Puto sandini* Washburn, which infests Engelmann spruce, *Picea engelmannii*, in Utah, at elevations of 10,000–11,200 ft, this mealybug goes through a very complicated 4-year life cycle involving annual multiple migrations. As a demonstration of the complexity of the life cycle, here is what happens during the first year. The mature adult females produce the first-instar nymphs under the bark chips on the bole of the tree. These nymphs migrate from the bole to the duff at the base of the tree in late September where they remain under the snow until sometime in May. At this time, they migrate back up the tree to the foliage where they feed until mid-July. At this time, they migrate back down the bole and hide in the bark crevices. In September, many specimens go back to the foliage again where they feed intermittently until late September. They then move down to the ground, crawl into the duff where they remain until the following May. This type of migration seems feasible for other conifer-infesting *Puto* because in some California species there are known records of infestations in the duff, on the bark and in the foliage.

Areas other than the bark of conifers are also infested. The foliage region is particularly well inhabited. In most instances, the mealybugs are found at the bases of the needles. As far as is known, the total life cycle of these species is spent in the region of the foliage. Some species found in the foliage area are *Crisicoccus pini* (Kuwana), *Dysmicoccus pinicolus* McKenzie, *D. ryani* (Coquillett), *Ehrhornia cupressi* (Ehrhorn), *Puto cupressi* (Coleman) and *Spilcoccus implicatus* Ferris. Root infestations in coniferous trees are not common.

Fern-inhabiting mealybugs are not at all common. *Rhizoecus pritchardi* McKenzie is, however, a species which is often found on the roots of maidenhair fern, and is perhaps more commonly associated with the roots of African violet. Several other mealybugs are also found on, although not restricted to, various types of ferns in nurseries. Perhaps the most common species in this category is *Pseudococcus longispinus* (Targioni-Tozzetti). Several species of *Pedronia* are restricted to ferns in Hawaii.

12.2.5 Inanimate Objects

Occasionally, mealybugs are found in association with nonbiological objects, especially during winter. *Misericoccus arenarius* (Done and Steinweden) is often found under the rocks or cracks in the rocks during the winter period. *Phenacoccus colemani* Ehrhorn is commonly found in the pits and crevices under the lava rocks. *Heliococcus stachyos* (Ehrhorn) is found under the rocks deeply embedded in cracks in the rocks. Wooden boards also serve as the habitat of some mealybugs. *Chorizococcus rostellum* (Hoke) is commonly found under the wooden boards.

12.3 Host Plant Position

Mealybugs show preference to certain positions within the plant. Development of mealybug population can be related to the plant growth and development. The mealybugs are relatively abundant more on the fruits than on the other plant parts. This is true in several fruit crops. Mealybugs are found under loose bark and also on aerial roots in the case of grapevine when fruit bunches are not available. Congregation of mealybugs is observed in the nodal region of the stem. They are seen usually on the lower surface of the leaves, more near the veins in the leaf. Mealybugs are seen in large numbers on the fruits and are rarely seen on the leaves and trunk in the case of custard apple. In ornamentals, the mealybugs are distributed on the leaves, terminal shoots and flower buds. Some arboreal mealybugs extend their feeding on the parts just below the soil.

12.4 Seasonal Development

Abiotic and biotic factors play a major role in the seasonal development of mealybugs besides the phenology of the crop. Weather conditions, especially temperature and relative humidity (RH), are major ecological factors that have been found to severely affect mealybugs and their natural enemies.

12.4.1 Overwintering

Temperature is the driving force for mealybug development. Many mealybugs overwinter as second-instar nymphs, although adult females, first-instar nymphs and eggs also can fulfil this function (Miller 2005). For example, *Phenacoccus azaleae* Kuwana overwinters as a second-instar nymph within a wax cocoon (Xie et al. 1999), *Planococcus vovae* as first and second instars (Francardi and Covassi 1992), *Pseudococcus viburni* as first instar in bark crevices, and rarely as second or third instars (Kosztarab 1996), and *Pseudococcus maritimus* (Ehrhorn) as eggs and first instar under the bark (Geiger and Daane 2001). *Ps. maritimus* and *Pl. ficus* overwinter primarily under the bark of the trunk and cordon, with some of the population found underground on the roots.

The temperature has an impact on the development times and temperature thresholds for different species. The number of generations of the mealybug varies with the species, locality and climatic factors. Most mealybug species are uni- or bivoltine, although some are reported to have as many as eight generations per annum in greenhouses. There are ten generations of *Planococcus minor* in a year, eight during February–November and two during November–January; *M. hirsutus* had ten generations per year in India. For example, *Pseudococcus maritimus* will have two generations in California's interior valleys, whereas *Planococcus ficus* can have seven generations in the same region but is reported to have only three generations per year in Italy. Similarly, *Pl. citri* in Brazil has six generations per year in the south, but up to 11 per year in the northeast where grapes are produced throughout the year (two harvests per season). Other than *Ps. maritimus* and *H. bohemicus*, there does not appear to be winter dormancy for the mealybugs. There is also a variation in the seasonal feeding location and movement on the plant among and within species, depending on factors such as regional temperatures and vineyard management practices, as described for *Ps. maritimus* and *Pl. ficus*. The mealybug population overwinters primarily under the bark of the trunk and cordon, with some of the population found underground on the roots, especially when tended by ants. There is no diapause. On warm days, development may occur during the winter months, with completion of the first generation almost entirely under the bark. From spring to summer, the *Pl. ficus* population follows the movement of plant resources from roots to shoots to leaves. Four to five generations are completed and population density can increase rapidly, although high summer temperatures, in excess of 40 °C, may slow the growth of the population and increase mortality. As berries ripen and sugars develop, mealybugs move into the berry clusters, first attacking those near the vine cordon. The rapid population increase in summer is followed by an equally rapid decline after harvest, resulting from biological controls and abiotic mortality associated with high temperatures and vine senescence.

The optimal temperature for populations of the cassava mealybug is between 20 and 30 °C. The cassava mealybug has poor survivability during rainy season because it is washed off the plant and drowns. The preferred temperature range for the vineyard mealybug *Planococcus vitis* (Nied.) was 16–34 °C, and this preference was unaffected by relative humidity. Linear velocity increased with rises in the temperature. Individuals that had been preconditioned at 95 % RH showed no consistent preference when provided with a choice of relative humidities, but those that had been desiccated avoided low humidities. The degree of humidity is probably perceived over the whole body. The mealybug is photonegative, and the reduced compound eyes are probably the photoreceptors. A rough substratum was generally preferred to a smooth one. Temperature appeared to be the main factor determining the behaviour of the adults, and orientation in relation to temperature, light, humidity and contact is mainly achieved by klinokinesis, klinotaxis and orthokinesis. Catches of the male mealybug, *Pseudococcus calceolariae* (Mask.), were registered at intervals of 2 h for 24 h on two separate days in July and September, respectively. In both the months, there was a high peak of activity at sunset and a lower one at sunrise; in July, the peaks were separated by many hours of low catches, whereas in September the morning peak was much higher and the morning and evening peaks were somewhat closer together than in July, owing to the shorter day length.

In tropical countries, the mealybugs occur on the plants throughout the year. Development of mealybug population can be related to the plant growth and development. The mealybugs will be relatively abundant more on the fruits than on the other plant parts. The population is low in winter and rainy seasons and higher in summer months. There was a highly significant positive correlation of maximum and minimum temperature and a highly significant negative correlation of morning and evening relative humidity and a nonsignificant negative correlation of rainfall with mealybug population in vineyards in South India. They manage to survive under loose bark, feeding at bases of spurs and callus tissue at the site of girdles in the off-season. In the absence of rains, there is a sudden spurt in the mealybug population in dry seasons. Females of the mealybug *Glycycnyza turangicola* are enclosed in a capsule formed by hardened honeydew. This specialization is regarded as an adaptation to desert conditions where humidity is extremely low in the Amudar'ya plain.

Heavy sporadic rains and cool temperatures of less than 20 °C result in the temporary reduction in the mealybug population. The pest population build-up coincides with a high temperature of 30–40 °C, low humidity (less than 40 %) and fruit development.

There is also a variation in the seasonal feeding location and movement on the vine among species and within species depending on regional temperatures and vineyard management practices. There is no diapause, and slow development may occur during the winter months under South Indian conditions. *M. hirsutus* was active during winter also, without hibernation but was most active during March–October on roselle around West Bengal. In North India, the mealybug *M. hirsutus* on mesta overwintered in overlapping stages in the capsules of mesta beneath the persistent calyx and epicalyx of the old and dried plants and also in the soil during December and January, when food plants were not available. Mealybugs developed from a fraction of third-generation eggs that did not enter winter diapause.

Water-stressed plants have been reported to favour the increase in the mealybug population. High nitrogen application enhances the results in increase in the population of mealybugs.

In Java, *Ferrisia virgata* appears in large numbers during dry seasons of the year. It is more abundant from February to May in Philippines. In Saudi Arabia, three generations were observed in a year, early June, early July and August, and the population increased with each generation. It overwintered between January and early June as an adult female in the cracks and crevices of trunks and branches and also on the fallen leaves. The female mealybug also migrated to the soil in winter. The peak activity of *F. virgata* was observed during June–September in West Bengal. On a number of host plants, it was most active during August–November and March–April but was very much reduced during December–January (Mani and Krishnamoorthy 1993). Several environmental factors influence the population of *F. virgata*. Numerous records refer to heavy attack by *F. virgata* after prolonged drought. The mealybug is favoured by dry weather in Java. The most important factor was atmospheric humidity which exercises an indirect effect through its influence on parasitic fungi. Temperature did not appear to have much effect on *F. virgata* in Java. But a significant positive correlation was found between the population density and daily maximum and minimum temperatures in Saudi Arabia. Wind influences the dispersal and establishment of *F. virgata* in addition by walking of the mealybugs. Windy areas are highly susceptible to attack which is more severe on hill tops than in valleys. *F. virgata* attacks the weak plants easily and spreads quickly on the younger plants exposed to sun and protected from wind. It appears to prefer below 5,000 ft altitude.

The ensete root mealybug *Cataenococcus ensete* Williams and Matile-Ferrero is a major pest in the ensete-growing regions of southern Ethiopia. The ensete root mealybug, was observed between 1054 and 2977 meter above sea level (masl). Its infestation was severe only between 1400 and 2200 masl. The highest infestation (53.6 %) was recorded between 1600 and 1800 masl (Addis et al. 2010).

12.4.2 Dispersal

Adult male mealybugs are winged. The first-instar nymphs (crawlers) have been found to possess numerous characteristics that have been considered adaptations for dispersal behaviour, including long legs and antennae (Gullan and Kosztarab 1997). Adult males and newly emerged first-instar nymphs of most mealybug species display dispersal actively. Most mealybugs remain relatively stationary throughout their life (Miller 2005). However, some species move to different areas of the host for overwintering, feeding, mating, ovipositing and moulting (Franco 1994; McKenzie 1967; Miller 2005). The occurrence of seasonal movements within the host has been reported for various mealybug species, especially those associated with woody plants such as *Pl. citri, Ps. calceolariae, Ps. viburni* and *Ps. longispinus* in citrus (Franco 1994; Nestel et al. 1995); *Pl. ficus* and *Ps. maritimus* in grapevine (Geiger and Daane 2001; Godfrey et al. 2003); *Pl. vovae* in *Juniperus* spp. (Francardi and Covassi 1992) and *Ph. azaleae* in bunge prickly ash (Xie et al. 1999). Franco (1994) suggested that immature feeding stages of mealybugs on citrus tend to search for and to settle at the major 'sinks', for example, growing fruits, of the host plant in each phenological period. We believe this hypothesis may also explain the migratory movements of other mealybug species within various hosts. For example, *Pl. kraunhiae* Kuwana was reported to feed on bacterium galls because they are sinks for assimilates and have more nutritious phloem sap and parenchyma than do normal plant tissues (Yamazaki and Sugiura 2005). Other nymphal stages and adult female mealybugs are wingless, and some even legless; hence, they are not highly vagile, often fixed to plants by their mouthparts and always have a restricted distribution. However, the cassava mealybug (*Phenacoccus manihoti*), first reported in 1973 from the Congo areas of Kinshasa and Brazzaville, had become established throughout the whole cassava belt of Africa as far south as Mozambique by 1986 on the single plant genus *Manihot* (Herren and Neuenschwander 1991). Mealybugs, particularly crawlers, having legs move limited distances within the plant and also between the plants (Kosztarab and Kozár 1988). Nevertheless, if conditions are favourable, crawlers usually settle on the natal host plant, often close to their mother, which leads to an aggregative distribution (Gullan and Kosztarab 1997; Nestel et al. 1995). Similarly to most scale insects, crawlers are the mealybugs' main dispersal agents, even though the mortality is very high (Gullan and Kosztarab 1997). First-instar mealybugs are easily transported by the wind (Gullan and Kosztarab 1997). However, Williams and Granara de Willink (1992) reported that mealybugs were believed to be distributed by air currents over only short distances. In addition, dispersal strategies may be more passive, and crawlers of several species have been found to exhibit behaviours that increase the chances of wind dispersal and to use wind dispersal to migrate for several kilometres (Washburn and Washburn 1984). In India, *Paracoccus marginatus* spread very fast by wind dispersal of crawlers from the state Tamil Nadu to other states. Crawlers from several species have also been found to be able to survive without food for extended periods, which should again enhance their dispersal success (Gullan and Kosztarab 1997). Male and female nymphs do not differ in their dispersal behaviour or in their dispersal success when dispersal is via crawler locomotion. All the mealybug instars can be transported on infested leaves blown by the wind. In addition, water, bed-soil, humans and domestic and wild animals may aid the passive dispersal of mealybugs (Kosztarab and Kozár 1988). Transport of nursery plants (ornamentals and fruit plants) infested with mealybugs aids the spread of mealybugs from one location to another location.

Among arthropods, ants have also been reported to disperse many mealybug species (Gullan and Kosztarab 1997; Malsch et al. 2001; Ranjan 2006). Ants transported mealybugs from plant to plant between and within fields, thus facilitating mealybug dispersal; adult females and immatures of some mealybug species, associated with the ant genus *Acropyga* Roger, are carried by queens in their mandibles when founding new colonies (Williams 1998). Associations among invasive species of ants and mealybugs can be important in their success in new locations (Helms and Vinson 2002). It is also observed that mealybugs and other scale insects cling to locusts during swarming. Misra (1920) reported another phoretic method of eggs and nymphs of *Maconellicoccus hirsutus* (Green) being transported by nymphs and adult females of another mealybug *Ferrisia virgata* (Cockerell).

All these methods are responsible for the local and short-distance dispersal. Long-range dispersal of mealybugs is usually accomplished by the transport of infested plant material. Many species of mealybugs have been widely distributed by commercial traffic, mostly carried on imported plant material (Williams and Granara de Willink 1992). Papaya mealybug *Paracoccus marginatus* had spread very fast through the transport of fruits infested with mealybugs from Tamil Nadu to other states in India. Plants and their associated insects must have been carried to new areas by people for many centuries and people still carry infested plant material, as shown by the numerous quarantine interception records. Because of their cryptic habits and small size, mealybugs are difficult to detect at borders during quarantine inspections, especially if their population density on plants is low (Gullan and Martin 2003).

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13 Natural Enemies of Mealybugs

A.N. Shylesha and M. Mani

Mealybugs are found attacked by various natural enemies in nature. The outbreak of mealybugs was observed in many instances with the application of broad-spectrum insecticides, which might have disturbed the activity of natural enemies particularly parasitoids and predators. This clearly indicates the importance of natural enemies in the regulatory role of the mealybug population. In fact, there is a very rich natural complex on arboreal mealybugs, but there is a poor natural enemy complex, particularly natural predators or parasites on root mealybugs. Withdrawal of insecticides results in the reappearance of natural enemies, thereby regulating the mealybug population. The natural enemies of the pests can be divided into three categories depending on how they feed on the pests. They are predators, parasitoids or pathogens.

13.1 Predators

Insects belonging to Coccinellidae (Coleoptera), Chrysopidae and Hemerobiidae (Neuroptera), Lycaenidae and Noctuidae (Lepidoptera) and Syrphidae, Cecidomyiidae, Chamaeyiidae and Drosophilidae (Diptera) are known to feed on the mealybugs besides the spiders, mantids, ground beetles, assassin bugs, predatory stink bugs, minute pirate bugs and predatory thrips. They are polyphagus feeding on a variety of mealybugs. Naturally occurring predators are capable of suppressing the mealybugs on several occasions.

13.1.1 Coleoptera

13.1.1.1 Coccinellidae

Both adults and larvae feed voraciously on all stages of the mealybugs including the egg masses. The larvae of many predatory coccinellids are covered with white waxy filaments very similar to the mealybugs. The adults are brightly coloured. The eggs are oval shaped, yellow and very small. The larvae are voracious feeders though the adults are also known to feed on the mealybugs. Development from egg to adult beetle takes 25–30 days at 25 °C. The species belonging to genera *Cryptolaemus*, *Brumus, Aspidimerus, Stictobura, Orcus, Diomus, Nephus, Sidis, Parasidis, Pseudoscymnus*, *Hyperaspis, Scymnus, Sasajiscymnus, Exochomus, Brumoides, Cleophora, Harmonia* etc. are some of the important predators of mealybugs. Among the coccinellids, *Cryptolaemus montrouzieri* Mulsant was extensively used to control a variety of mealybugs throughout the world.

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Cryptolaemus montrouzieri

Cryptolaemus montrouzieri is native of Australia popularly known as the Australian ladybird beetle, often referred to as the mealybug destroyer. Adult beetles are about 4 mm long, oval in shape, black in colour with a light brown head and posterior. *Cryptolaemus* larvae grow up to 13 mm long and are covered with long, white, waxy filaments. The *Cryptolaemus* preys upon several species of mealybugs. It is less effective when the temperature is below 20 °C or when the humidity level is low (<40 % relative humidity (RH)). *Cryptolaemus* prefers a warm and humid climate. The egg to adult development takes about 30 days at a temperature of 25 °C. During her lifespan, a female can lay up to 400 eggs. The eggs are deposited within the egg masses of the mealybugs. *Cryptolaemus* eggs are brighter and quite larger. The larvae are covered with long white wax filaments. At first sight, they very closely resemble the mealybugs. However, *Cryptolaemus* larvae move faster and are more fluffy in their appearance. The larvae will eat each other whenever the food availability is poor. For pupation, the larvae will go to a hidden place. The pupae look very similar to the larvae, quite larger and somewhat more fluffy (Mani et al. 1991).

Cryptolaemus on mealybugs

Nephus includens

Hyperaspis trilineata Mulsant

Hyperaspis trilineata Mulsant is a principal predator of *Saccharicoccus sacchari* (Cockerell). It is reported to have a peculiar type of egg that is at first flat and resembles a whitefly larva. They are laid singly and are hatched in 8–10 days. The young larvae feed for a time on mealybug crawlers before developing their cottony covering. About 3 weeks are required for larval development followed by pupal development and adult emergence.

Nephus includens Kirsch

Nephus includens Kirsch is a predator of the citrus mealybug. Adult beetles are dark; they have four orange/yellow spots on their backs. They are about 2 mm in size. Its eggs are laid in the egg mass laid by the mealybug. The female beetle can, during her lifetime, lay from 300 to 400 eggs. The larvae are covered with white waxy filaments, very similar to that of mealybugs. The beetle larvae are fluffier and can run faster. The larvae are often little in the crop because they are very small and often found in the egg mass of the mealybug. The eggs of mealybugs are oval shaped, yellow and very small, but in practice not visible. Both adult beetles and larvae eat mealybugs. When a mealybug is eaten, the dead remains can be seen on trees as white fluffy matter. The larvae mainly feed on eggs and young mealybugs. They can consume up to about 100 eggs per day or about 50 young mealybugs.

Scymnus coccivora Ayyar

Scymnus coccivora Ayyar is known to feed on several species of the mealybugs. Adults are light brown in colour measuring 1.7 × 1.3 mm in size. The pale yellow eggs are deposited singly in the colony of mealybugs. The grub has instars. Long waxy strands develop on the later stage of the grub. The pupa is oval and light brown in colour fringed with short brown hairs. The egg, grub, prepupal and pupal stages occupy 4.1, 4.2, 9.5, 1.2 and 5.2 days, respectively, and the total life cycle is completed in 23 days. The sex ratio is 1:1. A single grub *S. coccivora* was known to consume 308 eggs or 62 nymphs or 6.55 adult mealybugs (Mani and Thontadaraya 1987).

C. sexmaculata

B. suturalis

H. octomaculata

Nephus regularis

S. coccivora

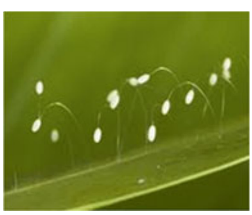
13.1.2 *Neuroptera*

13.1.2.1 Chrysopidae

Green lacewings are delicate insects 1⁄4- to 1⁄2-in. long with a wingspan of 6 to >65 mm, and the largest forms are tropical. Adults are often seen around the foliage. They are characterized by a wide costal wing venation, which includes the cross veins. The bodies are usually bright green to greenish-brown, and the compound eyes are conspicuously golden in many species. The wings are usually translucent with a slight iridescence; some have green wing veins or a cloudy brownish wing pattern. Eggs are deposited at night, singly or in small groups; each female produces approximately 100–200 eggs. Each egg is hung on a slender stalk about 1 cm in length, usually on the underside of a leaf. Immediately after hatching, the larvae moult, then ascend the egg stalk to feed. The larvae are spindle shaped, some camouflaged within the host mealybugs. They are voracious predators. Larvae of green lacewings found feeding the early stage of mealybug nymphs. A single larva of *Mallada boninensis* is capable of consuming 350–500 nymphs in its development. The species belonging to genera *Chrysopa, Chrysoperla* and *Mallada* are the well-known predators of mealybugs. The stalked eggs of the green lacewings are commonly seen in many plants infested with sucking pests including mealybugs. *Chrysoperla carnea* is used to control the mealybugs in green houses. They carry the trash over their bodies.

Life stages of green lacewing

Adult



Eggs

Larva on mealybugs

Larva carrying trash

Mallada boninensis

A single larva of *M. boninensis* was able to prey about 345, 490 and 560 nymphs of *Ferrisia virgata, Planococcus lilacinus* and *P. citri*, respectively (Mani and Krishnamoorthy 1990).

Chrysoperla carnea

The larvae of the *Ch. carnea* grubs were found as active predators on the mealybugs, and the predatory grub preyed on all the stages of the mealybug. A single larva was known to consume 378 eggs or 730 nymphs, or 95 adult females of *P. citri.*

13.1.2.2 Hemerobiidae

Hemerobiidae is a family of the Neuropteran insects commonly known as brown lacewings. These insects differ from the somewhat similar Chrysopidae (green lacewings) not only by the usual colouring but also by the wing venation. Hemerobiids have numerous long veins that are lacking in chrysopids. Some of the costal cross veins are forked. The larvae of the brown lacewings belonging to genus *Hemerobius,* and *Sympherobius* prefer to prey the early stage of the mealybugs, though they are known to feed all the three nymphal instars of the female mealybugs. The first-instar larvae of *Sympherobius fallax* consume the second stage of the long-tailed mealybug *P. longispinus* more than any other stages and did not eat the fourth (adult) stage, while the second-stage *S. fallax* preferred the third-stage mealybugs. The third-stage *S. fallax* also preferred the third-stage mealybugs. In the choice experiment, the first-stage larval predators preferred the second-stage mealybugs significantly more than the other two stages, while the second- and third-stage predators preferred the third-stage mealybugs significantly more than the second and the fourth stages. Darkness had a marked effect on the feeding efficiency of all stages of *S. fallax*. The number of mealybugs eaten in the light was significantly greater (Gillani et al. 2009).

Larva of *Sympherobius*

Adult *Sympherobius*

13.1.3 *Lepidoptera*

13.1.3.1 Lycaenidae

The Apefly *Spalgis epeus* Westwood is a small butterfly found in Asia. It gets its name due to the face resemblance of ape that can be seen from the head-on view of the pupa. The male is dull brown on the upperside and slightly darker towards the apex of the forewing; also a more or less quadrate whitish spot beyond the apex of the cell on the same wing can be seen; in some specimens, this spot is slightly diffused. On the underside, it is pale, silky, brownish-white; fore- and hindwings crossed by numerous, very slender, short, sinuous, transverse, dark brown strigae, which are outwardly slender edged with brownish-white of a shade paler than that of the ground-colour. Both the wings have an anticiliary dark brown line on the inner side with similar edging. Forewing, in addition, has an oval white spot beyond the cell.

The cilia of both the fore- and hindwings are of the same shade as that of the ground colour of the wings. The antenna, head, thorax and abdomen are pale brown in colour, and the club of the antennae is ochraceous at apex; beneath are the palpi and thorax brownish-grey and the abdomen pale brown in colour. In female, the upperside is slightly paler brown. In the forewing, the cell and apex are darker, with a white spot similar to that in the male but larger, beyond the apex of the cell; in most specimens, it is extended diffusely outwards and downwards. The hindwing is similar to that of the male. The underside is as precise as in the male.

Life stages of *Spalgis epeus*

Second instar caterpillar · Third instar caterpillar · Final instar caterpillar · Adult butterfly

The lycaenid predator *Spalgis epeus* was commonly associated with the natural control of the mealybugs *Rastrococcus iceryoides, Planococcus lilacinus, Pl. citri, Ferrrisia virgata, Paracoccus marginatus* etc. The larvae of *Spalgis epeus* were observed to predate on root mealybug colonies especially those at the base of the stems (Devasahayam et al. 2009). Although *Spalgis lemolea* was a common natural enemy of *Phenacoccus madeirensis* infesting cassava in Africa (Herren and Neuenschwander 1991), its potential utility as an effective biological control agent was thwarted by its erratic occurrence. At 25–30 °C and 40–60 % RH, the mean duration of the egg, larval and pupal stage of *Spalgis epeus* on *Pa. marginatus* is 3.5, 12.0 and 10.3, respectively, and the mean duration from egg to adult emergence was 26 days, and it takes 24 days on *Pl. citri* to complete the life cycle (Dinesh et al. 2010). As for the predatory potential of *S. epeus*, the total number of papaya mealybugs consumed during the larval stage was 4,115 eggs, 281 nymphs and 77 female adults.

13.1.4 Diptera

Several dipterans are found as predators in the concealed mealybug niche. The insects belonging to Drosophilidae, Cecidomyiidae, Syrphidae etc. are known to attack the mealybugs. The dipteran larvae feed voraciously on the mealybugs.

13.1.4.1 Cecidomyiidae

In this family, the larvae of a large number of species are predaceous on the mealybugs. These insects are very tiny, usually only 2–3 mm in length. The adults, which are very tiny, fragile midges, locate colonies of appropriate prey. The eggs are laid near the base of the mealybug host; the larva tunnel underneath the host and feed on the eggs or developing coccid nymphs. As the small, maggot-like larvae are incapable of moving to considerable distances, there usually has to be a fair population of the prey present, before the adults will lay eggs. The life cycle is completed in 25 days. The total number of eggs deposited by the female averaged 36 during her very short lifespan, which averaged 2.3 days. The larvae of *Dicrodiplosis manihoti* Harris were found to prey on the egg masses of the cassava mealybug, *Phenacoccus manihoti* in the Congo and Senegal. *Kalodiplosis pseudococci* Felt has given significant control of *D. brevipes* in conjunction with two parasitoids. *Triommata coccidivora* Felt plays a supplementary role in regulating the mealybug population.

13.1.4.2 Chamaeyiidae

Chamaeyiidae is a small family of acalyptratae flies. The larvae are the predators of the mealybugs.

13.1.4.3 Drosophlidae

Larvae of the predatory drosophilids are found feeding on the colonies of nymphs. They play a supplementary role in regulating the mealybug population.

13.1.4.4 Syrphidae

Syrphid larvae are predatory on the mealybugs but are of minor importance (Table 13.1).

13.1.5 Other Predators

The rat *Millardia meltada meltada* gnawed through the lower dry leaf sheaths and devoured the mealybugs *Saccharicoccus sacchari* at the nodes of sugarcane.

Pirate bugs feed on the mealybugs

Crab spiders feed on the mealybugs

Table 13.1 List of predators recorded on the mealybugs

Predator species	Mealybug species
Coleoptera, Coccinellidae	*Coccidohystrix insolita*
Anegleis cardoni (Weise)	
Brumoides suturalis (Fab.)	*M. hirsutus, P. lilacinus, F. virgata, Ph. solenopsis, Pa. marginatus, Coccidohystrix insolita* (Green)
Cryptolaemus montrouzieri Mulsant	Many mealybug species
Coleophora pupillata (Schonherr)	Several mealybugs
Cheilomenes sexmaculata (Fab.)	*Ph. soleneopsis, F. virgata*, *Pa. marginatus*
Curinus coeruleus Mulsant	*Nipaecoccus nipae* (Maskell)
Chilocorus stigma (Say)	*Pl. citri*
Chilocorus nigrita (Fabricius)	*S. sacchari*
Chilocorus sp.	*Pa. marginatus*
Chilocorus bipustulatus L.	*Phenacoccus mespili* Ben-Dov
Decadiomus bahamicus (Casey)	*Pl. citri*
Diomus notescens (Blackburn)	Several mealybugs
Diomus hennesseyi Fiirsch	*Ph. manihoti*
Exochomus flaviventris Mader	*Phenacoccus manihoti* Matile-Ferrero
Exochomus troberti Mulsant	*Phenacoccus manihoti*
Exochomus flavipes (Thunberg)	*Phenacoccus manihoti*
Exochomus concavus Fursch	*Phenacoccus manihoti*
Exochomus metallicus Korsch	*Planaococcus citri* (Risso)

(continued)

Table 13.1 (continued)

Predator species	Mealybug species
Exochomus nigripennis (Erichs.)	*Nipaecoccus viridis* (Newstead)
Exochomus melanocephalus (Zubkoff)	*Saccharicoccus sacchari* (Cockerell)
Harmonia octomaculata (F.)	*Phenacoccus solenopsis* Tinsley
Harmonia maindroni Sicard	*Maconellicoccus hirsutus* (Green), *P. lilacinus, Coccidohystrix insolita* (Green)
Hippodamia convergens (Guérin-Méneville)	*Ph. solenopsis*
Hippodamia variegata Goeze	*Ph. solenopsis*
Hyperaspis limbatus Casey	*Saccharicoccus sacchari* (Ckll.)
Hyperaspis silvestri Weise	*Dysmicoccus brevipes* (Cockerell)
Hyperaspis trilineata Mulsant	*Saccharicoccus sacchari*
Hyperaspis onerata (Mulsant)	*Phenacoccus herreni* Cox and Williams
Hyperaspis egregia Mader	*Planococcoides njalensis* (Laing)
Hyperaspis marmottani (Fairm.)	*Phenacoccus manihoti*
Hyperaspis senegalensis hottentotta Mulsant	*Phenacoccus manihoti*
Hyperaspis raynevali (French)	*Phenacoccus manihoti*
Hyperaspis aestimabilis Mader	*Phenacoccus manihoti*
Hyperaspis pumila Muls.	*Phenacoccus manihoti*
Hyperaspis onerata (Muls.)	*Phenacoccus manihoti*
Horniolus vietnamicus Miyatake	*P. lilacinus*
Midas pygmaeus Blackburn	*Ps. calceolariae*
Nephus vetustus Weise	*Phenacoccus manihoti*
Nephus regularis Sicard	*Ph. solenopsis, Coccidohystrix insolita*
Nephus reunion (Fursch	*Pseudococcus* sp.
Nephus bipunctatus (Kug.)	*N. viridis*
Nephus bilucernarius Mulsant	*Nephus bilucernarius* Mulsant
Pesudoscymnus pallidicollis (Mulsant)	*M. hirsutus*
Platynaspis strictica philippenensis Korchefsky	*Planococcus kenyae* (LePelley)
Pseudoscymnus pallidicollis (Mulsant)	*Pl. citri*
Pullus pallidicollis (Mulsant)	*P. lilacinus, Pl. citri*
Sasajiscymnus quinquepunctatus (Weise)	*Paracoccus marginatus* Williams and Granara de Willink
Scymnus binaevatus Mulsant	*Pseudococcus calceolariae* (Maskell)
Scymnus coccivora Ayyar	*M. hirsutus, P. lilacinus, F. virgata, Ph. solenopsis, Pa. marginatus*
Scymnus nubilus Muls.	*M. hirsutus*
Scymnus syriacus	*F. virgate*
Scymnus gratiosus Wiese	*M. hirsutus*
Scymnus severini Weise	*P. lilacinus*
Scymnus margipaliens Muls.	*D. brevipes*
Scymnus couturier G.	*Ph. manihoti*
Scymnus sp.	*Geococcus citrinus* Kuwana
Scymnus flavifrons Blackburn	*Pl. citri*
Scymnus (Pullus) *uncinatus* Sicard	*D. brevipes*
Scymnus pictus Gorham	*D. brevipes*
Coleoptera, Nitidulidae	*S. sacchari*
Carpophilus marginellus Motsch	

(continued)

Table 13.1 (continued)

Predator species	Mealybug species
Coleoptera, Lathridiidae	*M. hirsutus*
Melanophthalma carinulata Motsch	
Diptera, Cecidomyiidae	*Planococcus kenyae*, *Planococcoides njalensis* (Donald)
Coccodiplosis coffeae (Barnes)	
Coccodiplosis citri Barnes	*Phenacoccus manihoti*
Cleodiplosis koebelei (Felt)	*D. brevipes*
Diadiplosis koebelei (Koebele)	Several mealybugs
Diadiplosis coccidivora (Felt)	*F. virgate*
Dicrodiplosis manihoti Harr.	*Phenacoccus manihoti*
Dicrodiplosis sp.	*Planococcus citri, P. lilacinus, N. viridis*
Gitona sp.	*F. virgate*
Kalodiplosis koebelei (Felt)	*Ps. calceolariae*
Kalodiplosis pseudococci (Felt)	*D. brevipes*
Kalodiplosis coccidarum (Felt)	*Ph. herreni*
Lobodiplosis pseudococci Felt	*D. brevipes*
Triommato coccidivora (Felt)	*P. lilacinus* (Risso)
Vincentodiplosis pseudococci	*D. brevipes*
Diptera, Chamaeyiidae	*R. iceryoides, P. lilacinus, Brevennia rehi*
Leucopis luteicornis Malloch.	
Leucopis sp.	*F. virgate*
Leucopis ocellaris Mall	*Pseudococcus comstocki*
Leucopis alticeps Czerny	*Phenacoccus mespili* Ben-Dov, *P. citri*
Diptera, Drosophilidae	*P. citri, P. lilacinus, S. sacchari*, *Phenacoccus manihoti*
Cacoxenus (Gitonides) perspicax (Knab)	
Rhinoleucophenga capixabensis sp. nov.	*Dysmicoccus brevipes*
Domomyza perspicax (Knab)	*P. citri, Brevennia rehi* (Lindinger)
Diptera, Syrphidae	
Ocyptamus argentinus Curr.	*F. virgata*
Xanthogramma javana Wd.	*F. virgate*
Allobaccha eclara (Curran)	*Phenacoccus manihoti*
Diptera, Chloropidae	*Brevennia rehi* (Lindinger)
Anatrichus pygmaeus Lamb	
Neuroptera, Chrysopidae	*M. hirsutus*
Apertochrysa sp.	
Anisochrysa basalis Walker	*Pl. citri*
Anisochrysa boninensis (Okaomota)	*Coccidohystrix insolita*
Brinckochrysa scelestes Banks	*M. hirsutus*
Ceratochrysa antica (Wlk.)	*Phenacoccus manihoti*
Chrysopa ramburi Schneider	*Ps. Calceolariae*
Chrysopa sp.	*Phenacoccus manihoti, N. viridis*
Chrysoperla carnea (Stephans)	*P. citri, F. virgate*
Chrysopa lacciperda (Kimmis)	*P. citri*, *Ph. solenopsis*, *Ph. mespili*
Chrysoperla rufilabris (Burmeister)	*Ps. longispinus* (Targioni Tozzetti)
Chrysoperla zastrowi Sillemi (Esben-Petersen)	*Pa. marginatus*
Chrysopa lateralis Guerin	*Pl. citri*

(continued)

Table 13.1 (continued)

Predator species	Mealybug species
Oligochrysa lutea (Wlk.)	*Ph. solenopsis*
Mallada boninensis (Okamota)	Many mealybugs
Plesiochrysa lacciperda (Kimmins),	*Pl. citri*
Neuroptera, Hemerobiidae	*Ps. calceolariae*
Sympherobius amicus Navas	
Sympherobius barberi (Banks)	*Ps. longispinus, P. citri*
Sympherobius pygamaeus (Rambur)	*M. hirsutus*
Psectra iniqua (Hagen)	*Rastrococcus invadens* Williams
Neuroptera, Coniopterygidae	*M. hirsutus*
Conwentzia psociformis (Curtis)	
Cryptoscenea australiensis (Enderlein)	*Pseudococcus viburni* (Signoret)
Lepidoptera, Lycaenidae	*Planoccuus kenyae, F. virgata, P. manihoti*
Spalgis lemolea Druce	
Spalgis epeus West wood	*P. citri, P. lilacinus, Ph. solenopsis, Pa. marginatus, Coccidohystrix insolita, Nipaecoccus nipae*
Lepidoptera, *Pyralidae*	*P. citri*
Laetilia coccidivora (Comstock)	
Lepidoptera, Momphidae	*S. sacchari*
Batrachedra sp. near *psilopa* Meyrick	
Lepidoptera, Noctuidae	*P. lilacinus*
Eublemma sp.	
E. geyri Rild	*M. hirsutus*
E. trifasciata Moore	*M. hirsutus*
Autoba silicula Swinhoe	*M. hirsutus*
Hemiptera, Coreidae	*M. hirsutus*
Geocoris tricolor (Fab.)	
Hemiptera, Miridae	*F. virgate*
Deraeocoris sp.	
Hemiptera: Anthocoridae	*Ph. manihoti*
Cardiastethus exiguus Poppius	

13.2 Parasitoids

13.2.1 Hymenoptera

The parasitoids belonging to families Encyrtidae, Aphelinidae, Platygastridae, Pteromalidae, Braconidae, Eucoilidae, Signiphoridae and Eulopidae are known to attack the mealybugs. Among them, encyrtids, aphelinids and platygastrids play a major role in the regulation of mealybugs.

13.2.1.1 Encyrtidae

Major parasitism in the mealybugs involves members of the wasp family Encyrtidae. The encyrtids are koinobiont endoparasitoids, so that the parasitized mealybug continues to live for a few days, to grow and even to reproduce to some extent. This time gap between parasitization and deterioration of the physiological condition enables the mealybug to confront the immature individual parasitoid by encapsulation. The encapsulation is a common immune defense mechanism that involves the formation of a capsule around the parasitoid egg or larva; it is usually composed of host blood cells and the pigment melanin. The capsule may kill the parasitoid and thus prevent successful parasitism (Blumberg 1997). Various levels of encapsulation have been shown to occur in different mealybug species, in response to parasitism by encyrtids (Blumberg 1997; Blumberg and van Driesche 2001; Chong and Oetting 2007; Giordanengo and Nenon 1990; Sagarra et al. 2000). Conversely, encyrtid parasitoids may use superparasitism as a strategy to overcome the immune response of unsuitable hosts (Blumberg et al. 2001). Besides superparasitism, other factors also affect the frequency of parasitoid encapsulation including: (a) host and parasitoid species; (b) the host's physiological age and condition; (c) the host and parasitoid origins (or strains); (d) the rearing and/or ambient temperature; and (e) the host plant species and stress conditions (Blumberg 1997; Calatayud et al. 2002).

Noyes and Hayat (1994) recorded 49 encyrtid species as parasitoids of mealybugs in India. The family Encyrtidae dominates the parasitoid complex of mealybugs. *Anagyrus*, *Apoanagyrus, Adolescentus*, *Aenasius*, *Leptomastix, Leptomastidea*, *Blepyrus, Gyranusoidea, Praleurocerus, Mahencyrtus, Acerophagus, Coccidoxenoides, Epidinocarsis, Neodusmetia, Hambletonia, Pseudaphycus* and *Alamella* are some of the important genera under encyrtidae attacking the mealybugs. They are sexually dimorphic and both males and females are different from each other. The males are smaller than the females and have hairy antennae. The females have a bright band across the abdomen. The encyrtids are known to attack nymphs and adults of mealybugs. Each species tends to specialize in terms of the stage of development of the host. Certain species like *Blepyrus insularis*, *Coccidoxenoides perminutus*, *Acerophagus papayae* prefer earlier stage that is 5–8-day-old nymphs (early Second instar) for parasitization, whereas species like *Anagyrus dactylopii*, *Leptomastix dactylopii* etc. prefer 15–20-day-old mealybugs (third instar and young adult female). They breed very well when they are exposed to the preferred stage. The duration of the life cycle is about 3 weeks at 25 °C. Mealybugs that are parasitized turn into small cocoons, a little darker in colour than live mealybugs. The young full-grown parasitoid emerges through an exit hole at the distal part of the cocoon, leaving the lid behind. Full development of the parasitoid takes place inside the mealybug. Adult parasitoids feed themselves by piercing the young instars of the mealybugs and sucking from their bodies. By doing so, they can extend their lifespan. This feeding behaviour kills the young mealybug-instars. Parasitized mealybugs turn into a yellow/orange cocoon and become hard (like mummies). These mummies are difficult to see, because of their small size. In this period, a female can lay about 80 eggs, most of them in the first weeks of her life.

Anagyrus is a large genus of the family Encyrtidae that attacks the mealybugs. Some important species like *Anagyrus aegyptiacus, A. dactylopii, A. kamali, A. pseudococci* play the major role in suppressing the mealybugs. Other encyrtids, namely *Leptomastidea abnormis*, *Leptomastix dactylopii*, *Acerophagus papayae, Apoanagyrus lopezii, Aenasius bambawalei* and *Aenasius advena* Comp., are found to be very effective parasitoids of mealybugs.

Anagyrus antoninae (Timberlake)

It is an internal gregarious parasite of *Antonina graminis*. It is oriental in origin but common in Hawaii. It is active in cooler and high-humid areas. The female mates soon after the emergence and starts laying eggs immediately. Attack is on the gravid female mealybugs. The stalked eggs are unattached and free in the body fluids of the mealybug and are hatched in 3–4 days. The larval and prepupal stages cover 8–10 days. The pupal stage takes about 6–8 days, and the total life cycle is completed in 18 days. Up to seven adult parasites emerge per mealybug and the sex ratio is 1:1. It is carried out very well under Florida conditions.

Neodusmetia sangwani (Subba Rao)

It is an internal gregarious parasitoid of *Antonina graminis* and is native to India. Adult females are brachypterous and males are winged. They live only for 2 days. The female produces up to 55 progeny. The sex ratio is 1:7. Life cycle is completed in 17–23 days. Normal dispersal is very slow since the females are wingless. It has done very well under Texas conditions.

Neodusmetia sangwani

Hambletonia pseudococcina

Pseudaphycus mundus **Gahan**

It is mainly a parasitoid of *Dysmicoccus boninensis,* native of Lousiana. It attacks all stages of the mealybug except the first-instar nymphs. It deposits eggs in the body fluids of the mealybug. From 2 to 15 min is required for oviposition. It takes 16–18 days to complete the life cycle. It is solitary in small mealybugs but lays up to 19 eggs on larger mealybugs. It did very well against *D. boninensis* in sugarcane fields at Hawaii.

Hambletonia pseudococcina **Compere**

It is bisexual in Brazil and unisexual in Columbia. The unisexual race was found to be relatively successful against *D. brevipes* in Hawaii. It is a solitary parasitoid. The females attack half-grown mealybugs and takes 24–30 days to complete the life cycle.

Aenasius advena

Aenasius advena Comp is a solitary internal parasitoid of *Ferrisia virgata*. It occurs in large numbers at times on *F. virgata* in guava and other crop ecosystems in India and elsewhere. It prefers 15-day-old mealybugs and the lifecycle is completed in about 18 days. Along with *C. montrouzieri*, *A. advena* gives the perfect control of *F. virgata* on guava and other crop ecosystems in India.

Blepyrus insularis

It is also another internal parasitoid of *F. virgata*, preferring to parasitize the early instars of the mealybugs. It performs very well in glasshouse crops infested with *F. virgata* (Mani and Krishnamoorthy 1991).

Coccidoxenoides perminutus

Coccidoxenoides perminutus Girault (*Pauridia peregrina* Timberlake, *Coccidoxenoides peregrinus* (Timberlake)) is an endoparasitoid of *Planococccus citri* widely present throughout the world. *Coccidoxenoides perminutus* alone or along with other natural enemies is capable of suppressing *P. citri*. Besides *Pl. citri*, it also attacks *Pseudococcus longispinus*, *Pl. ficus* and *Pseudococcus viburni*. Adult parasitoids are black in colour with noticeable translucent wings, with relatively long antennae and are approximately 3 mm long. Females lay their eggs into the first three instars but prefer the second instar of *Pl. citri* and are able to lay 60–90 eggs each. The eggs develop into pupae within the mealybug slowly feeding off the host. About 16 days after egg laying, adult *C. perminutus* wasps emerge from pupae, and are immediately ready to mate and continue the cycle. The speed of the lifecycle is dependent on temperature and humidity. Generally, *C. perminutus* adults are active for about 7 days and are most effective at temperatures between 20 and 30 °C and humidity between 50 and 90 %. Each female lives for approximately 7 days.

Anagyrus fusciventris (Girault)
It is a parasitoid of *Pseudococcus longispinus*. Females are grey-brown in colour and have bright blue eyes. Males are black in colour. Both sexes are about 3 mm in size. Mealybugs that are parasitized turn into small cocoons, a little darker in colour than the live mealybugs. It prefers larger instars for parasitization. The females lay one egg per host; from each parasitized mealybug, one adult wasp will emerge. The lower temperature threshold for the parasitoid is 18 °C. The parasitoid development from egg to adult takes about 3 weeks at a temperature of 25 °C. Full development of the parasitoid takes place inside the mealybug. Adult parasitoids feed themselves by piercing the young instars of the mealybugs and sucking from their bodies. By doing so, they can extend their life span to about 2 months. This feeding behaviour kills the young mealybug instars.


Coccidoxenoides perminutus


Anagyrus fusciventris

Anagyrus pseudococci (Girault)
Anagyrus pseudococci (Girault) is native of Mediterranean areas. It is known to attack *Pl. citri* and *Ps. citriculus.* It attacks all the nymphal stages and the adult females but prefers the third instar of the mealybug. About 45 eggs are laid per female at the rate of three to four per day. The eggs hatch in 44 h and the lifecycle is completed in 18 days at 27 °C.

Leptomastix dactylopii Howard
It is widely used against *Planococcus citri*. Besides *P. citri*, it also breeds well on *Pl. ficus.*

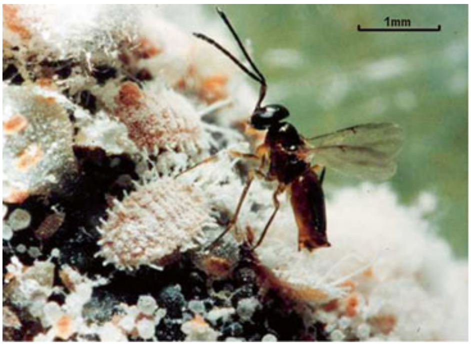
It is a small yellow-/brown-coloured parasitic wasp with distinctively long dark antennae. It is about 3 mm long. Males are smaller and darker than females. The antennae of the females are bended; the antennae of the males are hairy. Eggs are laid in the third instar and in the young adult female mealybug. The females deposit one egg inside the mealybug body. A female lays about 100 eggs. After hatching, the young larva of the parasitoid eats the mealybug from inside out. The parasitized mealybugs turn into a yellow-brown cocoon and become hard (like mummies). The lower temperature threshold for *Leptomastix dactylopii* is 20 °C, but the optimal temperature is 26 °C. At 25 °C, this development takes about 15–17 days.


Anagyrus pseudococci


Leptomastix dactylopii

Leptomastix epona

It is a parasitoid of *Pseudococcus viburni* (*Ps. affinis*) and *Spilococcus cactearum*. Adult wasps are brown-black with thin, long, black antennae. Their wings are mainly translucent with slight dark bands. *Leptomastix epona* is 3 mm in size. Mealybugs that are parasitized turn into yellow cocoon like 'mummies', easily distinguishable from live mealybugs. The adult parasite emerges from a circular exit hole at the proximal end of the cocoon, leaving a 'lid' on the mummy. It mainly parasitizes older instars of *Ps. viburni* and *Spilococcus cactearum*. It lays one egg per mealybug. Mealybugs are killed by the growing larva approximately 10 days after parasitization. Lower temperature threshold for *Leptomastix epona* is 15 °C.



Leptomastix epona

Pseudaphycus maculipennis

Acerophagus maculipennis

Pseudaphycus maculipennis (*Acerophagus maculipennis*) was shown to be an arrhenotokous, synovigenic, gregarious endoparasitoid of *Pseudococcus viburni*. Both females and males lived for 16 and 11 days, respectively, when fed either honey-agar or mealybug honeydew. Relatively, large instars (third instar or adult females) were preferred for oviposition; mated females parasitized more mealybugs than unmated females, and the progeny sex ratio favoured females by 3:1. Egg load increased with age from emergence to day 8, averaging 23 mature eggs per female. Mean realized daily fecundity never exceeded 5, with a mean lifetime fecundity of 46 eggs per female. Parasitized mealybugs remained alive for about 5 days and then mummified. Total development period was 20–21 days (larva 4–5 days, prepupa 3 days, pupa 8–9 days). A mean of 3.0 parasitoids per mealybug were reared after individual parasitism events, increasing through superparasitism (either self or conspecific) to nine parasitoids per mealybug when hosts were exposed to competing females.

Pseudaphycus malinus

It is an internal parasitoid of *Pseudococcus comstocki* believed to be a native of Japan. It develops as a solitary parasite in smaller mealybugs but gregarious in larger mealybugs. Females deposit about 100 eggs in 4–10 days. Incubation is completed in 3 days, larval development in 8 days and pupal stage in 10 days.

Leptomastidea abnormis

Leptomastidea abnormis mainly parasitizes *Planococcus citri*. It is a grey-yellow parasitic wasp, 0.75–1.5 mm in size; dark bands are clearly visible across the wings. Males are smaller than females and have hairy antennae. The females have a bright band across the abdomen. The parasitized mealybugs turn into a yellow/orange cocoon and become hard. Leptomastidea emerges from a circular hole in the proximal end of the mummy. Eggs are laid in the first and second instars of its host, one egg per mealybug. The inconspicuously stalked eggs are laid in the body fluid of the mealybugs and are hatched in 3 days. The tailed larva complete the development in 8 days and the lifecycle is completed in 17 days at

26 °C. Mealybugs are killed by the larva of the parasitic wasp, growing inside the mealybug. Leptomastidea can survive temperatures up to 40 °C.

Acerophagus papayae

It is a solitary endoparasitoid of papaya mealybug *Paracoccus marginatus* A. It parasitizes the early-stage (II instar) nymphs of the mealybug. It is a tiny small wasp with yellowish body, transparent wings and grey/bluish eyes with three black triangular spots in the forehead. The male parasitoid is much smaller than the female parasitoid. This parasitoid affects mainly the second stage after hatching from the egg. Each female is capable of laying 50 eggs in its lifetime of 35 days. Normally, single egg is laid inside a mealybug; occasionally more than one egg is also laid.

Acerophagus papayae

Leptomastidea abnormis

Anagyrus dactylopii

It is the principal parasitoid of *Nipaecoccus viridis* and *Maconellicoccus hirsutus*. It parasitizes all the nymphal instars but prefers third-instar nymph and adult female. They are sexually dimorphic. Males are small, black with branched antennae. Females are larger and brown in colour; complete their life cycle in 15 days.

Anagyrus aegyptiacus

It is a solitary parasitoid of *N. viridis*. Females deposit eggs in all the three nymphal instars and hatch them in 4 days. There are six larval instars. The complete life cycle covers 16 days.

Anagyrus kamali

It is a solitary internal parasite of *Maconellicoccus hirsutus.* The female deposits stalked eggs; the attachment to the host derm is visible as an external protrusion. The eggs hatch in 4 days. There are six larval instars. The combined prepupal and pupal stages cover only 3 days. The life cycle is completed in 18 days at 25 °C.

Anagyrus indicus

The gregarious encyrtid parasitoid, *Anagyrus indicus*, oviposits in all three nymphal stages and in the adult female stage of the spherical mealybug, *Nipaecoccus viridis*. But it prefers to the third nymphal and the adult female mealybugs. The parasitoid development was the fastest, the number of parasitoids emerging was the greatest and the ratio of female to male parasitoids was the highest following oviposition in the third nymphal and the adult female hosts.

Anagyrus ananatis

The encyrtid *A. ananatis* (Subba Rao) prefers to parasitize adult females of *Dysmicoccus brevipes*. It is capable of parasitizing up to 27 mealybugs. It can be found attacking the mealybugs in the presence of ants, although its impact on mealybug mortality is low. When ants are absent, the parasitoid is highly effective in lowering the mealybug populations in pineapple plantings.

Anagyrus indicus

Gyranusoidea tebygi

Gyranusoidea tebygi

It is a native parasitoid of *Rastrococcus invadens* Williams in India. The introduction of *Gyranusoidea tebygi* Noyes into Togo and Benin was capable of eliminating *R. invadens*. It reproduced on first, second and third instars and it avoided hosts that were already parasitized. Host feeding was occasionally observed. Sex ratios of the offspring were male biased in smaller hosts, as opposed to being female biased in larger hosts. Females had longer developmental times than males, developed faster in larger mealybugs than in smaller ones and were always larger than the males emerging from the same host instar. Their size increased with the instar of the host at oviposition. About 90 % of all ovipositions in second- and third-instar nymphs resulted from an attack with multiple stings, starting with a sting in the head of the host for the most part.

Apoanagyrus lopezii

Apoanagyrus (Epidinocarsis) lopezi (De Santis) is a species of the parasitic wasp native to Central America. It is used as a biological control agent against the cassava mealybug *Phenacoccus manihoti* Matile-Ferrero in Africa. The parasitoid is found to parasitize and complete development in all developmental instars of *Ph. manihoti*. However, the parasitoid mortality was high (15 %) when the development took place in the first nymphal instar of the host. Complete development from egg to adult emergence was prolonged in smaller hosts, and the developmental periods recorded were 18, 17, 16 and 14 days for the first, second, third and fourth nymphal instars, respectively. Oviposition commenced within 24 h of emergence and lasted effectively for 6 days, during which 95 % of its eggs were laid and 10–12 large hosts were killed through host feeding. Sex ratio is 1:3.

Aenasius bambawalei

It is a solitary endoparasitoid of *Phenacoccus solenopsis* Tinsley in India and Pakistan. Egg and larval stages of the parasitoid are not visible being an internal feeder, but swelling and poor movement of the parasitized mealybugs were observed after 2–3 days of parasitization. The parasitized mealybugs transformed into dark-brown mummies within 4–7 days. The pupae of *A. bambawalei* Hayat were barrel shaped with dark-brown colour. Duration of the pupal period ranged from 5 to 8 days. Adults emerged by cutting a circular small hole on the mummies after completion of the pupal period. The adults of both the sexes are shiny black in colour. Males were smaller than females. The maximum developmental time was recorded for the second-instar host nymph as compared to the third instar. The males developed faster than the females in all host stages. The overall sex ratio was 1:2. The maximum number of female wasps developed at third-instar nymph (59.6 %), and it was concluded that the third-instar host nymph appeared to be the most suitable host stage for mass rearing.

***Clausenia purpurea* Ishii**

It is a known parasitoid of *Ps. citriculus* and *Ps. comstocki.* It attacks the first and second mealybug instars. Males are rare. Each female deposits about 200 eggs in 15–20 days. Life cycle is completed in 25–30 days.

***Hungariella* spp.**

H. pretiosa (Timverlake) is known to attack *Ps. fraglis*. It is a solitary internal parasitoid of the second-instar mealybug nymphs. Most of 100–200 eggs per female are laid during the first day of its life. The egg enlarges eightfold before hatching. Incubation and larval period are 6 and 17 days, respectively. The life cycle is completed in 23 days. Sex ratio is 1:1. *H. peregrina* (Compere) is attacking *Ps. longispinus*.

***Anarhopus sydneyensis* Timberlake**

It is native of Australia known to parasitize *Ps. longispinus*. It is a solitary parasitoid preferring to attack the third-instar nymphs and the life cycle covers 1 month.

***Tetracnemoidea inica* (Ayyar)**

It is a solitary parasitoid of *Planococcus lilacinus.* It attacks all the nymphal instars but prefers 5-day-old nymphs, which yielded higher number of parasitoids and also female progenies. It takes 26–33 days to complete the life cycle (Mani and Krishnamoorthy 1995).

13.2.1.2 Platygastridae

Parasitoid wasps, belonging to the hymenopteran family Platygastridae (sometimes incorrectly spelled Platygasteridae), are mostly very small (1–2 mm), black and shining, with elbowed antennae that have an eight-segmented flagellum. The wings most often lack venation, though they may have slight fringes of setae. Several species of the genus Allotropa are known to attack mealybugs. They complete the life cycle in 25 days at 25 °C. It oviposits on all the three nymphal stages and on the adult female mealybugs. It prefers 10–15-day-old mealybugs (second and early third instar nymphs) for parasitization. Adults are small and short lived (Mani and Krishnamoorthy 1989; Clancy 1944; Gilliat 1939). They play a supplementary role in suppressing the mealybugs.

Allotropa burrelli

Allotropa burrelli Mues. is a gregarious parasitoid of *Pseudococcus comstocki* (Kuw.), with incubation stage averaging 9.5 days and larval stage averaging 6.5 days. There is a single larval instar; prepupa averaging 2.0 days; pupa averaging 13.0 days. The sex ratio has ranged from 2:1 to 3:1, with females predominating. The adults are small and short lived, and oviposit at random in the host body cavity. There is no preoviposition period. All nymphal stages of the mealybugs are attacked, but a preference is shown for those at least half grown. The life cycle ranges from 26 to 38 days, with an average of 31 days.

Allotropa citri

It can parasitize all stages of *Pseudococcus cryptus*. It prefers the first- and the second-instar nymphs. The lower developmental threshold temperature and thermal constant of *A. citri* for the first- and second-instar nymphs of *P. cryptus* were 10.1 °C and 518.1 degree-days (DD), respectively.

Allotropa suasaardi

Allotropa suasaardi Sarkar and Polaszek is a parasitoid of *Phenacoccus manihoti* Matile-Ferrero on cassava in Thailand. The mean developmental time was shorter and a higher number of progeny were produced in *Dysmicoccus neobrevipes* followed by *Ph. manihoti*.

Allotropa japonica

Allotropa japonica is a platygastrid parasitoid of *Maconellicoccus hirsutus* (Green). It oviposits on all the three nymphal stages and the adult female mealybugs. Freshly laid eggs of *A. japonica* are very small, elongated, whitish and transparent. They become more or less spherical after 24 h. Incubation period ranges from 4 to 6 days, the average being 5.5 days. Usually one to three eggs are found in a parasitized mealybug. The larval development is completed in 4–6 days, there is but one larval instar with ten body segments. Prepupal and pupal periods last for 2–3 days and

12–90 days, respectively. The total life cycle of *A. japonica* sp. n. is completed in 25.5 days. Adults are small and short-lived. Longevity of the adults ranges from 7 to 11 days. The males have long, hirsute, moniliform antennae, while the females have shorter and distinctly clavate antennae. Mating and oviposition takes place readily. The adults exhibit a very good searching capacity. A maximum of 238.16 parasitoids was obtained when the third-instar nymphs of 15 days old were offered to *A. japonica* sp. n. for parasitization (Mani and Krishnamoorthy 1989)

***Allotropa utilis* Muesbeck**

It is an internal, solitary parasitoid of nymphs of *Phenacoccus aceris* (Signoret) and *Ph. pergandi* Ckll, native of Nova Scotia. It is reported to have a single generation. It attacks the smaller nymphs from July to October. Eggs laid in the body fluid of the mealybugs increase sixfold during incubation. Overwintering is by immature larvae in the parasitized mealybugs. Pupation occurs in the spring. The adult emergence takes place in May from the overwintering host nymphs.

13.2.1.3 Aphelinidae

Along with Encyrtidae, this 'family' provides most of the biocontrol agents. Aphelinids are small, soft-bodied parasitic wasps, yellow or brown in colour and do not typically exceed 1.5 mm in length. The larvae of the majority are the primary parasitoids on mealybugs. They are found throughout the world in virtually all habitats and are extremely important as biological control agents. With regard to their biology, Aphelinidae more closely resemble Encyrtidae. Characters uniting the family Aphelinidae are not apomorphic; that is, they are not uniquely derived. The characters of Aphelinidae are complete notaular lines of the mesoscutum; transverse or broad petiole (propodeum); long marginal; short stigma; and short or absent postmarginal wing veins; and third valvula distinctly separated and articulated with third valvifer. These character combinations might also serve to differentiate Aphelinidae from other families of Chalcidoidea.

Adult aphelinids may feed on honeydew exuded by their hosts or on secretions issuing from the wound caused during oviposition. The eggs of aphelinids are often stalked. A number of endoparasitic species have an apneustic caudate primary larva. Those that are endoparasitoids (e.g. *Coccophagus*) have larvae with neither spiracles nor a functioning tracheal system. Some species pupate inside the living host within a pupation chamber, which becomes filled with air. There is some evidence that the air inside this chamber is derived from the hosts' tracheal system as in the Encyrtidae. Parasitoids emerge by cutting a hole through the integument of the host mummy; but if the mealybug has a delicate covering, they push their way out from beneath it. The adults of some such species lack functional mandibles. Overwintering is normally as a mature larva or pupa. The Aphelinidae are very unusual in that the males and females may have different ontogenies. The females of such species always develop as primary endoparasitoids of mealybugs.

Coccophagus gurneyi

It is quite polyphagous and is native of Australia. It is a solitary internal parasitoid of all the nymphal instars of *Ps. fragilis, Ps. comstocki* and *Ps. longispinus. Coccophagus gurneyi* Compere has a complex developmental biology. The female-producing eggs are laid free in the body fluids of the mealybug, where they hatch in about 4 days at 27 °C. The larva develops in 10 days followed by a 2-day prepupal stage and an 11-day pupal stage. The total duration goes up to 44 days. The male-producing egg of the parasitoid is deposited in the developing larva of the female parasitoid. It gave a good control of *Ps. fragilis* in South Africa and Chile.

13.2.1.4 Other Families

There are species belonging to the families Braconidae, Eucoilidae, Signiphoridae, Eulopidae and Pteromalidae that are known to attack the mealybugs but are of minor importance (Table 13.2).

Table 13.2 List of some important encyrtid parasitoids of mealybugs

Parasitoid	Mealybug
Hymenoptera, Encyrtidae	*Maconellicoccus hirsutus*
Anagyrus kamali Moursi	
Apoanagyrus (Epidinocarsis) lopezi (De Santis)	*Phenacoccus manihoti*
Anagyrus ananatis Gahan	*Dysmicoccus brevipes*
Hambletonia pseudococcina Compere	*D. brevipes*
Anagyrus aegyptiacus Moursi	*Nipaecoccus viridis*
Anagyrus dactylopii (Howard)	*M. hirsutus and N. viridis*
Anagyrus pseudococci (Gir.)	*Planococcus citri*
Anagyrus fusciventris (Girault)	*Pseudococcus longispinus*
Anagyrus loecki Noyes and Menezes	*Paracoccus marginatus* and *Phenacoccus madeirensis*
Anagyrus punctulatus Agarwal	*Saccharicoccus sacchari*
Anagraphus sp.	*P. citri*
Pseudectroma sp.	*Pseudococcus viburni*
Acerophagus maculipennis (Mercet)	*Pseudococcus viburni*
(*Pseudaphycus maculipennis*)	
Acerophagus notativentris (Girault)	*Ps. longispinus*
Arhopoideus peregrinus (Compere)	*Ps. longispinus*
Anarhopus sydneyensis Timberlake	*Ps. longispinus*
Leptomastidea abnormis (Girault)	*Pl. citri*
Leptomastix dactylopii Howard	*Pl. citri*
Leptomastix epona (Walker)	*Pseudococcus affinis* and *Spilococcus cactearum*
Pseudleptomastrix mexicana Noyes and Schauff	*Pa. marginatus*
Praleurocerus viridis (Agarwal)	*Rastrococcus iceryoides*
Pseudaphycus phenacocci Yasnosh	*Phenacoccus mespili*
Pseudaphycus utilis Timberlake	*Nipaecoccus nipae*
Pseudaphycus malinus Gah.	*Ps. comstocki*
Pseudaphycus angelicus (Howard)	*Pseudococcus maritimus*
Acerophagus notativentris (Girault)	*Pseudococcus maritimus*
Apoanagyrus (Epidinocarsis) lopezii De Santis	*Phenacoccus manihoti*
Gyranusoidea tebygi Noyes	*Rastrococcus invadens*
Gyranusoidea indica Shafee, Alam and Agarwal	*M. hirsutus*
Praleurocerus viridis (Agarwal)	*Rastrococcus icerioides*
Acerophagus papayae Noyes and Schauff)	*Paracoccus marginatus*
Aenasius bambawalei Hayat	*Penacoccus solenopsis*
Aenasius advena Comp.	*F. virgata*
Aenasius abengouroui (Risbec)	*Planococcus njalensis*
Cheilonerus sp.	*M. hirsutus*
Alamella flava (Agarwal)	*M. hirsutus*
Tetracnemoidea indica Ayyar	*Planococcus lilacinus*
Acroaspidia myrmicoides (Comp and Zinna)	*F. virgata*
Blepyrus insularis (Camp.)	*F. virgata*
Bothriocraera bicolor (Comp and Zinna)	*F. virgata*
Chrysoplatycerus splendens How.	*F. virgata*
Neodiscodes martini Comp.	*F. virgata*
Neodusmetia sangwani (Subba Rao)	*Antonina graminis*

(continued)

Table 13.2 (continued)

Parasitoid	Mealybug
Tananomastix abnormis Gir.	*F. virgata*
Zarhopalus inquisitor How.	*F. virgata*
Neodusmetia sangwani (Subba Ra)	*Antonina graminis*
Rhopus nigroclavatus (Ashmead)	*Brevennia rehi*
Leptomastix nigrocincta Risbec	*Coccidohystrix insoilta*
Leptomastix nigrocoxalis Compere	*Coccidohystrix insoilta*
Leptomastix epona (Walker).	*Spilococcus cactearum*
Leptomastidea abnormis (Girault)	*Pl. citri*
Leptomastix dactylopii How	*Pl. citri*
Pseudleptomastrix mexicana Noyes and Schauff	*Pa. marginatus*
Alamella flava Agarwal	*Pl. citri*
Coccidoxenoides perminutus (Timberlake)	*Pl. citri*
Platygasteridae	*Pl. citri*
Allotropa citri Mues.	
Alltropa japonica sp. nr	*M. hirsutus*
Allotropa burrelli Mues.	*Pseudococcus comstocki*
Allotropa *utilis* Mues.	*Phenacoccus aceris*
Allotropa convexifrons Mues.	*Pseudococcus comstocki*
Allotropa mecrida (Walker)	*M. hirsutus, P. citri*
Leptacis sp.	*Pseudococcus* sp.
Braconidae	
Phanerotoma dentata (Panzer)	*M. hirsutus*
Trioxys angelica Hal	*F. virgata*
Eucoilidae	*M. hirsutus*
Leptopilina sp.	
Signiphoridae	*M. hirsutus*
Chartocerus walkeri sp. nr.	
Chartocerus spp.	*C. insolita*
Aphelinidae	*M. hirsutus*
Aphelinus sp.	
Erioporus aphelinoides (Comp.)	*M. hirsutus*
Coccophagus caridei (Brethes)	*Planococcus citri*
Coccophagus sexvittatus Hayat	*Rastrococcus invadens*
Coccophagus sexvittatus Hayat	*Rastrococcus iceryoides*
Coccophagus gurneyi Comp.	*Ps. calceolariae*
Coccophagus pseudococci Compere	*C. insolita*
Eulopidae	*F. virgata*
Syntomosphyrum zygaenarum Ferriere	
Aprostocetus ajmerensis (Khan and Shafee)	*C. insolita*
Pteromalidae	*F. virgata*
Anysis alcocki Ashm.	
Catolaccus crassiceps (Masi)	*C. insolita*

13.3 Entomopathogens

The wax cover and the secretion process are involved in mealybug defence against natural enemies particularly the pathogens. Among the microbes, only the entomopathogenic fungi are recorded as causing natural infection against the mealybugs and these records are sparse and confused. The pathogens of the mealybugs appear to be restricted as yet to the Zygomycotina and Deutromycotina and the former to the class Zygomycetes. The class contains two orders, namely Mucorales and Entomophthorales. Table 13.3 records a number of pathogens from the mealybugs. Pathogenicity of many of the pathogens have not been seen on mealybugs. Some of the records might have resulted from saprophytic growth on the dead mealybugs. A total of 13 pathogens were reported in different countries (Moore 1988).

Neozygites fumosa Speare was found to be a very important natural agent in regulating the mealybug *Phenacoccus manihoti* Matile-Ferrer in Congo (Le Ru 1986). Development of epizootics appeared to be influenced by a relative humidity of 90 % or more, minimum daily temperatures greater than 20 °C and the mealybug density. Adult mealybugs are more susceptible than the

Table 13.3 List of entomopathogens and entomopathogenic nematodes recorded on mealybugs

Pathogens/nematodes	Mealybugs
Entomopathogens	
Fusarium pallidoroseum (Cooke) Sacc	*Phenacoccus solenopsis*
Fusarium equiseti (Corda) Sacc	*Coccidohystrix insolita*
Verticillium lecanii (Zimm.)	*Paracoccus marginatus*
Lecanicillium (*Verticillium*) *lecanii* (Zimm.)	*Phenacoccus solenopsis,* M. hirsutus
Metarhizium anisopliae (Metsch.) Sorokin	Root mealybugs (*Planococcus* sp., *Planococcus citri*, *P. lilacinus*, *Dysmicoccus brevipes* and *Ferrisia virgata*
Metarhizium anisopliae	*Maconellicoccus hirsutus*
Metarhizium sp.	*Dysmicoccus boninsis*
Pseudomonas fluorescens Migula	*Paracoccus marginatus*
Beaveria bassiana (Bais-Criv) Vuill	*Paracoccus marginatus*
Neozygites fumosa (Speare)	*P. citri, Phenacoccus* sp., *Phenacoccus manihoti*
Cladosporium sp.	*Phenacoccus herreni* Cox and William
Entomophthora fumosa Speare	*Planococcus citri*
Entomophthora fresenii (Nowak.)	*P. citri, F. virgata, Nipaecoccus nipae*
Aspergillus parasiticus Speare	*Saccharicoccus sacchari, Dysmicoccus boninsis, Planococcoides njalensis* (Laing)
Aspergillus flavus Link	*Pseudococcus calceolariae* (Maskell) *Dysmicoccus boninsis* (Kuwana) *Saccharicoccus sacchari* (Cockerell)
Cephalosporium sp.	*Planococcoides njalensis* (Laing)
Cladosporium oxysporum Berk and M.A. Curtis	*Planococcus citri* (Risso)
Conidiobolus pseudococci (Speare)	*Pseudococcus calceolariae*
Hirsutella sphaerospora H.C. Evans and Samson	*Rastrococcus invadens*
Entomopathogenic nematodes	
Steinernema thermophilum Ganguly and Singh	*Phenacoccus solenopsis*
Steinernema meghalayensis sp. n.	*Phenacoccus solenopsis*
Steinernema riobrave Cabanillas, Poinar and Raulston	*Phenacoccus solenopsis*
Steinernema harryi. sp. n.	*Phenacoccus solenopsis*
Heterorhabditis zealandica Poinar	*Pseudococcus viburni*

immature mealybugs. Besides *Neozygites fumosa*, the fungi that have been confirmed as pathogenic to mealybugs are *Hirsutella sphaerospora*, *Verticillium lecanii, Aspergillus parasiticus* and possibly *Cladosporium oxysporum. Entomophthora fumosa* caused up to 58.1 % mortality of the third-instar nymphs and adult *Planococcus citri* (Risso) in a period of high rainfall and humidity in the wet season in January (Murray 1978). The fungal pathogen *Metarhizium anisopliae* (Metsch.) Sorokin was found to cause 79.6 % reduction in the mealybug population, 30 days after the treatment under laboratory conditions (Devasahayam and Koya 2000). *Beauveria bassiana* (Bals.) Vuill and *Metarhizium anisopliae* (Metschn.) Sorokín, *Lecanicillium lecanii* (Zimm.) Zare and W. Gams and *Isaria fumosoroseus* (Wize) were found pathogenic to *Maconellicoccus hirsutus* Green at 15 and 20 °C. The fungus *Beauveria bassiana* (Bals.-Criv.) Vuill. was found to cause high mortality in short time periods in adult females of the mealybug *Dysmicoccus texensis* (Tinsley) (Andalo et al. 2004). *Fusarium pallidoroseum* caused 80–95 % mortality of *Ph. solenopsis* (Monga et al. 2010). The fungal pathogen *Lecanicillium* (*Verticillium*) *lecanii* was found to be pathogenic to *Ph. solenopsis* in Tamil Nadu (Banu et al. 2010). Cadavers of *Ph. solenopsis* infected with *Fusarium pallidoroseum* (Cooke) Sacc were collected from Haryana and Punjab during 2007–2010. In the laboratory, *F. pallidoroseum* caused 80–95 % mortality of *P. solenopsis* (Monga et al. 2010). The fungal pathogen *Lecanicillium* (*Verticillium*) *lecanii* was found to be pathogenic to *Ph. solenopsis* in Tamil Nadu (Banu et al. 2010).

In vitro application of *Verticillium lecanii*, *Beauveria bassiana*, *B. brongniartii* and *Metarhizium anisopliae* at single dose (1×10^7 conidiospores/mL) against *P. citri* inflicted a mortality of 91.1, 75.5, 66.6 and 45.3 %, respectively. *Verticillium lecanii* at five doses (ranging from 1×10^5 to 1×10^9 conidiospores/mL) caused a mortality of 45, 65, 80, 90 and 95 %, respectively (Saranya 2008). *Pseudomonas fluorescens* Migula, a common Gram-negative, rod-shaped bacterium, as foliar application, was found to cause 72 % reduction in the mealybug population (*Pa. marginatus)*.

Root mealybugs: Drenching of 3 % Neem seed kernel extract (NSKE) and *Verticillium lecanii* Econil 7 g/L) was effective against the root mealybugs (Smitha and Mathew 2010).

13.4 Entomopathogenic Nematodes

Entomopathogenic nematodes (EPNs) have potential for biological pest control and have been successfully used in several countries in soil and cryptic pest control. It is hypothesized that the rarity of infestation by nematodes is related to the wax shield. Stuart et al. (1997) found a varied susceptibility of *Dysmicoccus vaccinii* Miller and Polavarapu to several nematode species; they showed that the removal of the waxy coating from the mealybug did not influence their susceptibility to *Heterorhabditis bacteriophora* Poinar. *Heterorhabditis bacteriophora* has been successfully shown to kill mealybugs. *Planococcus citri* was found to be the most susceptible to *Steinernema yirgalemense* and *Heterorhabditis zealandica*, causing 97 % and 91 % mortality, respectively.

In Western Cape Province, South Africa, an isolate of *Heterorhabditis zealandica*, has resulted in mortality of *Pseudococcus viburni* (Signoret) up to 80 % after 48 h. All stages of *P. viburni* beyond crawlers appeared to be susceptible to the nematode infection. Hence, the control in the field should take place when the intermediates and adults are most abundant (Stokwe and Malan 2010). In India, *Steinernema thermophilum* caused 83 % mortality of the mealybug (*Ph. Solenopsis*) within 72 h after inoculation at 50 IJ/mL and 100 % within 48 h at 500 IJs/mL. *Steinernema riobrave* and *S. harryi* n. sp. produced intermediate mortality of about 66 % within 60 h at 500 IJs/mL. Emergence was observed only in 16.6 % of the mealybug cadavers infected with *S. thermophilum* and *S. harryi* sp. nr. Entomopathogenic nematode *Steinernema glaseri* was also known to cause mealybug mortality under laboratory conditions.

The nematode *Steinernema carpocapsae* (Weiser) was found to cause high mortality in short time periods in adult females of the mealybug *Dysmicoccus texensis* (Tinsley) (Andalo et al. 2004). The aqueous suspension of EPN (JPM3) was more efficient with 70 % control efficiency on the root mealybug *Dy. texensis* (Alves et al. 2009). *Heterorhabditis bacteriophora* Poinar strain HC1 was known to cause 100 % mortality in the inoculated coffee mealybug complex (Rodriguez et al. 1998). *Dysmicoccus texensis* is an example for the coffee root mealybug. Greenhouse results demonstrate that the aqueous suspension (JPM3) was more efficient with 70 % control efficiency.

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Semiochemicals in Mealybugs 14

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A semiochemical (from Greek *semeon* meaning "signal") is a generic term used for a chemical substance or mixture that carries a message for purpose of communication. Semiochemical communication can be divided into two broad classes: communication between individuals of the same species (intraspecific) or communication between different species (interspecific). It is usually used in the field of chemical ecology to encompass pheromones, allomones, kairomones, attractants, and repellents. Many insects, including parasitic insects, use semiochemicals, which are natural chemicals released by an organism that affect the behaviors of other individuals. Pheromones are intraspecific signals that aid in finding mates, food and habitat resources, warning of enemies, and avoiding competition. Interspecific signals known as allomones and kairomones have similar functions.

The existence of female sex pheromone in a coccid, *Matsucoccus resinosae* Bean and Godwin, was first demonstrated by Doane (1966), followed by other coccid *Aonidiella aurantii* (Makell) (Tashiro and Chambers 1967). Identification and synthesis of sex pheromone in *A. aurantii* became a turning point in the pheromone research for the coccoids (Roelofs et al. 1978). In Italy, the sex pheromone released by females of *Planococcus citri* (Risso) was extracted from unmated females (Rotundo and Tremblay 1976). The identification of sex pheromones of several mealybug species has facilitated the development of monitoring techniques and management tactics based on these compounds. However, experience shows that the efficiency of tactics such as mass trapping, mating disruption, and lure and kill may be constrained by a lack of knowledge of basic features of the life history and mating behavior of male insects and the mechanisms involved in their interactions with pheromone sources. A comprehensive account of pheromones of coccoids was provided by Dunkelblum (1999) in the book "Pheromones of Non-lepidoteran Insects".

14.1 Mealybug Pheromone Characteristics

These pheromones all share a number of desirable characteristics and also some undesirable characteristics for use in pheromone trapping.

- Sex pheromones are very powerful attractants for male mealybugs. The males hide and live in protected areas and are not harmed by the insecticides. Using pheromones even small populations can be detected at earlier stages of occurrence.

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- The standard rubber septum-type pheromone lures remain attractive for 2–3 months under field conditions, minimizing the number of lure changes required throughout one season.
- The lures require only a tiny dose of pheromone (0.025 mg or less), which will help to keep lure manufacturing costs down.
- The chemical structure of each pheromone is different; therefore, each pheromone specifically attracts only its own species. Sometimes in the orchards with more than one mealybug species, pheromones could be combined to lure or to attract several species simultaneously (Waterworth et al. 2011).
- Multi-season plastic Delta traps are sugested for monitoring and mass trapping most invasive insect pests.
- Most pesticides require direct contact with the mealybug; hence, it will not be effective against those under the bark. Many of the "softer" insecticides are not able to penetrate the waxy exterior; however, pheromones are volatile molecules dispersed through the air and sensed by the insect without requiring penetration-reach target spot.
- A possible alternative to visual sampling, which may both decrease monitoring time and increase the sensitivity of mealybug detection methods, is the use of pheromone-baited traps. Specifically, pheromone traps were more sensitive than visual methods for detecting mealybug infestations. The number of insects caught on traps was correlated with mealybug abundance in the field indicating that pheromone traps can be used in place of laborious, and annual sampling to monitor the mealybug populations.
- A second benefit of the pheromone use over conventional broad-spectrum pesticides was that the ecological balance and natural predator populations were preserved. Secondary pest populations often surge later in the season when broad-spectrum pesticides are used because the pesticides kill natural predators of the primary pest, but with the use of pheromones pest resurgence was contained.
- Vine mealybug pheromones are often integrated into pest management systems, particularly for the first several years when pest pressure is high. When used in management systems, they are often combined with neonicotinoids, insect growth regulators, or other biopesticides.
- Pheromone traps were used to determine, for example, mealybug species composition, relative seasonal abundance, and density. In the vineyards infested with mixed mealybugs, using traps activated with pheromones, it was found that *Planococcus ficus* was more abundant than *Planococcus citri* in Italy (Ortu et al. 2006).
- The ability of the pheromone control programs to target a specific pest and not harm pollinator bees and beneficial insects pays big dividends.
- This can also be an advantage and a disadvantage that mealybugs have been caught in traps located over one quarter mile from the nearest known infestation.
- The sensitivity of the multiplex polymerase chain reaction (PCR) to identify adult males collected in pheromone traps was shown, with reliable identification of *Pl. ficus* aged for 6 days in pheromone traps (Daane et al. 2011)

14.2 Techniques for Isolation of Pheromones

The pheromones of moths, due to their larger size, were easily identified using the electrophysiological and analytical techniques; however, it is difficult to identify the pheromones from mealybugs mainly due to their smaller size and availability in lesser quantity of pheromones. Large numbers of virgin females of mealybugs were required for the extraction of the female sex pheromone (Rotundo and Tremblay 1976). The large-scale production of mealybugs is done on potato sprouts or ripe pumpkins in several countries (Smith and Armitage 1920; Joshi et al. 2010; Ahmad and Ghani 1970; Chacko et al. 1978). Behavioral attributes such as age of the calling females and influence of photo/scoto phases and host plants complicate the process of pheromone identification in mealybugs. For the isolation and identification of coccoid sex pheromones, continuous mass rearing of virgin females is required, along with the sufficient numbers of males for bioassays. Sexual separation of males was done either through the mechanical separation using a water spray/brush or through the application of juvenoids, which selectively prevent male maturation. Pheromone production in virgin females of *Pseudococcus calceolariae* was not appreciably affected by the juvenile hormone treatment (Rotundo 1978). Compounds such as dichlorvos, triprene, RO 10–3108, etc. have been used for the collection of females.

As a first stage in research on the nature of the female sex pheromone of the citrus pest *Pseudococcus calceolariae*, a method was described for collecting and extracting the pheromone from the air above virgin females reared on potato sprouts in the laboratory; virgin females sexed by insect growth regulators (which prevented the development of males) and maintained with or without food produced pheromones for about 16 days. Out of three absorbent materials tested, Poropak Q proved to be the most effective in absorbing the pheromone, which was eluted from it with ethyl ether and concentrated by distillation or evaporation of the solvent in nitrogen and the active fraction was subjected to gas–liquid chromatography. All pheromone samples were evaluated by bioassay on the Poropak in an olfactometer into which males were introduced, or on filter paper in a petri dish containing males (Rotundo et al. 1979a, b). In the course of rearing *Pseudococcus comstocki* (Kuw.) on ripe pumpkins in a laboratory in Japan, it was found possible to separate the sexes by the simple expedient of wrapping the pumpkins on which the mealybug was being reared in a double-folded sheet of tissue paper. Only the male nymphs crawled into the paper. Adult males crawled out from the papers and began to fly soon after a lamp was lit (Negishi et al. 1980a).

14.3 Pheromone Glands

The site of production and release of sex pheromones in female mealybugs have not yet been determined, although it has been suggested that it might be the translucent pores on the hind legs coxae (metathoracic legs) (Gullan and Kosztarab 1997). The source of pheromone gland was suspected to be the abdominal glands for several species of mealybugs. The pygidial glands were identified as the pheromone-producing glands, the secretions of which are released through the anus via a fragile duct. The production of pheromone and the response of the males to the pheromonal glands vary with the rearing conditions. Feral mealybugs produce and respond to compound 1, whereas lab-reared adults reared on potato sprouts produce and respond to both the compounds (Zada et al. 2003). For the collection of pheromone, entrapment method using adsorbent compounds such as tenax, Porapak Q or cold trapping was followed. The pheromone gland extracted with glacial acetic acid or absolute ethanol was the most attractive pheromone formulation for *Planococcus citri* (Hwang and Chu 1987b). The plants that release volatiles (such as lemon) need to be avoided as laboratory host to keep away the possible interference of these plant volatiles in the pheromone collection. Potato tubers or potato sprouts are considered to be the best rearing media for the collection of pheromone.

14.4 Behavior of Male Mealybugs

The male mealybugs are known to fly about one-half mile. The adult males usually respond to the pheromone gland secretions, and this was confirmed through electrophysiological and behavioral studies. The daily rhythms of pheromone production and the responsiveness of males were very important. The males of *P. citri* were inactive in scotophase but were very active for 30 min after the beginning of photophase. However, the activity ceased after exposure to light. Besides the adult males, immature stages of mealybugs also respond to the pheromones of the female. Second-instar nymphs of mealybugs (*Pl. citri*, *Ps. cryptus*, *N. viridis*, and *Pl. ficus*) responded to the conspecific female sex pheromone directing the males themselves to a suitable pupation site near conspecific non-sibling mature females, thus preventing in breeding. Male nymphs are not attracted to heterospecific female pheromones; the repellency of heterospecific sex pheromones to males directed to look for a pupation site to avoid close contact with heterospecific females (Mendel et al. 2003, 2012). Pheromotypes were also known to occur in *Planococcus ficus* (Signoret) (Kol-Maimon et al. 2010). The males of *Pseudococcus calceolariae* on citrus were able to move against the wind in a zigzag progression (a klinotactic response), even in the absence of pheromones. In still air, they responded to the pheromone source (a wad of cotton wool bearing 100 *u* 1 of an ether extract of females), from within a radius of about 3 cm. In the presence of wind at the optimal speed (0.5 m/s) carrying the pheromone, they moved directly toward the pheromone source, even from a distance of over 1 m (a tropotactic response) (Rotundo et al. 1980). The turntable olfactometer method appeared to be the most efficient to study the attractiveness of the female sex pheromone of *Planococcus citri* to adult males. Forty 6–18-day-old females provided a sufficient pheromone source, and red color sticky card was the most attractive. During the scotophase, there was little flight by males; they were attracted to the pheromone with an obvious peak within 30 min after the beginning of the photophase. Male activity ceased 2 h after exposure to light (Hwang and Chu 1987b). The responses of males to the extracted fractions showed that virgin females of both species *Pseudococcus calceolariae* and *Planococcus citri* had no circadian rhythm of sexual activity but emitted the pheromone consistently and continuously throughout the day until mated (Rotundo and Tremblay 1980).

14.5 Male Flight and Mate Location

In light of the pattern observed among the few species whose sex pheromones were identified, mate location by mealybug males seems to rely mainly on chemical cues, that is, adult females of biparental mealybug species utilize sex pheromones to attract males (Dunkelblum 1999). Males of *Pl. citri*, *Pl. ficus*, and *Ps. comstocki* are morning fliers, whose flight begins just after sunrise (Moreno et al. 1972, 1984; Ortu and Delrio 1982; da Silva et al.2009a, b, c; Zada et al. 2008); males of *Maconellicoccus hirsutus* and *Nipaecoccus viridis* (Newstead) fly mainly around sunset (Francis et al. 2007); and males of *Ps. calceolariae* fly both in the early morning and late afternoon (Rotundo and Tremblay 1976). Moreno et al. (1984) suggested that the daily cycle of *Pl. citri* male flight activity is determined by the scotophase period and its onset in response to exposure to light. In light of the findings of Moreno et al. (1984) and O. Bar-Shalom and Z. Mendel (unpublished data), an endogenous circadian rhythm, imprinted by the photoperiod, may also be involved. Recently, Mendel et al. (2008) and da Silva et al. (2009a, b, c) studied seven mealybug species of the genera *Planococcus*, *Pseudococcus*, and *Nipaecoccus* to estimate for how long and at which physiological age the mealybug males are sexually active. Adult males take 30–40 h to achieve sexual maturity before being able to fly or to mate. Most mature males live for 2–3 days, during which mating opportunities may be continuously available, but searching for a mate by flight is limited to 2–4 h per day. The finding that mealybug males appear to fly only after exposure to daylight suggests that visual cues also may be involved in male flight and mate location. Findings of recent experiments aimed at studying the effects of the color and design of sticky traps baited with sex pheromone on male captures support this hypothesis (Franco et al. 2008a). The lack of simple eyes in apterous males of polymorphic species of mealybugs, such as *S. sacchari* (Afifi 1968), is also an indirect evidence that vision might be involved in male mealybug flight and mate location. As in other neococcoid families, mealybug males typically have a pair of dorsal and ventral simple eyes plus a pair of smaller lateral ocelli (Afifi 1968; Gullan and Kosztarab 1997). There is a lack of clear knowledge about the functional aspects of this bizarre visual system. Duelli (1985) suggested that the eyes in scale insect males are positioned in a horizontal ring around the head because the male's body axis is maintained almost vertical during flight. The main purpose of the eyes would be to monitor the presence of females in conjuction with pheromones.

Unlike neotenic adult females, male mealybugs are active fliers, do not feed, and they live only a few days. The response of males of different ages to a synthetic pheromone and virgin females was tested. In the petri dish bioassay, class I males (up to 10 h after eclosion) and less than 20 % of class II males (10–29 h after eclosion) responded to the pheromone or virgin females. On the other hand, most of class III males (29 or more hours after eclosion) showed a clear response. After eclosion, most *P. citri* males need to complete a period of sexual maturation of at least 30 h before they can respond to the sex pheromone and mate. Without mating, the maximal lifespan of males was approximately 5 days and 50 % of males lived only up to 4.4 days (25.0 ± 0.5 °C). Most *P. citri* males have less than 3 days to find a receptive female and mate with her. However, since *P. citri* males only fly within a period of approximately 4 h after sunrise, the total effective time available for mate location by flight is only less than 12 h (da Silva et al. 2009a, b, c).

14.6 Identification/Isolation of Pheromones

Using sophisticated analytical and bioassay instruments such as gas chromatography–mass spectral detector (GCMS), gas chromatography electroantennogram detector (GCEAD), vibrational circular dichroism (VCD) spectroscopy, and nuclear magnetic resonance (NMR) spectroscopy, the sex pheromones of some economically important species of mealybugs have been identified and synthesized. These include the Comstock mealybug *Pseudococcus comstocki* (Negishi et al. 1980b), citrus mealybug *Planococcus citri* (Bierl-Leonhardt et al. 1981), vine mealybug *Planococcus ficus* Signoret (Hinkens et al. 2001), citriculus mealybug *Pseudococcus cryptus* Hempel (Arai et al. 2003), pink hibiscus mealybug *Maconellicoccus hirsutus* (Green) (Zhang et al. 2004), obscure mealybug *Pseudococcus viburni* (Millar et al. 2005b), grape mealybug *Pseudococcus maritimus* (Ehrhorn) (Figadère et al. 2007), passionvine mealybug *Planococcus minor* (Maskell) (Ho et al. 2007), Japanese mealybug *Planococcus kraunhiae* (Kuwana) (Sugie et al. 2008), long-tailed mealybug *Pseudococcus longispinus* (Millar et al. 2009), Madeira mealybug, *Phenacoccus madeirensis* Green (Ho et al. 2009), citrophilous mealybug *Planococcus calceolariae* (Maskell) (El-Sayed et al. 2010) and *Dysmicoccus grassii* Leonardi (de Alfonso et al. 2012).

All known mealybug pheromones are monoterpenoid esters, mostly of simple acids. However, most of them are irregular non-head-to-tail monoterpenoids, with unusual connections of two isoprene units (Millar and Midland 2007). The majority of naturally occurring isoprenoid compounds that have been identified have 1´–4,head-to-tail linkages between isoprenoid units, whereas most irregular terpenoids with non-head-to-tail linkages have been found in members of the plant family Asteraceae (Rivera et al. 2001). Non-head-to-tail isoprenoid compounds are produced in three biosynthetic reactions, that is, cyclopropanation, branching, and cyclobutanations (Thulasiram et al. 2008). Millar and Midland (2007) suggested that terpenoid biosynthetic pathways in mealybugs are distinctly different from the typical terpenoid pathways found in other organisms, representing a variety of enzymes that can catalyze cyclizations and rearrangements. On this basis, and considering that mealybug endosymbionts are believed to be important to the nitrogen and sterol requirements of their hosts and may play a role in physiological processes such as resistance to microbial pathogens or detoxification of plant secondary compounds, we tend to speculate that these enzymes may originate, at least in part, from mealybug endosymbionts. Thus, for example, a variety of symbionts associated with bark beetles are capable of producing compounds that are used as pheromones. Spectroscopically, pheromones have been isolated and identified from several species of mealybugs. A list of pheromones identified for several species is given in Table 14.1.

Table 14.1 Pheromone compounds identified from different species of mealybugs

Sl. No.	Species	Chemical identified	Identification reference	Synthesis references
1	*Crisicoccus matsumotoi* (Siraiwa)	3-methyl-3-butenyl-5-methyl-hexanoate	Tabata et al. (2012)	Tabata et al. (2012)
2	*Maconellicoccus hirsutus* (Green)	Trans-1R,3R-chrysanthemyl (R)-2-methyl butanoate and (R) lavandulyl (R) methyl butanoate (93:1)	Zhang et al. (2004)	Zhang et al. (2004); Zhang and Nie (2005)
		(*R*)-2-isopropenyl-5-methyl-4-hexenyl (*S*)-2-methylbutanoate [common name is (*R*)-lavandulyl (*S*)-2-methylbutanoate] and [(*R*)-2,2-dimethyl-3-(1-methylethylidene) cyclobutyl]methyl (*S*)-2-methylbutanoate [which we refer to as (*R*)-maconelliyl (*S*)-2-methylbutanoate	Zhang and Nie (2005)	–
3	*Phenacoccus madeirensis* Green	Trans (1R,3R)-chrysanthemyl (R)-2-methyl-butanoate and (R) lavandyly(R-methylbutanoate	Ho et al. (2009)	–
4	*Planococcus citri* (Risso)	(+)-(1R)-cis-2,2,-dimethyl 3-isopropenyl cyclobutane methanol acetate (1R,3R) 3-isopropenyl-2,2-dimethyl cyclobutane methyl acetate	Bierl-Leonhardt et al. (1981, 1982)	Kukovinets et al. (2006); Zada et al. (2004); Passaro and Webster (2004); Chibiryaev et al. (1991); Odinokov et al. (1991); Serebryakov et al. (1986); Wolk et al. (1986); Odinokov et al. (1984a, b); Carlsen and Odden (1984); Bierl-Leonhardt et al. (1981)
5	*Planococcus minor* (Maskell)	E-2-isopropyl-5-methyl-2-hexadienyl acetate	Ho et al. (2007)	Millar (2008); Ho et al. (2007)
6	*Planococcus ficus* (Signoret)	S-lavandulol and (S)-(+)-lavandyl senecioate	Hinkens et al. (2001); Zada et al. (2001); Zada et al. (2003)	Ujita and Saeki (2008); Zada and Dunkelblum (2006); Zada and Harel (2004); Zada et al. (2003), Millar et al. (2002), Hinkens et al. (2001)
7	*Pseudococcus comstocki* (Kuwana)	R-3-acetoxy,2,6-dimethyl-1,5,-heptadiene	Negishi et al. (1980b)	McCullough et al. (1991); Baeckstroem and Li (1990); Kang and Park (1990); Skatteboel and Stenstroem (1989); Larcheveque and Petit (1989); Fall et al. (1986); Baeckstrom et al. (1984); Nakagawa and Mori (1984); Bierl-Leonhardt et al. (1982); Mori and Ueda (1981); Uchida et al. (1981)
		2,6-dimethyl-1,5-heptadien-3-yl acetate	Bichina et al (1982)	

8	*Pseudococcus cryptus* Hempel	(1R3R)-3-isopropenyl-2-2-dimethmylcyclobutylmethyl-3-methyl-3-butenoate	Arai et al. (2003)	Nakahata et al. (2003)
9	*Pseudococcus calceolariae* (Maskell)	Chrysamthemyl 2-acetoxy-3-methylbutanoate	Unelius et al. (2011); El-Sayed et al. (2010)	Unelius et al. (2011); El-Sayed et al. (2010)
10	*Pseudococcus maritimus* (Ehrhorn)	(R, R)-trans-(3,4,5,5-tetramethyl cyclopent-2-en-1-yl) methyl 2-methyl propanoate	Figadère et al. (2007)	Figadère et al. (2007)
				–
11	*Pseudococcus viburni* (Signoret)	(1R,2R,3S)-(2,3,4,4-tetramethyl cyclopentyl)-methyl acetate	Millar et al. (2005b)	Hashimoto et al. (2008); Millar and Midland (2007)
12	*Pseudococcus kraunhiae* (Kuwana)	2-isopropylidene-5-methyl-4-hexen-1-yl butyrate	Sugie et al. (2008)	–
13	*Pseudococcus longispinus* (Targioni Tozzetti	2-(1,5,5-trimethylcyclopent-2-en-1-yl)ethyl acetate	Millar et al. (2009)	Millar et al. (2009)
14	*Planococcus minor* (Maskell)	2-isopropyl-5-methyl-2,4-hexadienyl acetate	Ho et al. (2007)	Ho et al. (2007)
15	*Dysmicoccus grassii* Leonardi	(−)-(R)-lavandulyl propionate and acetate	de Alfonso et al. (2012)	–

14.6.1 *Planococcus citri*

In Italy, the sex pheromone released by females of *Planococcus citri* was extracted from unmated females by ethanol, diethyl ether, or petroleum ether. Extracts in ethanol, diethyl ether, or petroleum ether placed on filter paper or hydrophilized poly(methyl methacrylate) discs elicited high attraction and pairing responses in the males (Rotundo and Tremblay 1976, 1982). *P. citri* pheromone is a cyclobutane compound.

14.6.2 *Pseudococcus calceolariae*

Headspace volatiles collected from virgin females of the citrophilous mealybug, *Ps. calceolariae*, containing the main female-specific compound is identified as [2,2-dimethyl-3-(2-methylprop-1-enyl)cyclopropyl]methyl 2-acetoxy-3-methylbutanoate (chrysanthemyl 2-acetoxy-3-methylbutanoate). The other two compounds are identified as [2,2-dimethyl-3-(2-methylprop-1-enyl)cyclopropyl]methanol (chrysanthemol) and [2,2-dimethyl-3-(2-methylprop -1-enyl)cyclopropyl]methyl 2-hydroxy-3-methylbutanoate (chrysanthemyl 2-hydroxy-3-methyl butanoate). Traps baited with 100 µg and 1,000 µg indicated that 100 µg of chrysanthemyl 2-acetoxy-3-methylbutanoate captured 4- and 20-fold more males than traps baited with virgin females (El-Sayed et al. 2010). The absolute configuration of the sex pheromone of *Pseudococcus calceolariae* was determined to be (1R,3R)-[2,2-dimethyl-3-(2-methylprop-1-enyl)cyclopropyl] methyl (R)-2-acetoxy-3-methylbutanoate NMR, derivatization reactions, chiral GCMS, and comparison with synthetic chiral reference compounds were used to determine the absolute configuration of this compound. Traps baited with 1,000 µg of the pheromone compound caught 367 times more males than traps baited with virgin females. A mixture of stereoisomers of pheromones can be used for field trapping without adverse effects on trap catches (Unelius et al. 2011).

14.6.3 *Planococcus kraunhiae*

A sex pheromone component of the Japanese mealybug, *Planococcus kraunhiae* was isolated and identified. A crude extract of the pheromone obtained by airborne collection was first fractionated with Florisil column chromatography. The active fraction was further purified by HPLC, and an active component was isolated by preparative GC. The purified compound was determined to be 2-isopropylidene-5-methyl-4-hexen-1-yl butyrate by GC–MS and NMR analyses showing the attraction activity to adult males of *P. kraunhiae* in the field (Sugie et al. 2008).

14.6.4 *Planococcus ficus*

The existence of pheromones was detected in the females of mealybugs *Planococcus ficus* (Signoret) by Rotundo and Tremblay (1982). The sex pheromone of *Planococcus ficus* has been identified as a single component, (S)-lavandulyl senecioate (LS) 2a. Males were equally attracted to either (S)-2a or racemic 2a, indicating that the unnatural enantiomer does not inhibit male behavioral responses. Female mealybugs also produced (S)-lavandulyl, but mixtures of racemic 1 with racemic 2a were less attractive to male mealybugs than racemic 2a alone. In field trials, lures loaded with 100 µg doses of racemic 2a attracted males for at least 12 weeks (Millar et al. 2005a).

14.6.5 *Phenacoccus madeirensis*

Two compounds in *Ph. madeirensis* Green were identified as trans-1R, 3R-chrysanthemyl (R)-2-methyl butanoate and (R) lavandulyl (R)-methyl butanoate in a ratio of 3:1. The structures of two pheromones differ significantly.

14.6.6 *Pseudococcus comstocki*

Pseudococcus comstocki pheromone is an aliphatic acetate. The sex pheromone produced by females of the *Ps. comstocki* Kuwana, was isolated and identified as 2,6-dimethyl-3-acetoxy-1,5-heptadiene. Synthetic pheromone showed a potent activity in laboratory bioassay and field test (Negishi et al. 1980b).

14.6.7 *Pseudococcus maritimus*

In *Pseudococcus maritimus* (Ehrhorn), an irregular non-head-to-tail monoterpenoid was identified as (R,R)-1-trans 3,4,5,5,-tetramethyl cyclopenta-2-en-1-yl) methyl-2-methyl propionoate (Figadere et al. 2007) and Zou et al. (2010) observed that racemic mixture of trans-alphanecrodyl isobutyrate is more attractive than (RR) or (SS) enantiomers.

14.6.8 *Pseudococcus longispinus*

The sex pheromone of the long-tailed mealybug *Ps. longispinus*, identified as 2-(1,5,5-trimethylc yclopent-2-en-1-yl)ethyl acetate, represents the first example of a new monoterpenoid skeleton. A [2,3]-sigmatropic rearrangement was used in a key step during construction of the sterically congested tetra alkyl cyclopentene framework (Millar et al. 2009).

14.6.9 *Crisicoccus matsumotoi*

Most of the mealybug pheromones are carboxyl esters of monoterpene alcohols; however, a hemiterpene pheromone (3)-methyl-3-butenyl 5 methylhexanoate was identified from *Crisicoccus matsumotoi* (Siraiva) (Tabata et al. 2012).

14.6.10 *Maconellicoccus hirsutus*

The two chiral centers in the sex pheromone of pink hibiscus mealybug, *Maconellicoccus hirsutus*, could elicit different male responses. The chiral center in the acid moiety of the pheromone seemed to be more critical than the alcohol portion of the pheromone molecule for attractiveness. Captures of male *M. hirsutus* showed that pheromone with the naturally occurring (*R*)-maconelliyl (*S*)-2-methylbutanoate and (*R*)-lavandulyl (*S*)-2-methylbutanoate [*R-S* configuration] was most attractive and that pheromone with the unnatural *S-S* configuration was less attractive. An inhibitory effect was observed when *R-R* and *S-R* were combined with naturally occurring *R-S* blend. Thus, *S* configuration on the acid moiety elicits attraction, whereas the *R* configuration induces inhibition. However, the attractive activity shows some degree of tolerance toward chirality change in the alcohol portion of the pheromone molecules (Zhang et al. 2006).

14.6.11 *Planococcus minor*

The sex pheromone of the mealybug, *Planococcus minor*, was isolated by fractionation of crude pheromone extract obtained by aeration of virgin females. The pheromone was identified as the irregular terpenoid, 2-isopropyl-5-methyl-2,4-hexadienyl acetate, by mass spectrometry, microchemical tests, and (1)H NMR spectroscopy. The stereochemistry of the pheromone was assigned as (E) by comparison with synthetic standards of known geometry. The compound was highly attractive to males in laboratory bioassays, whereas the (Z)-isomer appeared to antagonize attraction (Ho et al. 2007).

14.6.12 *Pseudococcus viburni*

The sex pheromone of the obscure mealybug, *Ps. viburni*, consists of (1R*,2R*,3S*)-(2,3,4,4-tetramethylcyclopentyl)methyl acetate, the first example of a new monoterpenoid structural motif in which the two isoprene units forming the carbon skeleton are joined by 2′–2 and 3′–4 connections rather than the usual 1′–4 head-to-tail connections. This highly irregular terpenoid structure, and the irregular terpenoid structures of related mealybug species, suggests that these insects may have unique terpenoid biosynthetic pathways (Millar et al. 2005b).

14.6.13 *Dysmicoccus grassii*

In *Dysmicoccus grassii*, a main pest of Canary Islands banana, the principal components (−)-(R)-lavandulyl propionate and acetate in a 6:1 ratio were identified by volatile collection and GC–MS analysis from aeration of virgin females. (R)-lavandulyl propionate induced a stronger attractive effect when compared with (R)-lavandulyl acetate (de Alfonso et al. 2012).

Although the males of several mealybug species are attracted to the females, sex pheromones are yet to be identified (e.g., *Phenacoccus herreni* (Cox&Williams)).

14.7 Synthesis of Pheromones/Pheromone Production

14.7.1 *Pheromone Production*

Pheromones must be isolated, identified, and synthesized before any basic or practical studies can be performed. Entomologists and chemists must cooperate closely in order to achieve these goals. Despite the availability of modern analytical equipment, the identification of natural mealybug sex pheromones remains a difficult and laborious task. Mealybugs are small or tiny insects that release minute quantities of pheromone; therefore large numbers must be reared, and often tedious separation of virgin females must be done to collect sufficient amounts of pheromone for isolation and identification. Males having a short lifespan of at most a few days are required for bioassay, either by attraction tests or by GC–EAG (gas chromatography electroantennography). All known mealybug pheromones are monoterpenoid esters, mostly of simple acids. Unlike moth sex pheromones, the mealybug pheromones are not homologous compounds; their structures vary significantly, and three types of structures have been found so far: open chain esters, cyclobutane derivatives, and cyclopentane rings. All mealybug pheromones, except the *Pl. minor* and *Pl. kraunhiae* pheromones, are chiral compounds. Generally, enantioselective synthesis of chiral compounds is much more complicated and expensive than that of racemic compounds but, fortunately, racemic pheromones can be used because the unnatural stereoisomers have no behavioral effect and, therefore, are benign (Zada et al. 2008). A unique case is the pheromone of *M. hirsutus*; it contains a chiral acid function that must have the correct chirality for biological activity (Zhang and Amalin 2005; Zhang et al. 2006). The passionvine mealybug is strongly inhibited by the (Z)-stereoisomer of its pheromone, suggesting that this compound may be the pheromone of a related sympatric species (Millar 2008). Unlike moths and beetles, which are generally sensitive to isomers (structural and chemical) of their pheromone components, mealybugs are less sensitive to stereoisomers. In practice, this means that the use of mixture of isomers of the pheromone will be effective for controlling most of the mealybug pheromones. Moreover, mealybugs are responsive to small amounts (doses of about 1 mg) of the pheromones (Millar et al. 2005b; Zhang and Amalin 2005; Sugie et al. 2008), so that potentially it is possible to achieve pheromone-based control at relatively low costs. Not all the mealybug sex pheromones are commercially available. In fact, most of them, except for those of the citrus mealybug and the vine mealybug, are synthesized only for research in small (milligram) quantities. The citrus mealybug pheromone, for example, which has a rather complex structure, has been synthesized via a variety of routes, but it still is not available in large quantities (hundreds of grams) required for mating disruption. At present, only commercial lures for monitoring are available. Because of the worldwide economic importance of the mealybugs, there is a need to improve the efficiency of pheromone synthesis and to make the pheromone available for control application. A series of analogs of this pheromone was prepared, in order to find a less expensive attractant (Liu et al. 1995; Dunkelblum et al. 1987), but most of them were insufficiently attractive, except for a homologue in which a cyclobutaneethanol moiety replaced the cyclobutanemethanol moiety in the natural pheromone. The homologue displayed about 40 % attractiveness as compared with the pheromone, and in some field tests it was as active as the latter (Dunkelblum et al. 1987). The advantage of the homolog is that its synthesis is easier and less expensive than that of the pheromone. Some pheromone analogs of the Comstock mealybug, *Pseudococcus comstocki* Kuwana, were also synthesized and tested in the field (Uchida et al. 1981; Bierl-Leonhardt et al. 1982). 2,6-dimethyl-1,5-heptadien-3-yl acetate and three of its analogues of the sex pheromone of *Pseudococcus comstocki* (Kuw.), a pest of agricultural crops including apple and pear, were synthesized and evaluated for their attractiveness to males. All four compounds were found to be the effective attractants for the insect, but the synthetic sex pheromone showed a two- to seven fold higher activity than the analogues (Uchida et al. 1981).

14.7.2 Synthesis of Pheromones

Through modifications of acetoxy group, several pheromone analogues were synthesized for different species of mealybugs. A synthetic pheromone would provide a much more economical, convenient, and useful survey tool. Synthesis of pheromone compounds of *Pl. minor*, *Pl. citri*, and *Ps. viburni* was done successfully (Millar 2008; Ho et al. 2007; Kukovinets et al. 2006; Millar and Midland 2007).

14.7.2.1 *Planococcus citri*

The mealybug sex pheromones that have been identified generally are complex molecules, which are relatively difficult to synthesize on a large scale. Nevertheless, because male mealybugs are so exquisitely sensitive to the pheromone, with lures containing only a few micrograms remaining active for at least several months under field conditions, widespread use of pheromone-baited traps for monitoring mealybugs is economically feasible. For example, 1 g of racemic pheromone is sufficient to prepare 50,000 lures or more @20 μg per lure.

In *Pl. citri*, (1R,3R)-3-isopropenyl-2,2-dimethylcyclobutanemethyl acetate ($C_{12}H_{20}O_2$) was identified, and a simple synthesis path was developed in Israel, and the synthesized material (1R cis-3-isopropenyl-2-2-dimthyl cyclobutane methyl acetate) was found to attract males effectively (Dunkelblum et al. 1986). Alcohol analogue (1R-cis)-3-isopropenyl-2-2-dimethycyclobuanemethal) was an effective attractant to *P. citri*, and homologue (1R-cis)-3-isopropeny-2,2 dimethyl cyclobutane ethylacetate at 2,000 μg per dispenser was equal to 500 μg pheromone (Dunkelblum et al. 1986). Analogue of pheromone of *P. citri*, (+)-(1R)-cis-2-2-dimethyl-3-isopropenyl cyclobutano methanol acetate was synthesized using starting material *cis*-pinoic acid or *cis*-pinonic aldehyde, which were obtained from cheap α-pinene and conversion of the pinonic derivatives to pinononic derivatives was achieved through Hundsdiecker reaction. Pinononyl aldehyde was used for synthesis of pheromone through Wittig reaction (Dunkelblum et al. 2002). Structural analogue of (+) *cis*-(1R)-(3)-isopropenyl-2-2-dimethyl cyclobutane methyl acetate, the sex pheromone of *P. citri*, was synthesized and field-tested in grapefruit orchards and the most active analogue was (+)-(*cis*-(1R)-2-(3-iso-propenyl-2-dimethyl cyclobutane ethyl acetate (Dunkelblum et al. 1987).

14.7.2.2 *Maconellicoccus hirsutus*

The sex pheromone of *M. hirsutus*, Maconelliol, was synthesized in steps from Alpha pinene, and the key step was the dehydration of steps 5–7 through the intermediate 6 (Zhang et al. 2004).

14.7.2.3 *Pseudococcus viburni*

An improved diastereoselective synthesis of (1R*,2R*,3S*)-1-acetoxymethyl-2,3,4,4-tetramethylcyclopentane 1, the sex pheromone of *Pseudococcus viburni*, was described and the key step was diastereoselective catalytic hydrogenation of the tetrasubstituted double bond in 2,3,4,4-tetramethyl-cyclopent-2-enone 4 to give the thermodynamically less favored *cis*-2,3,4,4-tetramethyl-cyclopentanone 3a (Zou and Millar 2011). The pheromone of *P. viburni* was also synthesized from pentalactone (Hajare et al. 2010).

In the obscure mealybug *Ps. viburni*, 2,3,4,4-tetramethylcyclopentyl)methyl acetate was identified as the sex pheromone. The active compound has a number of isomers, and all were made to conclusively verify the identity of the insect-produced compound. An efficient synthesis of the active compound, capable of being scaled up to produce multigram quantities, was then developed. The pheromone was field-tested in California vineyards and nurseries, and by collaborators in South America and New Zealand. The pheromone is extraordinarily active, with lures loaded with sub-milligram quantities remaining attractive to male mealybugs for several months. In South Africa, The sex pheromone for *P. viburni* was recently identified and synthesized in South Africa. There was a positive and significant relationship between the fruit infestation and number of *P. viburni* adult males caught in pheromone-baited traps ($r^2 = 0.454$, $P < 0.001$) in pome orchards. The action threshold level was estimated to be 2.5 male *P. viburni* caught per trap per fortnight at an economic threshold of 2 % fruit infestation. This monitoring method was less labor-intensive, more accurate, and quicker than the current visual sampling and monitoring techniques (Mudavanhu et al. 2011).

14.7.2.4 *Pseudococcus calceolariae*

Traps baited with 100–1,000 µg of racemic chrysanthemyl 2-acetoxy-3-methylbutanoate captured 4–20-fold more males than traps baited with virgin females. In Chile, a single dose of 100 µg was known to capture 1,171 males, whereas none were captured in control traps. An isomeric mixture of synthetic 3 proved to be highly attractive to male mealybugs in the field in New Zealand and in Chile. Male mealybugs were highly attracted to the racemic material and this will greatly facilitate the development of the pheromone for monitoring and control of this pest, because racemic 3 can be readily synthesized from commercially available intermediates (El-Sayed et al. 2010). This activity of 1R,3R)-[2,2-dimethyl-3-(2-methylprop-1-enyl)cyclopropyl]methyl (R)-2-acetoxy-3-methylbutanoate in *Pseudococcus calceolariae* was further confirmed by testing synthetic stereoisomers of the compound as lures in traps for adult male mealybugs. Traps baited with 1,000 µg of the pheromone compound caught 36 times more males than traps baited with virgin females. A mixture of stereoisomers of the pheromone compound can be used for field trapping without adverse effects on trap catch (Unelius et al. 2011).

14.7.2.5 *Pseudococcus longispinus*

A single compound was unique to the headspace of the sexually mature female *Ps. longispinus*. The first reported synthesis involves a polyphosphoric acid-mediated cyclization of isobutyl 2-butenoate. The cyclopentenone was then converted into the allylstannane after being reduced. A short and efficient synthesis of the mealybug pheromone was developed from readily available iodoketone with an overall yield of 21 %. The pheromone has been shown to have extremely high biological activity; in lures, just 25 µg of the racemic pheromone can attract males for more than 3 months (Bakonyi 2012). The synthesis of a recently identified and highly active sex pheromone of *Ps. longispinus*, was reported by Kurhade et al. (2013).

14.7.2.6 *Pseudococcus comstocki*

The synthesis of the acetate of 2,6-dimethylhepta-1,5-dien-3-ol—the sex pheromone of the Comstock bug—has been carried out by condensing isobutenyl lithium with 3,4-epoxy-2-methylbut-1-ene and acetylating the 2,6-dimethylhepta-1,5-dien-3-ol formed. The overall yield of pheromone was 46 % (Ishchenko et al. 1989). The synthesis of racemic versions of pheromones of *Ps. comstocki* was done through reductive lithiation of allyl phenyl thioesters followed by transmetallation, producing allylmetallics, which react selectively with carbonyl compounds at the most on least-substituted terminus and the latter results in cis-olefin (McCullough et al. 1991).

14.8 Commercial Development of Pheromones

Currently, of these seven pheromones, only the vine mealybug *Pl. ficus* pheromone is commercially available, but Millar is working to transfer the manufacturing technology to companies that produce pheromone products. None of the pheromones are protected by patents; therefore, all are freely available for the commercial development. Companies also need to know that there is a substantial market for these products, so growers should communicate their needs to company representatives to expedite the entry of mealybug pheromone traps into the market place.

Chemist Aijun Zhang in Beltsville, MD, developed the pheromone of *M. hirsutus*, which mimics the female mealybug's scent, according to a news release. South Carolina Scientific Inc., of Columbia, SC, will market the chemical. The sex pheromone, placed inside sticky traps, effectively monitors and traps male mealybug. By luring males to traps, the pheromone would provide a much more useful detection tool. Relatively high concentrations of the pheromone repel males away from the source, disrupting mating. However, natural enemies of the mealybug are not attracted to the scent, so biological control would not be compromised (http://www.thegrower.com/news/firm_to_market_pink_mealybug_ pheromone_117886474.html#sthash.2KIGfvcv.dpuf). Commercial lures of *Ps. longispinus* and *Ps. maritimus* also became available from Suterra LLC (Bend, OR) in 2010.

14.9 Traps

Pheromone traps can attract the mealybugs within one-quarter mile from the trap site.

14.9.1 Trapping Guidelines

14.9.1.1 Trap Assembly

- Obtain or purchase a red Delta trap, preferably with a white sticky bottom panel for ease of viewing mealybugs.
- Assemble the trap by folding in the side edges to reduce the size of the openings.
- Place the rubber septum containing the pheromone (lure) inside the trap on top of the sticky coating on the bottom panel.

14.9.1.2 Trap Placement

- Tie the trap to the plant at 2–3 feet above ground level. Traps baited with virgin *Pseudococcus comstocki* females, placed in *Ps. comstocki-infested* fruitless mulberry trees about 9 ft above ground level, had caught an average of 225 *Ps. comstocki* males compared with 6 ft by each of the other traps (Moreno et al. 1972). Make sure leaves and shoots are not obstructing the entrance into the trap. Do not hang it too low or too high in the canopy.
- Place the trap at the center of the block for surveying the largest area possible.

14.9.1.3 Labeling Traps

- Label the trap with the block name and row number, where the trap was placed and the dates it was set out in the field and removed.
- Label the outer side of the trap with the following information: date of placement (DOP), vineyard and block name, row and vine number, and lure (L) type. When you remove the trap, write the date of removal (R). Use a permanent marker.

14.9.1.4 Trap Density

- Place one trap per hectare or one per smaller orchard.

14.9.1.5 Trapping Season

- Placement of traps based on the information gathered on the seasonal activity more closely in the locality. In California, placement of traps begins in late March to June (depending on region) and trapping is continued through October or until the first rain in vineyards.

14.9.1.6 Checking Traps

- Check traps every 2 weeks for the presence of mealybugs on the sticky surface.

14.9.1.7 Trap Replacement

- Replace the trap when it becomes soiled.
- Lures are effective for a maximum of 8 weeks. If no male mealybugs are found, new pheromone lures can be placed into old traps. Do not forget to re-label the new trap and note when new lures are placed in the trap.

14.9.2 Types of Traps

Multi-season plastic Delta traps are used for monitoring and mass trapping the mealybugs. These Delta traps areresistant to severe weather conditions. They are very easy to assemble and collapse flat for storage. Hwang and Chu (1987a) developed an effective, cylindrical, and transparent plastic trap (diameter 8 cm and length 8 cm) with white sticky card (8 × 12.5 cm) inserted at the bottom, and traps placed at 100 cm and above caught more than 50 % of males. Commercially developed traps with more surface such as green Delta, Pherocon IIB, and Pherocon V captured more males than other traps (Vitullo et al. 2007). Delta sticky traps, baited with 50 or 200 µg of LS were used to determine the daily flight pattern and the seasonal flight activity including vine plant infestation for *P. ficus* (Zada et al. 2008). A method is described for handling sticky trap cards and evaluating catches, using the sex pheromones of *Planococcus citri* and *Pseudococcus comstocki* (Fargerlund and Moreno 1974). In USA and Japan, 2,6-dimethyl-1,5-heptadien-3-yl acetate was identified in *Ps. comstocki* and a synthetic material was prepared in the Moldavian area of the USSR. The sticky traps proved very successful in attracting and catching male mealybugs in mulberry ecosystem (Bichina et al. 1982). Pheromone-baited traps with larger trapping surfaces (green Delta, Pherocon IIB, and Pherocon V) captured more males of *Maconellicoccus hirsutus* per trap than those with smaller surfaces (Jackson and Storgard Thinline), and fewest males were captured by Storgard Thinline traps. However, Jackson traps captured as many or more males per square centimeter of trapping surface than those with larger surfaces, and the time required to count males in Jackson traps was significantly less than in green Delta, Pherocon IIB, and Pherocon V traps. Although all trap designs accumulated some debris and nontarget insects, it was rated as light to moderate for all designs. The Jackson trap is most suitable for monitoring *M. hirsutus* populations. In addition, unlike the other traps evaluated, which must be replaced entirely or inspected in the field and then redeployed, only the sticky liners of Jackson traps require replacement, enhancing the efficiency of trap servicing (Vitullo et al. 2007). Adhesive traps, baited with virgin females of *Maconellicoccus hirsutus* and placed on hibiscus, captured more males than did unbaited traps (Serrano et al. 2001).

The color of the pheromone trap influenced the numbers of males of *Pseudococcus comstocki* (Kuw.) caught. Multi-season plastic Delta traps are available in red and white. Generally, yellow traps with sticky surfaces were effective in trapping males. Pheromone traps baited with green Delta, Pheroxin IIB, and Pherocon V trapped more males in *Maconellicoccus hirsutus*. Moreover, Jackson traps captured more adults per square centimeter (Vitullo et al. 2007). The color preference was red = dark green = black > green > yellow > white. According to Hwang and Chu (1987a, b), red color sticky cards are the most attractive to the males of *Planococcus citri*.

Triangular tent-shaped Yellow trap Yellow traps

14.10 Pheromone-Based Management Tactics

Sex pheromones of insects, including mealybugs, are natural compounds emitted by virgin females in order to attract conspecific males for mating. The sex pheromones are effective in extremely small quantities; they are nontoxic and can be applied in various ways. Unlike pesticides, these chemicals are species specific and do not affect beneficial insects. The behavioral impacts of the semiochemicals are limited to the target pest organisms. The potential of mealybug sex pheromones as an alternative and ecologically friendly means for monitoring and control is important and promising. Sex pheromones are used in lures for monitoring, for detection of outbreaks, and for population management. Monitoring systems provide vital information for the timing of insecticide applications. Population levels can be reduced or controlled by mass trapping, mating disruption, or lure and kill. The success of these methods depends on the availability of the pheromone, and on an appropriate formulation and deployment. In contrast to the extensive use of sex pheromones in controlling beetle and moth pests, sex pheromones are yet to be used to a great extent in controlling the mealybugs.

14.10.1 Monitoring

Sampling is a key element of mealybug management, because of the need for real-time information on the mealybug population and the potential damage. Monitoring for mealybug infestation is quite labor intensive as mealybugs are often located in the protected areas of plants like bark crevices and leaf axils. Pheromone traps may be used as an early warning tool for grape growers to monitor mealybug activity and to detect the initial establishment of mealybug colonies. The traps are baited with female mealybug pheromone impregnated in a rubber lure. The traps are placed within the vine canopy to attract winged male mealybugs. When the mealybug population is small, using a sex pheromone trap to attract winged males is far more efficient than trying to search vines over a large area for hidden females. The male mealybugs can fly about one-half mile, and it can be wind-blown much further. Mealybug monitoring methods involve examination of specific plant parts for live individuals, and detection of honeydew, sooty mold, or ant activity (Franco et al. 2004a, b; Millar et al. 2005a). Sampling procedures have been developed for several mealybug species and various crops, such as the citrus mealybug, *Pl. citri* (Martinez-Ferrer et al. 2006), the grape mealybug, *Ps. maritimus* (Geiger and Daane 2001), or the sugarcane mealybug, *S. sacchari* (Allsopp 1991; Debarro 1991). However, the cryptic occurrences of mealybugs as well as their typical clumped spatial distribution (Allsopp 1991; Martinez-Ferrer et al. 2006; Nestel et al. 1995) make monitoring laborious and often impracticable. Population estimates based on the level of male capture in pheromone-baited traps are considered more convenient (Millar et al. 2005a). Much work has been done to optimize these sampling methods, especially in relation to trap design, trap color, type of dispenser, pheromone dose, and bait longevity and range (Francis et al. 2007; Franco et al. 2004a, 2008a, 2009; Millar et al. 2002; Vitullo et al. 2007; Walton et al. 2004; Zada et al. 2004, 2008). Nevertheless, the use of pheromone traps as a monitoring tool for mealybug damage risk assessment depends on the existence of a reasonable relationship between the number of males captured in pheromone-baited traps and other mealybug infestation parameters, as recorded by other means, usually, visual sampling. A linear relationship was found to exist between the vine mealybug, *Pl. ficus* (Walton et al. 2004), and the citrus mealybug, *Pl. citri* (Franco et al. 2001). However, this correlation may be affected by different factors, including the weather, the activity of natural enemies, and the phenological gap between male captures and infestation level (Franco et al. 2001, 2008a).

14.10.1.1 *Pseudococcus comstocki*

The seasonal flight activity of *Ps. comstocki* in California was monitored with sex pheromone traps (Meyerdirk and Newell 1979). In the Moldavian area of the USSR, a synthetic material of sex pheromone proved very successful in detecting not only the presence of *Ps. comstocki* but also the information on its population density in mulberry ecosystem (Bichina et al. 1982). Pheromone of *Ps. comstocki* containing 2,6,-dimethyl-1,5,-heptadient at the rate of 200 μg per trap, placed at a height of 1.52 m, was able to trap the adult males, and used for recording the fluctuation of daily and seasonal flight dynamics (Smetnik and Rozinskaya 1988).

14.10.1.2 *Planococcus citri*

Monitoring population densities of *Planococcus citri* in citrus ecosystem was based on male capture using traps baited with female sex pheromones. Pheromone of *Pl. citri* was used for the early detection of the pest occurrence in citrus fields (Ortu and Delrio 1982). In Israel, the seasonal population fluctuations and trends of *Pl. citri* were monitored (Hefetz and Tauber 1990; Tauber et al. 1985) and traps were being used in conjunction with biological control methods. Information on the level of male capture in spring or early summer by application of pheromone traps is used to predict mealybug density or percentage of fruit infestation and consequently to assist in the decision making for the purpose of the citrus mealybug management (Franco et al. 2001). The analogous compound, 1R *cis*-3-isopropyl-2-2-diemthyl cyclobutyl methyl acetate was impregnated at 2,000 μg in each dispenser almost equaling 500 μg of pheromone of *Pl. citri* to monitor the mealybugs (Franco et al. 2004b). In Mediterranean Basin, the best time for releasing the natural enemies *Cryptolaemus montrouzieri* Muls. and *Leptomastix dactylopii* How. for the control of *Pl. citri* in citrus orchards was deduced from mealybug population monitoring by means of traps containing the sex pheromone of *P. citri* (Panis 1981).

14.10.1.3 *Pseudococcus longispinus* and *Pseudococcus viburni*

Positive and significant relationship exists between pome fruit infestation and number of *Ps. vulbuni* in pheromone traps baited with pheromone, and pheromone monitoring was done to estimate the action threshold, which was estimated to be 2.5 male *Ps. viburni* (Mudavanhu et al. 2011). Lures containing 25 μg per lure was attractive to *Ps. viburni* and *Ps. longispinus*. Racemic mixtures of S-lavandulyl senecioate and (S)-lavandulyl isovalerate recorded good capture (Zada et al. 2008). Operational parameters of traps baited with the pheromones of three mealybug species were optimized in nurseries producing ornamental plants. All pheromone doses (1–320 μg) attracted *Ps. longispinus* and *Ps. viburni* males, with the lowest dose (1 μg) attracting the fewest males for both species. Lures containing 25-μg doses of either pheromone had effective field lifetimes of at least 12 weeks. Pheromone traps were used to detect infestations of *Ps. longispinus* throughout the season and to track population cycles. When pheromone-baited traps for *Ps. longispinus* were compared with manual sampling, trap counts of male mealybugs were significantly correlated with mealybugs counted on plants in the vicinity of the traps (Waterworth et al. 2011).

14.10.1.4 *Planococcus ficus*

Vine mealybug *Pl. ficus* pheromones are placed in traps and used to deduct the infestation of mealybugs. Typically, they are effective in detecting new infestations. A sex pheromone produced by female mealybugs is used inside each trap to attract adult males nearby. The males enter seeking the females and become trapped inside. Although they may be designed in different shapes, tent-shaped red traps are recommended. In field trials conducted by Millar et al. (2002), it was observed that the rubber septa loaded with 100 µg of racemic pheromone was able to effectively capture the males of *Pl. ficus* for a period up to 12 weeks, and Delta traps were more effective than double-sided adhesive sticky cards (Millar et al. 2002).

14.10.1.5 *Maconellicoccus hirsutus*

The pheromone was used to attract the males of *Maconellicoccus hirsutus* (Vitullo et al. 2007). Laboratory-prepared (R)-lavandulyl (S)-2-methylbutanoate and (R)-maconelliyl (S)-2-methylbutanoate blended in a ratio of 1:5 on rubber septa impregnated with a dose of 1–10 µg were attractive to males of *M. hirusutus* for a period of 21 weeks (Zhang and Amalin 2005). It was found that the mixture of lavandulyl and maconellyl in a 1:5 ratio significantly attracted more males of *M. hirsutus* and was used to track the geographical dispersal of the species (Gonzalez-Gaona et al. 2010).

14.10.1.6 *Phenacoccus madeirensis*

The pheromones *trans*-1R,3R-chrysanthemyl R-2-methylbutanoate and R-lanadulyl R-2-methylbutanaoate have shown the effectiveness in attracting males of *P. madeirensis* (Ho et al. 2011).

14.10.1.7 *Pseudococcus viburni*

Pheromone-baited traps have been used in New Zealand to detect *Ps. viburni* in apple orchards (Bell et al. 2005).

14.11 Mixed Mealybugs

Often in field conditions, more than one mealybug species complex exist, necessitating the use of blend of more than one pheromone for trapping multiple species. The same generic lure can attract three species of mealybugs, which would cut costs for growers by allowing them to deploy a single pheromone trap rather than three. Lures loaded with a mixture of the pheromones of *Ps. longispinus*, *Ps. viburni*, and *Pl. citri* were as attractive to *Ps. viburni* and *Ps. citri* as lures with their individual pheromones. Response of *Ps. longispinus* to the blend was decreased by 38 % compared with its pheromone as a single component. This should not affect the overall efficacy of using these lures for monitoring the presence of all three mealybug species simultaneously (Waterworth et al. 2011). Trapping indicated a sharp peak in male citrophilus mealybug flight activity in mid-February with a gradual decline thereafter. Long-tailed mealybug flight activity increased during March and peaked in late April when trapping ceased. Higher numbers of citrophilus mealybug males (36,764) were trapped than long-tailed mealybug (693).The dominant species was the longtailed mealybug, identified on 92 % of infested fruit. Citrophilus and obscure mealybugs (*Ps. viburni*) were identified on 3 % and 5 % of infested fruit, respectively (Shaw and Wallis 2011).

14.11.1 Mating Disruption

Mating disruption seems to be more advantageous in mealybugs than in Lepidoptera as mealybug females are sessile and cannot migrate from one area to another as moths do. On the other hand, mating disruption of mealybug pests presents problems, especially because the complex structure of the pheromones prevents large-scale synthesis. The vine mealybug pheromone is the only mealybug pheromone that can readily be synthesized in one step from two commercial starting materials, so that it can be prepared in large quantities, sufficient for field work, including mating disruption (Ujita and Saeki 2008; Walton et al. 2006). When the pheromone was applied to the leaves as a sprayable microcapsule formulation, crop damage was reduced from 9 to 11 % in control plots to 3–4 % in treated plots; however, the effective life of the formulation presents a technical problem that needs to be solved. The efficiency of the pheromone formulation in the field declined after 3 weeks, indicating that more than four applications per season were needed. The proximity of the mealybug sexes on emergence may also impair the success of mating disruption (Walton et al. 2006). Mating disruption in *Planococcus kraunhiae* through the use of pheromone, 2-isopropyliden-5-methyl-4-hexenyl butyrate controlled the mealybug populations in the field in Japan (Teshiba et al. 2009). There was a lesser density of *Planococcus ficus* on leaves of vines treated with plastic dispensers with 100 mg each of synthetic sex pheromone than the control; however, the difference was not significant (Cocco et al. 2011). Due to its effectiveness in traps, developing the pheromone to control vine mealybug populations (*Planococcus ficus*) using mating disruption was pursued (http:// advancinggreenchemistry. org/ catch-all/ mating-disruption-as-a-pest-management-tool-in-californias-wine-industry/).

14.11.2 Mass Trapping

An artificial lure might also enable the development of mass trapping and mating disruption technology for managing this pest, which would complement the ongoing biological control eradication efforts. In addition to their use for detection and monitoring of insect populations, pheromones also have a potential use in insect control, for example, by mating disruption or attract-and-kill technologies.

14.11.2.1 *Planococcus citri*

Pheromones are yet to be exploited to a great extent for mass trapping of mealybugs. There was a significant reduction in the population of *P. citri* when pheromone was used for mass trapping, but not significant enough to cause any reduction in the infestation on fruits in Mediterranean countries (Franco et al. 2003). Similarly in Israel and Portugal, significant reduction of male numbers can be achieved by mass trapping with sticky plate traps (30 cm × 30 cm) baited with 200 μg of pheromone used at a rate of one per citrus tree, although fruit infestation did not reduce significantly. Therefore, as the pheromone trapping system used cannot reduce the number of attracted males effectively, it is most likely that many of them originated from outside the subplot. In fact, males are attracted to the pheromone source from ranges up to at least 100 m (Branco et al. 2006; Franco et al. 2004a). On the other hand, the higher level of mating observed in mass-trapping plots early in the spring, when the mealybug density is usually very low, suggested that mass trapping led to a strong attraction of males from outside the subplots. In light of this finding, it was postulated that early in the season, when the male population is usually low, the attraction of males to the edge of the orchard by using attract–annihilate tactics combined creates a “male vacuum” inside the plot and, consequently, reduces mating and infestation (Franco et al. 2004a).

14.11.2.2 *Maconellicoccus hirsutus*

The quantum of pheromones produced through synthesis was not sufficient to use for mass trapping and mating disruption. However recently, Chemist Aijun Zhang in Beltsville, MD, developed the pheromone, which mimics the female mealybug’s scent, and South Carolina Scientific Inc., of Columbia, SC, will market the chemical. There is also a second potential control strategy (http://www.thegrower.com/news/firmto market pink mealybug pheromone_117886474.html#sthash.2KIGfvcv.dpuf).

14.11.2.3 *Pseudococcus calceolariae*

In 1975, a mass-trapping experiment was carried out against *Pseudococcus calceolariae* (Mask.), which was causing heavy damage on citrus near Salerno, Italy; 79 traps baited with 1,538 virgin females were placed in 25 orange trees over an area of 1 ha in a single orchard, and they caught about 300,000 males of the species. Populations were sampled in 1975–1978 in order to assess the long-term effect of the traps on population dynamics. Up to 1976, a sevenfold reduction in captures of males and a tenfold decrease in populations on fruits in this orchard were registered. Flight peaks of *Ps. calceolariae* occurred in mid-May, mid-July, and late September. It was not possible to determine from the experiments whether the decline in *Ps. calceolariae* was due to either the earlier catches of males in the traps or sudden increases in populations of coccinellid predator (Rotundo et al. 1979a, b).

14.11.2.4 *Planococcus ficus*

The use of synthetic sex pheromones, such as those found in Suterra's CheckMate® products for mating disruption of vine mealybug, aims to prevent adult males from mating. The use of degree-day models, pheromone traps, and field observations are helpful for detecting the earliest colonies of mealybugs. By preventing mating and subsequent egg laying, vine mealybug populations can be dramatically reduced to below economically damaging levels.

14.11.3 *Kairomonal Response*

The pheromone-filled air also acts as kairomones for several predators and parasitoids. The sex pheromone emitted by mealybug virgin females provides reliable information on the location of a potential host for mealybug parasitoids, because of the sedentary nature of mealybugs. Furthermore, because of the typical clumped spatial pattern of mealybugs, the sex pheromone will also be a convenient chemical cue by which the parasitoid can efficiently locate aggregates (colonies) of hosts, which are expected to emit a stronger pheromonal signal than that of single virgin females (functional response). Thus, sex pheromones of mealybugs could serve as a novel and efficient tool to support the classical biological control of invasive mealybug species, by identifying, in the region of origin of the target species, parasitoids that could be the potential candidates for use in the biological control program (Franco et al. 2008c).

The sex pheromone of mealybugs may be used by their natural enemies as a kairomonal cue in host or prey selection. *Anagyrus pseudococci* sp.n. is an effective parasitoid of vine mealybug *Pl. ficus* and citrus mealybug *Pl. citri*. *Anagyrus pseudococci* in California vineyards was attracted to the pheromone (−(+)-lavandulyl senecioate (LS)) of *Pl. ficus* (Millar et al. 2002; Franco et al. 2008c) but *Anagyrus pseudococci* sp.n. was not attracted to the pheromone ((+)-(1R,3R)-*cis*-2,2-dimethyl-3-isopropenyl-cyclobutanemethanol acetate (PcA, namely, planococcyl acetate) of *P. citri* (Franco et al. 2008c, 2011; da Silva et al. 2009a, b); and this kairomonal response was an innate behavior trait. An interesting aspect of this program is that a parasitoid of the vine mealybug (*Anagyrus pseudococci*) may be attracted to the mealybug pheromone as a host-finding cue, resulting in greater levels of biological control. There is a minimal risk of parasitoids being caught if lures are deployed in triangular tent-shaped Delta traps. It was also found that the presence of *Pl. ficus* sex pheromone significantly increases the parasitization rate of *Pl. citri* colonies by *Anagyrus pseudococci*. (Franco et al. 2008b). In field trials in Portugal, Italy, and Israel, the rate of parasitism by *A. pseudococci* was improved through the use of pheromone (Franco et al. 2001). In Sicilian orchards (Italy) infested with *Pl. ficus*, the number of captured *A. pseudococci* females per trap was significantly higher in LS (sex pheromone (S)-(+)-lavandulyl senecioate (LS)-baited traps resulting in the enhancement of the parasitoid performance (Mansour et al. 2010).

Pheromone-based mating disruption of vine mealybug indicated that the treatment had no negative effect on the level of parasitization (Walton et al. 2006) with *Pl. ficus* by *A. pseudococci*. The kairomonal response of *Anagyrus pseudococci* sp.n. could be explored in connection with biological control tactics, by enhancing parasitization of *Pl. citri* as a component of integrated pest management strategies, by means of a similar approach to that used against aphid pests (Powell and Pickett 2003). Rotundo and Tremblay (1975) reported that traps baited with virgin females of *Ps. calceolariae* captured significant numbers of the encyrtid *Tetracnemoidea peregrinus* (Compere) (=*Tetracnemoidea peregrina*(Compere); *Arhopoideus peregrinus*). A kairomonal response of the encyrtid *Pseudaphycus maculipennis* Mercet to the sex pheromone of the obscure mealybug, *Ps. Viburni*, was also observed in field experiments with pheromone traps (Bell et al. 2008). Two species of mealybug parasitoids were caught in traps baited with the sex pheromone of *Ps. cryptus* in a citrus orchard in Japan (Arai 2002). Cassava plants infested with the mealybugs are attractive to the parasitoids such as *Aenasius vexans* Kerrich, *Apoanagurus diversicornis*, and *Acerophagus coccois* Smith. A compound O-caffeoylserine is attractive to the parasitoids of mealybugs (Calatayud et al. 2001).

In New Zealand, *Acerophagus maculipennis*, a recently introduced biocontrol agent, has been recorded from sex pheromone traps of its target host, obscure mealybug (*Pseudococcus viburni*). *Alamella mira* Noyes, an accidentally introduced parasitoid in New Zealand, was captured on sticky bases in citrophilus mealybug (*Pseudococcus calceolariae*) sex pheromone traps that were being monitored at heavily infested mealybug orchards. It is quite conceivable that the high numbers of parasitoids in pheromone traps and the low numbers of citrophilus mealybugs in fruit at harvest indicated that it was an effective biological control agent in these properties (Shaw et al. 2012).

14.12 Dogs for Monitoring Mealybug Incidence

Dogs have been trained to detect the presence of females of grapevine mealybugs in California. The 3-month-old puppies of Golden retriever have been frequently exposed to the pheromone component of grapevine mealybugs and when they are around 2 years old, they are fully trained to identify the presence of mealybugs. The dogs are capable of identifying even the twigs with the females. This method of using dogs' olfactory senses has resulted in saving of crops worth several millions besides saving the environment.

Dog squad strategies being considered to stop the vine mealybug

14.13 Future Prospects

- The pheromones for only a few of species such as *Planococcus citri* and *M. hirsutus* were isolated, identified, and used in other countries. Use of these pheromones as a monitoring tool will be a great boon for the farmers to identify the initial stages of infestation. However, the pheromone for several important invasive species such as *Paracoccus marginatus* Williams and Granara de Willink and *Phenococcus solenopsis* Tinsley needs to be identified for field monitoring. Besides monitoring the incidence, the pheromone may also be used to study the spread of the mealybug, for example, the dispersal pattern of *P. marginatus* and *Pseudococcus jackberdsleyi* Gimpel and Miller can be easily documented in time and space.
- There are several species of potential invasives such as *Phenacoccus manihoti*, and the identification of pheromones for these species will enable us to monitor the entry of this species into India. It will be worthwhile to isolate, identify, and synthesize these pheromones for the quarantine monitoring throughout the world. Installations at ports, airports, and other entry points will enable in the early detection of these mealybugs.
- The technique for the isolation, identification, and characterization of mealybug pheromones has been standardized over the years, enabling us to identify the pheromones for any species. Moreover, the synthesis of pheromones for a few species has been accomplished. However, the ability to synthesize pheromone on a large scale remains an unfulfilled task resulting in the use of pheromone only for monitoring, and not for the mating disruption and mass trapping. Efforts are needed to develop shorter synthesis schemes for the effective synthesis of pheromones in both quality and quantity.
- Often the infestation of complex species of mealybugs was encountered in many crops, thus necessitating the identification and use of generic pheromones. Generic pheromone or semiochemicals for the complex pheromone species in any crop will be advantageous to the farmers and such generic pheromone or semiochemical will also be of commercial success for the entrepreneurs.
- For the effective management of mealybug, mating disruption and inoculative releases of parasitoids (such as *Anagyrus pseudococci*) were considered as effective strategies for the management of mealybugs in vineyards (Daane et al. 2008). This will enable environmental friendly, healthy, and safe methods of mealybug management of the future.
- In India, the pheromones were seldom used though pheromones for several Indian species have been identified elsewhere. A concerted effort is needed to use pheromones for monitoring and for mating disruption of the mealybug species by the plant protection experts. The entrepreneurs should take efforts either to import the pheromone or to develop facilities for indigenously synthesizing the pheromones and market at a cheaper rate in order to guarantee the continuous availability of pheromones to the farmers.
- Wherever the pheromones were not identified for the species, both indigenous and exotic, efforts must be made to identify and synthesize pheromones that can be useful for monitoring the pests, which can be effective tools for quarantine monitoring and population studies.
- Awareness should be brought to the farmers and the pest management experts on the scope of using the pheromones for effective management of mealybugs.
- Work has to be initiated on the role of plant volatiles in the attraction of mealybugs and their natural enemies, which can be used both for monitoring of pest and natural enemies and for reinforcing the natural enemy populations.
- Collaborative efforts between countries need to be made through international funding to isolate, identify, and synthesize pheromones of potential invasives for quarantine screening, a prophylactic measure of biosecurity.

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15 Ant Association

M. Mani and C. Shivaraju

The classic ant–aphid mutualistic relationship has long been observed by naturalist and entomologist alike, and several studies were conducted on the actual/benefits and factors involved in these associations. This type of relationship between ants and other insects is known to occur in a number of homopterous groups, especially in the mealybugs. In the case of mealybugs, the degree of dependence on the ants may vary from strong and almost necessary associations to weak, casual seasonal relationships. The association of ants with the mealybugs resulted in the hypothesis "more the ants, more the mealybugs." Ants are often associated with mealybugs as honeydew consumers. Hemiptera-tending ants are mostly species of the subfamilies Myrmicinae, Dolichoderinae, and Formicinae (Degen and Gersani 1989; Mittler and Douglas 2003). Samways et al. (1982) reported that 11 % of the 123 ant species identified in citrus orchards in South Africa were associated with mealybugs. Some mealybugs have an obligatory association with ants: all Southeast Asian myrmecophilous mealybugs have been collected only with ants of the genera *Acropyga*, *Dolichoderus*, or *Polyrhachis*, which attend the mealybugs either in subterranean nests or on aerial plant parts (Gullan and Kosztarab 1997). Aboveground nests were also observed on grapevines in Europe in association with *Phenacoccus aceris* (Signoret; Sforza 2008).

15.1 Benefits to Mealybugs

Benefits derived by mealybugs are more numerous than might be expected.

15.2 Protection from Natural Enemies

Ants protect mealybugs from their natural enemies; this is a very important and long-realized aspect of mealybug benefit. Natural enemies are easily disturbed by movements of the ants. Ants are naturally hostile to any quick or obviously harmful movements around the honeydew sources (Herzig 1938; Nixon 1951). The disruption of the activity of natural enemies by ants provides a temporal refuge for mealybugs (Gutierrez et al. 2008). Ants have long been known to aggravate mealybug populations and other honeydew-producing insect species by disrupting the natural biological controls on these species.

Ants deter the natural enemies of mealybugs. There are numerous examples of ants deterring the predators and parasites of mealybugs. For instance, ants also reduce parasitism of the cassava mealybug, *Phenacoccus manihoti*

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Matile-Ferrero (Cudjoe et al. 1993). A wide variety of natural enemies are known to prey on pineapple mealybugs. Ants protect mealybugs from their natural enemies (González-Hernández et al. 1999). In the field, *Pheidole megacephala* (Fabricius) had a positive association with *Dysmicoccus neobrevipes* Beardsley and a negative association with the predators of mealybugs (Jahn and Beardsley 2000). Collectively, *P. megacephala* deters predators from attacking *D. neobrevipes*. Ants are known to attack the parasitoids and predators of scales and mealybugs while attending the sucking pests. In Kenya, *C. montrouzieri*, released for the control of *Planococcus kenyae* (LePelley), was eliminated by ants (Anderson 1926). The ant *Pheidole punctata* (F. Smith) was known to destroy the larvae and adults of *Cryptolaemus montrouzieri* Mulsant preying on *Planococcus citri* in South Africa (Kirkpatrick 1927). The ineffectiveness of *C. montrouzieri* against *Planococcus citri* (Risso) at Liguria (Italy) was due to the attack of ants such as *Tapinoma erratium nigerrimum* Oryl and *Iridomyrmex humilis* Mayr (Constantino 1935).

Mealybugs and ants on a fruit of noni (*Morinda citrifolia*)

Ants attending the mealybugs

The presence of Argentine ant, *I. humilis*, appeared to be partly responsible for the failure of *Cryptolaemus* to become permanently established in Bermuda (Bennett and Hughes 1959). In India, the failure of establishment of *C. montrouzieri* in the mealybug-infested citrus orchards of Assam was due to the activity of ant *Oecophylla smaragdina* (Fab.) (Narayanan 1957). The control of *P. citri* with *Cryptolaemus* was made ineffective in the presence of ant attendants (Panis and Brun 1971). Loss of results with *C. montrouzieri* was caused by *I. humilis* in France (Greathead 1976). The ants Cremaster and *Iridomyrmex* were known to prey on *C. montrouzieri* (Collins and Scott 1982). The failure of ant control is detrimental to biological control of citrus mealybug (Singh 1978; Narayanan 1957). The observation of the protective behavior of *P. megacephala* against the attack of *C. montrouzieri* on the pink hibiscus mealybug *Maconellicoccus hirsutus* (Green) showed that all *C. montrouzieri* introduced were killed and removed in 132.5 min. The mealybugs that associated with ants are indeed protected from attack by their predatory natural enemies, although mealybugs and ants do not have an intimate association (Lai YiChun and Chang NiannTai 2007). There was an interaction involving the pink mealybug *Saccharicoccus sacchari*, the ant *Camponotus compressus* (Fabricius), and the predator *C. montrouzieri* in sugarcane (Srikanth et al. 2001). *C. montrouzieri* was found more in numbers and proved successful against the mealybugs in the absence of ants (Van der Goot 1948; Murray 1982). In South Africa, the control of ants like *I. humilis* and *Anoplolepis custodiens* F. aided the predator *C. montrouzieri* to give very good control of *P. citri* (Greathead 1971). Poutiers (1922) also suggested protecting *C. montrouzieri* from *I. humilis* in France.

Protection of mealybugs from predators

Associations among invasive species of ants and mealybugs are very important in their success in new locations (Helms and Vinson 2002). The Argentine ant *Linepithema humile* (formerly *Iridomyrmex humilis*) (Mayr) is an example of an invasive ant species that is a significant pest in both natural and managed habitats, and it is commonly associated with mealybug outbreaks (Daane et al. 2006; Silverman and Brightwell 2008).

Saying that ants "protect" mealybugs from natural enemies does not necessarily mean that ants are attacking the natural enemies to save honeydew as a food resource. Ants deter the natural enemies of mealybugs (Jahn and Beardsley 1994; Rohrbach et al. 1988). The encyrtid parasitoid *Anagyrus ananatis* Gahan of pineapple mealybug is not only scared away from when ants are present but they are also rarely killed by predators such as the ladybird beetles. When ants are absent, the parasitoid is highly effective in lowering the mealybug populations in pineapple plantings. Ant and mealybug interactions were studied in a pineapple field near Honolu on the island of Maui, Hawaii. Big-headed ant *Pheidole megacephala* was found to have a positive association with gray pineapple mealybug *Dysmicoccus neobrevipes* but no association with *Dysmicoccus brevipes* (Cockerell). Sticky trap collections revealed that *D. neobrevipes* and *D. brevipes* are dispersed by the wind. The positive association between *P. megacephala* and *D. neobrevipes* was not due to ants transporting mealybugs but could have resulted from ants deterring natural enemies or removing honeydew (Gary and Beardsley 2000).

However, some mealybug predators, such as coccinellids, apparently become tolerated by ants by mimicking the waxy body cover of the mealybugs (Daane et al. 2007). This condition of parasite–predator adaptation is often observed. The type of ladybird beetle larva is usually very mealy in appearance and blends in well with its pseudococcid host. Thus, the parasite or predator species is well adapted to the use of ant-attended hosts. Ladybird beetle predators are often found among formicid attendants. Ants seem unable to recognize the ladybird beetle larva as a predator. There is, therefore, little doubt that the seemingly mimetic resemblance of the beetle larva to the mealybug is an aid to its more perfect predaceous habitat. Another possible mealybug parasite adaptation has been noted in a species of fly larva. This larva apparently remains outside its host's body and extracts food externally. This habit would seem to make it readily susceptible to the attack by ants. In order to overcome the problem, the larva is always found completely hidden beneath the mealybug, and only when the host insect is removed can the larva be seen.

15.3 Ant Constructions

Ants protect the mealybugs from adverse weather by building earthen shelters around them and moving them to protected places; and some ant species actively construct shelters for mealybugs that provide some protection from unfavorable environments and natural enemies (Franco et al. 2000; Helms and Vinson 2002; McLeod et al. 2002). There are two main types of ant constructions which are important to mealybugs. The first is the actual ants' nest and the second is the so-called carton or ant tent. The latter is not important in California, although Wheeler (1926) mentioned several instances of "carton nests" in North America. Ant-nest isolation of the mealybugs is considered quite important and has been observed on several occasions in California. In one instance, *Phenacoccus artemisiae* Ehrhorn was found in some of the upper chambers of a *Crematogaster* nest. These mealybug specimens were found at least 2 ft from the nearest host plant and in two instances were being transported in the mandibles of an ant. This particular collection was made in early February, which is a time of very low insect activity and high precipitation rate. The mealybugs were quiescent for the most part and were found in close contact with one another on the ceiling of ant nest chambers. It seems likely also that parasite protection would be important.

Fungus is also a parasite of mealybugs, although infestation is not normally observed until the pseudococcid has been mounted; when examining mealybug preparations, however, fungus infestation is often seen. Ant-nest protection from a highly humid environment is therefore an important factor in mealybug welfare and is probably directly connected with protection from fungus contamination. Protection from harsh winter conditions is perhaps the most important factor of ant-nest benefit to mealybugs in California.

For the most part, ant tents are important in the tropical areas, where two primary types are found. The first is constructed with the silk-forming glands of the ant larvae. The adult, which has no silk gland, holds a larva in its mandibles and forces the immature form to produce its silken product in the desired area. The ant genus *Oecophylla* is well known for this habit. The second type of tent is made of earth, "paper" formed by the ant, and leaves. Any or all of these materials may play a role in the tent construction. The tents are normally built over mealybug colonies which may have as many as 1,200 individuals. Tent dimensions have been recorded up to 4.5 × 2.3 in.

Mealybug-derived benefits are twofold. First, the tent provides some protection from direct drops of rain, although the tent itself is in no way waterproof. Second, the tent, which has only one very small entrance, is important in shielding the mealybugs from large parasites. Apparently, the mealybug parasites are unable to either find the tent entrance or push their way through. Although there are many records of tent parasitism, the rate of incidence is much lower than where no protection is afforded.

15.4 Removal of Honeydew

Ants prevent the accumulation of honeydew by consuming it (Jahn and Beardsley 1994; Rohrbach et al. 1988). Honeydew accumulation, and the sooty mold that can grow on honeydew, may be detrimental to mealybugs. These ants, especially *P. megacephala*, have been blamed for protecting them against their natural enemies while removing the excess honeydew produced by the mealybugs (González-Hernández et al. 1999).

One of the direct benefits of ant association to mealybugs is shown in relation to the production of honeydew and the subsequent contamination of the honeydew and source insect with sooty mold. Because this fungus contaminant is often the cause of mass destruction of mealybugs, certain adaptations have been made to rid the mealybug of the secretion. Ants remove honeydew from mealybugs, thereby preventing fungi from attacking mealybugs, and the removal of honeydew prevents contamination, which may be especially detrimental to first-instar nymphs (Cudjoe et al. 1993; Daane et al. 2006, 2007; Gullan and Kosztarab 1997; Moreno et al. 1987). Rohrbach et al. (1988) hypothesized that honeydew feeding by ants could benefit mealybugs by preventing the accumulation of honeydew on the mealybugs themselves. Presumably, immature mealybugs get stuck in honeydew and die if ants do not remove it. *Phenacoccus alieni* McKenzie is known to squirt a small globule of honeydew from the anus to a distance of over 4 in.. This distance is at least 20 times the total length of the insect and shows that mealybugs are quite capable of ejecting honeydew to distances well out of the range of their personal contamination. When ants are in attendance, they remove the honeydew as described above, thus eliminating the problem of sooty-mold contamination. Because of this, ant-attended mealybug colonies are quite often very dense with little distance between individuals to allow for honeydew ejection.

However, in California's coastal vineyards, Argentine ants increased densities of the obscure mealybug *Pseudococcus viburni* (Signoret), primarily by removing the honeydew that impedes the movement of crawlers. Meanwhile, the larvae of *C. montrouzieri* successfully forage in patches of high mealybug density. One hypothesis is that larvae of *C. montrouzieri*, being also covered with waxy structures, successfully mimic mealybugs and avoid detection by ants. Furthermore, when approached by an ant, the coccinellid larva stops moving and lowers its body against substrate, thus better resembling a sessile mealybug. The ants move around the larva, and stroke it with their antennae like they stroke the mealybug. After failing to obtain the honeydew, the ant moves away. Densities of *C. montrouzieri* were higher on ant-tended vines, where there were more mealybugs (Daane et al. 2007).

Ants stimulated increased feeding by mealybugs; tending by the ants may have other effects that alter mealybug densities: It may also improve the mealybugs' habitat or fitness (Daane et al. 2007). In the presence of ants, mealybugs are able to ingest larger quantities of sap (Degen and Gersani 1989). In several instances, ant-tended mealybug colonies will be much larger than colonies of the same mealybug species on the same host that are not tended by ants. Therefore, outwardly the ant's presence must be of some benefit to the mealybug, either directly or indirectly.

15.5 Transportation of Mealybugs

Ants are known to transport the mealybugs from plant to plant between and within fields, thus facilitating mealybug dispersal. In California, it is often possible to see ant *Camponotus* actually carrying from its host plant, directly into the ants nest. Ants are the primary or sole means of mealybug dispersal in pineapple. Illingworth (1931) observed *P. megacephala* carrying mealybugs from one cage of pineapples to another. The big-headed ant *Pheidole megacephala.* (F.), Argentine ant *Linepithema humile* (Mayr), and fire ant *Solenopsis geminata* (F.) are commonly found in the Hawaiian pineapple agroecosystem, where they tend pink pineapple mealybugs (PPM) and gray pineapple mealybugs (GPM) for honeydew. These ants, especially *P. megacephala*, have been blamed for dispersing mealybugs (González-Hernández et al. 1999).

15.6 Benefit to Ants

Access to honeydew has been shown to enhance the rate of increase of ant colonies. Honeydew accounts for more than half of the diet of many temperate wood ants (*Formica* spp.), and it is the dominant food source of some subterranean ants (Mittler and Douglas 2003). Mealybug exudates/honeydew is highly acidic (pH 3) with fructose (45 g), glucose (20 %), and other sugar contents in negligible quantity (0–2 %) per 100 g of solids (Ashbolt and Inkerman 1990). The normal ant–mealybug association when observed in the field is seemingly quite simple. The ants, which may be of various genera, normally move busily from one mealybug specimen to another. When a mealybug is contacted, the ant begins to fondle the mealybug with its antennae just as it might fondle its own brood.

The ants rest their heads on the dorsum of the mealybugs near the area of the ostioles for honeydew. Mealybugs extrude a solution from their ostioles when disturbed. This is possibly a defense mechanism. When *Phenacoccus echeveria* McKenzie is purposefully disturbed, it extrudes two small globules of honeydew through its posterior ostioles. An ant then comes along and within a few seconds ingests all of the extruded honeydew. It is clear that ants benefit from mealybugs in receiving honeydew from them, which is added to the ants' food supply. The amount that ants rely on honeydew for their existence varies greatly with the species involved. Some ants seem almost entirely unknown whether this adaptation to aid in procuring honeydew, or whether this is the normally in an adaptation to aid in procuring honeydew or whether the normally indigestible wax is actually used in ants' diet.

Globule of honeydew

A third and final benefit has been mentioned earlier and deals with the use of associated mealybug as a source of protein. Although predaceous non-honeydew-consuming ants are not known to attend mealybugs just for protein, some ants, which have both honeydew-consuming and predaceous habits, will occasionally kill mealybugs and use them for protein. In nutritional value, honeydew is more complete than might be expected. It may contain free amino acids, amides, proteins, many minerals, and B vitamins (Way 1963). The honeydew may vary greatly in its content depending on the species of mealybug, the host plant, the age of plant, the part of plant upon which mealybugs are feeding, and the length of time that the insect feeds. Normally, a complete diet of honeydew will not compensate for a protein deficiency in the ant, and supplementary protein must be added to correct the situation.

There are several records of ants keeping mealybugs pseudo wax-free. Ants might use mealybug wax for some nutritive value.

15.7 Predatory Effect of Ants

A final direct benefit not often realized, but perhaps a factor of importance in the understanding of the biological control of mealybugs, is that some ants actively regulate the population size of their hosts. It has been demonstrated that certain ant species will actually keep the mealybug population down to a size which they can control, thus eliminating production of honeydew. The ants regulate any excessive build-up of population by killing a number of mealybugs, and consuming the mealybugs is considered a supplement to the protein portion of the ant diet (Way 1963). This habit is also of importance in eliminating sooty-mold contamination in the mealybug colony. Some ant species may switch between tending and preying on mealybugs (Degen and Gersani 1989; Mittler and Douglas 2003; Way 1963). The predatory role of ants on the mealybugs is very meager in the regulation of mealybugs.

15.8 Strange Aspects of Ant–Mealybug Associations

Exceedingly unusual observations were made by Bunzli in relation to an association between the mealybug *Neorhizoecus coffeae* (Laing) and the ant *Acropyga paramaribensis* (Borgmeier). The eggs and immature mealybugs were kept in chambers with eggs and larvae of the ant. The immature female mealybugs apparently served as honeydew sources. When the mealybug matured, it no longer produced honeydew and was then transported by the worker ants to a separate mealybug chamber. The eggs that are laid by the mature females are then carried back to the brood chambers. This association is not too unusual. The extraordinary part of the relationship is the fact that the winged virgin female ants, when leaving the nest on their nuptial flight, always carry in their mandibles a fertilized female mealybug. This mealybug will soon be the beginning of the honeydew source of a newly formed *Acropyga* nest.

Another exceptional transport association is described by Reyne (1954) in Java. In this case, mealybug *Hippeococcus* is especially adapted with long raptorial legs and sucker-like digitules for clinging of *Dolichoderus* ants. When disturbed, the highly mobile immature mealybugs climb onto the bodies of the ants and are carried into the nest where large colonies of mealybugs are maintained.

In California, an exceptional relationship existed between the mealybug, *Cryptoripersia salina* (Ehrhorn) and the ant *Crematogaster.* The mealybugs are enclosed in a white-felted sac at maturity under rocks. When a rock was overturned, the mealybugs were all in one large chamber in the ants' nest and were in great numbers, mostly matured mealybugs. Once the rock had been overturned, masses of ants poured from the lower tunnels of the nest in pursuit of their honeydew "symbionts." Within a matter of 15 min the mealybug chamber had been emptied of its mealybug contents.

Another unusual observation was made in Modoc County involving an association between the mealybug *Phenococcus colemani* Ehrhorn and the ant *Formica subpolita*. This mealybug is very often found in cracks and pits on the underside of larvae rocks. When the mealybug-infested rock was distributed, associated ants hurriedly tore the mealybugs, waxy sacs and all, from their rock habitat and carried them into cracks in the soil. The ants removed the mealybug so rapidly that, in order to collect sufficient numbers of the mealybugs, the ants had to be removed first.

Another unusual observation was made in Nevada. Ants were busily tending their mealybug host in the usual fondling manner. In this case, the mealybugs were withholding their honeydew supply from the ants. The ants, however, had overcome this problem by butting the abdomen of the mealybug with their heads, thus causing the honeydew to flow from the mealybug ostioles. The ants then consumed the solution.

There was another kind of interrelationships of big-headed ants, mealybugs, and spread of mealybug wilt disease. The big-headed ant, *Pheidole megacephala* (Fabricius), is the dominant ant species in most of the pineapple fields in Hawaii. Ant and mealybug populations in infested plots increased gradually and appeared to be strongly influenced by the phenology of the pineapple plants during the first fruit crop. Unusually heavy rainfall caused the dramatic reduction in ant populations observed then. Highest ant population levels occurred about 3 years after planting, when all untreated plots became nearly uniformly infested. The incidence of mealybug wilt was higher when the ants and mealybugs were more (John et al. 1982).

15.9 Management of Ants

The association of ants with the mealybugs by giving protection to natural enemies, transport of mealybugs, and removal of honeydew from the mealybug colonies has resulted in an increase in the mealybug population. It serves the basis to develop the hypothesis "more the ants, more the mealybugs." Hence, it is necessary to check the activity of ants in the suppression of mealybugs. According to Mansou et al. (2012), the ants *Tapinoma nigerrimum* constitute a threat to biological control of *Planococcus ficus* (Signoret) and *Pl. citri* in the orchards in Italy by either the encyrtid parasitoids *Anagyrus pseudococci* (Girault) and *Leptomastix dactylopii* (How.) or larval stage of the coccinellid predator *Cryptolaemus montrouzieri*, and hence an adequate control of the ants is highly recommended before the release of any of these natural enemies.

General ant control measures may be adopted to suppress the activity of ants. It has been suggested to apply a band of diazinon granules around the plant about 1 ft from the main stem. Other control measures include destruction of ant holes, red ant nests, and skirting of trees after fruit harvest, which prevents the ant migration through side branches. After the patrolling (up and down) of ants on the trunk is stopped, the beetles can be released (Singh 1978). It was also suggested that ants should be prevented by rubbing magnesia or powdered tale in a 4-in.-wide band at the time of liberation of *Cryptolaemus* (Constantino 1935). Mealybug-infested custard apple plants were applied with sticky bands which had helped to prevent the movement of ants (Murray 1982). BHC solution (5 g/l) was poured into the anthills prior to the release of *C. montrouzieri* against *Ferrisia virgata* (Cockerell) in guava orchards (Mani et al. 1990). In the orchards where ants were partially excluded, a significant reduction in citrus mealybug populations and damage could be observed (Villalba et al. 2006). Applying a 6 % solution of chlorpyriphos to the base of the vine and supporting stake and to the surrounding soil gave the best results.

Liquid ant baits were evaluated for the control of Argentine ants *Linepithema humile* (Mayr) and associated mealybug pests (*Pseudococcus* species) in commercial vineyards. In all trials, liquid baits were an insecticide dissolved in 25 % sugar water. In 2002, a liquid bait – thiamethoxam, mixed at 0.0001 % (active ingredient, A.I.) – was delivered in ground-based (site 1) and canopy-based (site 2 and 3) dispensers that were recharged every 2 weeks and cleaned every 4 weeks, and deployed at rates of 160 (sites 1 and 2) and 620 (site 3) dispensers per hectare. There was a significant reduction of season-long ant densities in liquid bait treatments at all sites and of mealybug densities at two of three sites; crop damage was significantly lower in the liquid bait treatment at all sites. Similarly, studies in the pineapple field showed that eradication of the ants reduced the population of mealybug (Beardsley et al. 1982).

Gourmet ant bait (Innovative Pest Control Products, Florida USA), containing 1 % disodium octaborate tetrahydrate toxicant, dissolved in 25 % sucrose solution to make 0.5 % A.I., was overall the most preferred bait for Argentine ants *Linepithema humile* (Mayr), common pugnacious ants *Anoplolepis custodiens* (F. Smith) and cocktail ants *Crematogaster peringueyi* (Emery) during spring, summer, and autumn, and on some occasions being significantly more preferable to ants than the control solution. Management of Argentine ants is important in mealybug management in a vineyard because the ants will protect the mealybugs. Ant baits, placed in approved dispensers, can reduce Argentine ant populations to an acceptable level in 2–3 years. The baits need to be placed in the field during budbreak (March to June, depending upon location in the state) at a rate of 15–20 bait stations (UC bait station) per acre (Nyamukondiwa and Addison 2011). Ants can also be managed by applying tanglefoot every 1–2 weeks.

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16 Methods of Control

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Mealybugs pose a serious threat to several agricultural and horticultural crops throughout the world. They are a major problem in greenhouses and nurseries, where they often cause severe economic damage. It seems surprising that such a delicate soft-bodied insect is so difficult to control. There are, however, several reasons which may account for this fact.

Mealybugs developed several different defense mechanisms. Many of the species tend to establish themselves in protected sites, such as cracks and crevices in bark, leaf axils, root crowns, nodes of grass stems, under fruit sepals and within fruit navels, between touching fruits or fruits and leafs, and in tunnels bored by insect larvae in roots and stems (Franco et al. 2000; Kosztarab and Kozár 1988). This cryptic behavior of mealybugs may provide a spatial refuge from natural enemies and harsh environmental conditions (Berlinger and Golberg 1978; Gutierrez et al. 2008a). This type of plant colonization makes mealybugs practically invisible during the latent population phase. However, during outbreaks, the population "boils over" from the refuge and becomes conspicuous. In addition, other species have the habit of spending their entire lives deep in the soil, protected almost from insecticidal materials.

Mealybugs are noted for the production of dermal wax secretions. Adult mealybugs and the nymphal instars are covered with waxy coating. Also the eggs of mealybugs, protected by the waxy filamentous secretions of the ovisac, are almost impossible to reach with insecticides.

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Eggs protected with waxy ovisac

Adult mealybug covered with waxy coating

Mealybug crawlers not covered with waxy coating

The waxy secretion is the most common conspicuous trait of the mealybug family. It is a complex system that serves different functions, and which is produced by the epidermal wax glands and transported to the body surface *via* ducts, pores, and secretory setae of various types (Foldi 1983; Gullan and Kosztarab 1997). The main components of the wax of five mealybug species (*Planococcus citri* (Risso), *Pl. ficus* (Signoret), *Pl. vovae*, *Pseudococcus cryptus* Hempel, and *Nipaecoccus viridis* (Newstead)) were trialkyl glycerols and wax esters. The wax cover is believed to prevent water loss. The hydrophobic property of the wax enables the mealybugs to escape drowning or becoming swamped by water in their typical cryptic sites. The ovisac, which is also a wax secretion, is considered to be an adaptation that protects the offspring from both wet and dry conditions, and that may also provide an attachment to the host plant. Tubular ducts and multilocular disc pores, respectively, produce long hollow and shorter curled filaments, which make up the ovisac and the male cocoon (Cox and Pearce 1983; Foldi 1983). The white wax of mealybugs is strongly light reflective and may reduce desiccation. In some cases, the wax also serves to cover the honeydew droplets and to protect the mealybugs from contamination by their own honeydew and defensive exudates (Gullan and Kosztarab 1997). Normally, chemicals are used to control the mealybugs. However, the crawler stage is not covered with wax, and as a consequence, this is perhaps one of the most susceptible stages of mealybug to chemicals. On the other hand, natural enemies have given excellent control of some mealybugs. The purpose of this study is not to give specific recommendations for mealybug control. It will be dealt under the respective crops. General methods of mealybug control are summarized in this chapter.

16.1 Decision-Making System

The five key elements ought to be considered in a decision-making system in the management of mealybug population are (1) information on mealybug density, perhaps obtained late in the season, in case of overwintering population; (2) awareness of the population distribution in the target area; (3) information about the density of the relevant natural enemies; (4) the density of associated insect species, which may increase the damage or render the activity of the natural enemies; and (5) the risk of the spread of mealybug-transmitted viral disease. In this chapter, the current knowledge needed to take actions and to suggest solutions for different situations is reviewed. Based on such knowledge, the grower may select the appropriate control tactics.

16.2 Monitoring

Vigilance is important to eliminate them before there is a major outbreak of mealybugs. Monitoring for the incidence of mealybugs is a prerequisite to initiate the management practices. There are no simple and effective methods to visually monitor the mealybugs, and the process itself can be time consuming and laborious. As exemplified for *Pseudococcus maritimus*, the accuracy of monitoring the plant material will depend on the mealybug population density, and the number of samples needed for an accurate count is often high because most of the mealybugs have a clumped distribution pattern, often being found on only a small percentage of the plants. The appropriate sampling program will also vary throughout the season, depending largely on mealybug location as there are periods when much of the population is hidden (e.g., under bark) rather than exposed (e.g., on leaves). In addition, as species have different numbers of annual generations and preferred feeding locations throughout the season, there is not a single sampling procedure appropriate for all the mealybugs. In most cases, signals of an infested plant can be used to aid the sampling program. First, ants are closely associated with the mealybugs, and their presence can help select the plants for further sampling. Second, honeydew on the leaves can also be a good signal; a large population hidden under the bark will excrete enough honeydew that the infested trunk region will have a darker, wet appearance. Third, as mealybug numbers build up, their feeding damage may cause leaves to turn yellow or brown and drop from the plant. Finally, during the harvest time, fruits in direct contact with the spurs or trunk are more likely to be infested, and by selecting these fruits, a higher mealybug count can be made A faster sampling method is to use sticky traps baited with sex pheromone to lure in and trap the adult winged males. It has long been known that sexually mature female mealybugs like *Planococcus citri* emit a sex pheromone to attract the winged adult males. These pheromones can be synthesized and used in the field for monitoring the mealybugs. Thus, the monitoring provides essential information for making decisions indicating the presence and the numbers of mealybugs and their enemies occurring in nature; the degree of natural control by insects, which prey upon or parasitize the mealybugs; whether the mealybugs are high enough to require treatment; the lifecycle stages of any mealybugs present and, therefore, the most effective timing for the management options.

16.3 Cultural Method

A number of cultural controls are practiced and these vary greatly among regions. Crop sanitation is useful in reducing the mealybug population. Before applying the insecticides/pesticides, manual removal of the fluffy nests and most of the insects is advisable. It greatly increases the chance on complete elimination of the mealybugs. Removal of the weeds harboring the mealybugs eliminates the source of mealybug infestation. For example, crop sanitation including the removal of weeds was useful in the control of *Heterococcus pulverarius* (Newstead) (Dietz and Harwood 1960) and *H. nigriensis* Williams (Harris 1961). Burning and plowing the crop after harvest result in very little reoccurrence of the mealybugs. The control of certain garden mealybugs may be done simply by hosting the plants down with a strong stream of water (Michelbacher et al. 1959). Although this seems rather unorthodox, the control is fairly successful, especially if this treatment is used at regular intervals. In the case of woody plants, mealybugs are found underneath the bark of the trunk, cordon, spurs, and canes. These locations provide some protection from insecticides, natural enemies, and environmental conditions. Stripping the bark exposes the mealybugs to these mortality factors. The infested bark should be destroyed rather than left in the row middles as the mealybugs can move back. Cover crops have been used to improve soil health and lower-pest densities by increasing the natural enemy numbers or diversity.

Parasitoids that attack the mealybugs could utilize floral nectaries of some cover-crop species as a food source to increase adult longevity. Generalist predators, such as the lacewings and some ladybird beetle species, might also utilize these floral food resources as well as herbivores in the cover crop as alternate prey. Overly vigorous plants can increase mealybug populations in two ways. First, excess nitrogen has been shown to increase the size of mealybug females and the number of eggs in each ovisac. Second, the increased foliage associated with overly vigorous plants provides better shelter for the mealybugs by reducing temperatures inside the vine leaf canopy, and may reduce the amount of applied foliar insecticide that reaches the mealybug. Controlling plant vigor is, therefore, a practice that can help improve mealybug control.

16.4 Physical Control

The following physical control measures can be adopted to reduce the mealybug population on the plants: (1) flushing mealybugs off the leaves with water can provide immediate relief but will simply displace the mealybugs; (2) rubbing off and crushing the colonies with a cloth; (3) mealybugs can also be removed by dipping a cotton swab in alcohol or fingernail polish remover; (4) discarding heavily infested plants; and (5) pruning infested tissue off infested plants.

16.4.1 Hot Water Treatment

A quarantine treatment is needed to prevent the entry and spread of mealybugs like *Planococcus citri* (Risso) and *Pseudococcus odermatti* Miller and Williams infesting limes. A 20-min, 49 °C hot-water immersion treatment is effective in killing all the mealybugs without affecting the fruit quality (Gould and McGuire 2000).

16.5 Chemical Control

Waxy insects such as mealybugs and scale insects are difficult to kill using contact insecticides because the waxes produced by these insects form a physical barrier preventing chemical penetration. It is essential that the mealybug is killed promptly, but the cotton-wool cover can repel any insecticide sprayed onto it; therefore, often a wetting agent in the insecticide spray is required. Many contact insecticides are ineffective against mealybugs because the mealybug waxy covering repels polar chemicals (Walton et al. 2004). Insecticides, with contact and also systemic activity, are still primarily used to control or regulate the mealybug populations.

Normally chemicals are used to control the mealybugs. There are great similarities among the insecticide arsenals used to control mealybug species on different crops. In principle, three main modes of insecticide application are adopted: (1) foliage cover spraying for management of aboveground populations; (2) application of insecticide solution to the soil to enable it to penetrate to the root zone, so as to combat subterranean colonies; and (3) chemigation by application of systemic compounds *via* the irrigation system (Chemigation), for example, drip irrigation. Insecticides are also used against mealybugs by smearing them on the stem or main branches. For example, swabbing of grapevine trunk/stem with chlorpyriphos is recommended to control the mealybugs. Two other, less common, techniques are fumigation, usually applied for eradication, for example, with methyl bromide, and slow-release strips to prevent colonization.

16.5.1 Neonicotinoids

More recently, an effective group of compounds has been found, which combines toxicity to mealybugs with safety to other non-targeted organisms; they are the neonicotinoids. These compounds act on the central nervous system and easily replace carbamates, organophosphates, or pyrethroids, since there are no records of cross-resistance associated with them. These systemic compounds show high effectiveness against mealybugs. Examples include dinotefuran applied to the canopy; acetamiprid applied by smearing on the stem or the branches (Gross et al. 2000; Larrain 1999); and imidacloprid and thiamethoxam that are introduced by watering the soil (Daane et al. 2006; Fu Castillo et al. 2004; Grout and Stephen 2005; Martin and Workman 1999; Sazo et al. 2006). The insecticide arsenal that is both suitable for organic farming and able to cope effectively with mealybug pests does not exist in practice. Since the growers will need to treat small hot spots of the mealybug, it is expected that some soft insecticides will be used and that more than one application may be needed to selectively eliminate such hot spots. When these hot spots are treated, several points should be taken into account: (1) the hot spots are expected to be in areas that are practically free of problematic mealybug populations; they actually constitute oases for parasitoids and predators; therefore, the ratio of mealybug to natural enemy populations in the hot spots should be considered before initiation of any control operation; (2) an insecticide will be applied when augmentation with predators is not useful or cannot be implemented; (3) a low-residue short-life insecticide is the most appropriate; (4) an augmentation of natural enemies will be needed if the hot spots are too numerous.

16.5.1.1 Application Timing

Application timing is critical to control mealybugs with most insecticides. Exposed mealybugs are more easily killed than those under the bark, and the smaller stages are more susceptible than the larger mealybugs. This is especially true for insecticides with a short residual period. Much research, therefore, has been aimed at proper application timing and development of materials with better penetration into the protected habitats of mealybugs. Applications with systemic insecticides near bloom are often used, as the insecticide moves quickly in the plants.

16.5.2 Foliar Spray

The dispersive habit of the crawler should make it more susceptible to insecticides than the later developmental stages that live in sheltered sites. Spray application is to be timed to coincide with the crawler stage as it would be effective and would also permit the use of less persistent chemicals.

Not many specific insecticides are available against all the species of mealybugs, but parathion was primarily used as spray and dust in commercial agriculture. In the earlier years, organophosphates such as malathion, diazinon, tetraethyl pyrophosphate (TEPP), and dimefox have been used with partial success but they are not in use now due to one reason or the other. They may be extremely hazardous or can develop resistance (Madsen and Westgard 1962). Malathion is primarily used in the control of garden and nursery mealybugs (Michelbacher et al. 1959). TEPP, another organophosphate, has effectively controlled *P. citri, Ps. longispinus*, and *Ps. maritimus* (Jefferson and Pritchard 1961). Some old organophosphates, such as dichlorvos and chlorpyriphos, are still being used against mealybugs because they certainly are much less dangerous. Many of the chlorinated hydrocarbons, such as dichlorodiphenyltrichloroethane (DDT), lindane, aldrin, dieldrin, and endrin, and the organophosphate (parathion) are not in use now due to various reasons. Eventually, however, most of these materials became less effective also. Organophosphates, such as chlorpyrifos, acephate, dichlorvos, and diazinon, and, to a lesser extent, carbamates, such as aminocarb, carbaryl, thiodicarb, or methomyl, are broad-spectrum nerve insecticides, which have been used against mealybugs that colonize the plant canopy since the early 1960s (Gonzalez et al. 2001; Shafqat et al. 2007). These insecticides when applied in high volume could successfully overcome the obstacles that make mealybugs hard to kill. The obstacles are as follows: (1) their hydrophobic wax cover, which repels hydrophilic insecticides; (2) their tendency to feed in hidden and protected parts of the plant; (3) their typically dense colonies; and (4) the frequent overlapping of generations. Effective control is achieved when most of the mealybug population is in the dispersive crawler stage or the young nymphal instars, and when the host plant does not provide effective shelter. However, satisfactory control is often difficult to achieve over an extended period. These chemicals have detrimental effects on the environment as a whole and on natural enemies in particular (Anand and Ayub 2000; Babu and Ramanamurthy 1998; Meyerdirk et al. 1982). The multivoltine character of the pest mealybugs and the frequent application of inefficient control measures accelerate the development of insecticide resistance (Flaherty et al. 1982). Systemic organophosphates such as dimethoate could overcome some of these obstacles (Grout and Stephen 2005; Meyerdirk et al. 1982; Prasad et al. 1998). Chlorpyrifos-impregnated strips are applied to protect banana bunches from the mealybug infestation or applied as stem barriers for the control of ants (Addison 2002; Gross et al. 2001).

Newer materials, with more novel modes of action, have also gained in popularity, including neonicotinoids, insect growth regulators (IGRs), botanicals, and biosynthesis inhibitors. Application of spirotetramat 6 fl. oz/acre + adjuvant (Ventre 0.25 % v/v) 44 fl. oz/acre at a spray volume of 137 gal/ac was able to reduce the bunch infestation with mealybugs to 3 % fruit damage and there was little to no honeydew in that treatment. A major difference between the older and newer materials is the importance of coverage. As mentioned, a portion of the mealybug population is often under the bark and, for some species, on the roots. Many of the older foliar sprays did not effectively contact and kill mealybugs in these more protected locations. Some of the more novel materials have systemic properties, applied either through the irrigation system or as a foliar spray. For organic or sustainable farming programs, neem, light mineral oils, lime sulfur, citrus products, and fatty-acid soaps have been used.

Another historical difference is that the earlier materials were often broad spectrum and killed more than just the targeted mealybugs. The extensive use of DDT and other synthetic insecticides to control leafhoppers apparently disrupted the natural control of the mealybug *P. maritimus*.

16.5.2.1 Oil Emulsions/Mineral Oils/Botanicals

Oils

Oils have long been used for the control of scale insects but they have been ineffective against mealybugs. However, the integration of narrow refined oils with other insecticides was suggested as a means to dissolve the insect's wax covering and thereby improve the insecticide efficacy (Cranshaw et al. 2000; Morishita 2005). Summer oil emulsions/mineral oils are particularly effective in the control of mealybugs on ornamental plants. Applications should be made at regular intervals of 1–3 weeks (Michelbacher et al. 1959). Combinations of these oil emulsions with contact insecticides are quite effective in the control of garden and household mealybugs. Neem oil, horticultural oil, and insecticidal soaps are often regarded as "organic" or non-chemical methods, but this is not completely accurate. However, they are safer than the insecticides. They will not provide absolute control over mealybugs but can drastically reduce their populations. Chilli–Garlic extract is also used to control the mealybugs.

Botanicals

Neem has natural insecticidal properties but is biodegradable and non-toxic to several naturally occurring parasitoids and predators. It works by making the leaves unpalatable to the mealybugs. Neem is to be sprayed like other contact insecticides. Spraying should be in such a way that the undersides of all leaves are covered. In organic agriculture, azadirachtin, an IGR chitin inhibitor derived from the Indian neem tree, may be used in similar modes (Irulandi et al. 2001). Pyrethrins and rotenone replaced some of the old compounds in organic agriculture with limited effectiveness. Neem products have a repellent effect on some mealybugs. Neem oil is effective for mealybug suppression. Neem oil is generally considered safe for humans, pets, and plants unlike usual chemical insecticides. Neem oil is an all-natural organic insecticide. Unlike the toxic chemicals, neem oil interrupts the pest reproduction cycle and is, therefore, useful in eliminating mealybugs from the plants. Mix 5 ml (1 oz) of pure neem oil with 2.5 ml (1/2 oz) of a mild liquid soap and 1,000 ml of water (four cups). Mix neem oil and liquid soap first and then add water. Mix it thoroughly and spray. Neem oil solution smothers the mealybugs; therefore, complete coverage of all the plant parts is essential. Repeat every 5–7 days until the infestation comes under control. Bug Buster is a botanical solution for mealybugs. Two sprays of Bug Buster are recommended; first, at a dose of 4–5 ml/l of water at an interval of 3–5 days and thereafter, at an interval of 7–15 days. Bug Buster acts as a contact as well as systemic against mealybugs; it penetrates the waxy cover of the insect's body and eventually kills them; and it disrupts the structure and permeability of the insect cell membranes. Disruption of cell wall damages the cells resulting in quick killing of the mealybugs. Hence, Bug Buster is very effective for all the stages of mealybug, as it is biodegradable and safe for humans; compatible with most of the bio-pesticides/-fertilizers; free from harmful synthetic chemicals and water soluble; acts as systemic as well as contact against mealybugs; non-hazardous; safe to humans and pests; and non-polluting, eco-friendly, and no residual toxicity. Because it is a combination of active natural extracts, there is no possibility of developing resistance (http://www.ehow.com/list_7578648_home-remedies-mealybugs.html#ixzz2sd1mn MBI). Unripe fruit extract of the plant *Balanites aegyptiaca* showed inhibition of the mealybug *Ferrisia virgata* (Cockerell) after the third day of spraying. No mealybugs were observed on the leaf on the seventh day of the application (Wabale et al. 2010). About 90 % mortality of *Planococcus citri* was obtained with pepper and eucalyptus extract at 3,500 ppm (Ahmadi et al. 2012).

Horticultural Oil

Horticultural oils are petroleum distillates. They are to be applied underneath leaves, on pots, and areas surrounding the plants. These oils (if not phytotoxic) should not be applied to plants when temperature is greater than 85 °F or in direct sunlight.

Insecticidal Soaps

Insecticidal soaps are a solution of synthetic pyrethroids mixed with a mild detergent made from petroleum products. These soaps (if not phytotoxic) should be applied underneath leaves, on pots, and areas surrounding the plants and should also be used on greenhouse vegetables. Dishwashing soap can be used as an effective remedy for mealybugs. According to evergrowing.com, combine one tablespoon of dish soap with one pint of warm water. Mix the solution in a spray bottle and coat the plants with a layer of the solution. The soap penetrates the protective waxy coat created by mealybugs and kills the pests. Check all areas of the plant, including the underside regions, for infestation. Spray every region of the plant to ensure complete eradication.

16.5.3 Soil Drench

Soil drenching with malathion and parathion were partially effective against root mealybugs. Heavy infestations of *Rhizococcus pritchardi* McKenzie on roots of African violet have been successfully controlled by drenching the potted plants dimethoate (Snetsinger 1966). At present, the mealybug management is based on chemical treatments, primarily with neonicotinoid insecticides (e.g., imidacloprid, thiamethoxam, clothianidin). These are typically applied as a soil drench directed to the roots. Soil drench applications of imidacloprid is highly effective in reducing the mealybug populations, particularly when applied at 0.525-g ai/vine makes it extremely effective. In California, the mealybugs were also controlled when imidacloprid was applied through irrigation lines or into furrows (Sazo et al. 2006). A further benefit of soil drenching is that the insecticide is transported to the pest without harming the predators and parasitoids and can be applied before they are active. Under this condition, imidacloprid could be used to kill mealybugs on the roots of the plants. Imidacloprid soil treatments have good residual activity and the control is sustained even up to 2 years.

Systemic insecticides are applied preventatively to the growing medium as a drench or as a granule for uptake or absorption *via* the roots and then translocated throughout the plant through the vascular system. Most systemic insecticides are translocated through the plant *via* the transpiration stream, which is the movement of water through the plant by means of the xylem- or water-conducting tissues. They are primarily active on phloem-feeding insect pests with piercing–sucking mouthparts, such as mealybugs, as these insect pests feed exclusively within the xylem vessel elements or phloem sieve tubes. During the feeding process, these insects withdraw and ingest lethal concentrations of the systemic insecticide's active ingredient and are subsequently killed. There are a number of advantages associated with using drench or granular applications of systemic insecticides compared to foliar sprays. For instance, drench applications reduce exposure to workers and natural enemies, such as parasitoids and predators. In addition, systemic insecticides are translocated through the plant vascular system including the xylem and phloem, protecting the growth that would have been missed when applying a contact insecticide, as well as any new growth following the application. This may provide protection for extended periods of time. Furthermore, applying systemic insecticides as drenches reduces the amount of material lost due to evaporation, light degradation, and irrigation (wash-off).

16.5.3.1 Soil Application

Soil application of granular insecticides, namely phorate, disyston, and aldicarb, has been recommended to control the mealybugs. Phorate has been used in the control of *Heterococcus pulverarious* (Dietz and Harwood 1960), *Ferrisia virgata* (Ckll.), *Planococcoides njalensis* (Laing), and *Ps. comstocki* (Kuwana) (Abrahao and Mamprim 1958). Disyston has been used in the control of Dysmicoccus *brevipes* (Ckll) (Carter and Gortner 1958).

Aldicarb granules applied in soil resulted in excellent control of *Maconellicoccus hirsutus* (Green) (Mani and Thontadarya 1991). In Shanghai region, aldicarb (5 %) granules mixed in soil around the ornamental succulent *Kalanchoe blossfeldiana* plant roots or 40 % omethoate 100× poured over the roots resulted in 97 % control of *Planococcus citri* (Tang et al. 1992). Aldicarb when applied as 10 % granules into the soil with a drench of l water/plant resulted in the best control of *Planococcus citri* (Risso) infesting the gardens (Bivins and Deal 1973).

16.5.4 Insect Growth Regulators

The chemicals having the IGR activity are used to reduce the mealybug population. For example, the IGR ZR-777 (prop-2-ynyl 3,7,11-trimethyl-(2E,4E)-dodecadienoate), gave good control of nymphs in all instars of *Planococcus citri* (Risso) receiving 0.01 % sprays. One foliar application of ZR-777 gave good control of *Pseudococcus longispinus* (Targ.) and *Phenacoccus solani* Ferris after 5 days of application. The IGRs, such as buprofezin, a chitin-synthesis inhibitor, or kinoprene, which mimics juvenile hormone, were sought as replacements for organophosphates and carbamates in controlling mealybugs; they have been considered a suitable alternative because they exhibit low human toxicity. They are more selective to many beneficial species and they are specifically targeted at processes involved in particular stages of mealybug development. However, many of the IGRs are toxic to ladybeetles (James 2004; Cloyd and Dickinson 2006). Buprofezin is a commonly applied IGR against mealybugs (Muthukrishnan et al. 2005); however, its effectiveness is mainly limited to eggs and young stages, so that the adult females may escape the consequences of the treatment. Buprofezin also suffers from the same limitations as other foliar-sprayed compounds. Buprofezin (Applaud) is emerging as a prime control tool for mealybugs. When applied, for three seasons, the chemical works extremely well for the mealybugs. It is an IGR, and great control is achieved while allowing beneficial insects to continue feeding with no notable disruption. Chlorpyriphos is by far the most popular pre-harvest material, but buprofezin can also be applied post harvest. The IGR Applaud provides effective control of other sucking pests like soft scales, ash whitefly, etc. The active ingredient, buprofezin, is extremely effective against crawler and nymph stages of these pests by inhibiting chitin biosynthesis. Application of the juvenile hormone analogue epofenonane (RO 10–3108) at 10 ppm, together with adjuvants, inhibited the male and female development of *Pseudococcus calceolariae* (Mask.) (Rotundo 1978).

16.5.4.1 Pesticides Known to Control Mealybugs

Pesticides that are known to control mealybugs are as follows: acephate, acetamiprid, azadirachtin, bendiocarb, bifenthrin, buprofezin, carbaryl, chlorpyrifos, clothianidin, cyfluthrin + chlorpyrifos, cyfluthrin + imidacloprid, diazinon, dimethoate, fenpropathrin, flonicamid, fluvalinate, imidacloprid, kinoprene, lambda-cyhalothrin, malathion, permethrin, pyriproxyfen, S-kinoprene, and thiamethoxam.

16.5.4.2 Precautions

Pesticides can provide short-term control but are not recommended for long-term control because mealybugs often persist in hard-to-reach areas. Mealybugs are most susceptible to chemicals when they are in the crawler stage. A waiting period of at least 2 weeks after using pesticides before releasing the biological control agents is needed. High-volume wet sprays are needed in order to penetrate the waxy coating that protects mealybugs. It may take a series of applications at 10- to 14-day intervals to control mealybugs. Repeated use of the same pesticide or the pesticide combination more than three times in a row should be avoided.

16.5.4.3 Pheromone-Based Management Tactics

Sex pheromones of insects, including mealybugs, are natural compounds emitted by virgin females in order to attract conspecific males for mating. It has long been known that sexually mature female *Planococcus citri* emit a sex pheromone to attract the winged adult males. These pheromones can be synthesized and used in the field. Several chemicals have been identified to attract the mealybugs like *P. citri*, *Maconellicoccus hirsutus*, etc. The sex pheromones are effective in extremely small quantities; they are non-toxic and can be applied in various ways. Unlike pesticides, these chemicals are species specific and do not affect beneficial insects. The behavioral impacts of the semiochemicals are limited to the target pest organisms. The potential of mealybug sex pheromones as an alternative and ecologically friendly means for monitoring and control is important and promising. Sex pheromones are used in lures for monitoring, for detection of outbreaks, and for population management. Monitoring systems provides vital information for the timing of insecticide applications. Population levels can be reduced or controlled by mass trapping, mating disruption, or lure and kill. The success of these methods depends on the availability of the pheromone and on an appropriate formulation and deployment. In contrast to the extensive use of sex pheromones in controlling the beetle and moth pests, sex pheromones are not yet employed in the control operation of scale insects (Franco et al. 2009).

16.6 Biological Control

Although it is apparent that many problems arise when chemicals are applied for the control of any insects, some of these aftereffects warrant special mention in the case of mealybug control. Often when applications of insecticides are made for the control of certain mealybugs, instead of causing a decrease in the mealybug population, an outbreak is also noted. The density of a Japanese mealybug, *Planococcus kraunhiae*, on Japanese persimmon fruit was higher in plots frequently treated with cypermethrin than that in the untreated plot. The number of mealybugs found on “Fuyu,” a non-astringent cultivar, was higher than that on “Hiratanenashi,” an astringent cultivar (Morishita 2005). This is usually because the insecticides have little effect on the mealybug, but eliminate the natural enemies, which were at one time holding the mealybug population in check. At times, certain insecticides control the mealybugs; however, with the decrease of competition, other pests, particularly mites, increase. This second pest may become a more serious pest than the first. Finally, it has often been noted that, although a chemical may give excellent control for a short time, the mealybug population, when building up again, will reach an even higher level than it had attained before the chemicals were first applied. The frequent use of insecticides and labor for mealybug control has made their cost to the grower still greater.

Mealybugs have many natural enemies, including parasitic wasps, arthropod predators, and entomopathogenic fungi. However, parasitoid encyrtids and predatory ladybird beetles (Coccinellidae) are the most common natural enemies of mealybugs, and a tremendous amount of research has been done in this area, much of it quite successfully.

Mealybug-parasitizing encyrtids are primary endoparasitoids, most of them undergo solitary development. *Coccidoxenoides, Gyranusoidea, Leptomastidea, Leptomastix, Pseudaphycus*, and *Tetracnemoidea* are examples of encyrtid genera of mealybug parasitoids (Charles 1993; Franco et al. 2000; Noyes and Hayat 1994; Rosen 1981).

A number of predators contribute to mealybug control. Few specialize on mealybugs, whereas most are generalists that prey on any small, soft-bodied arthropods. Sometimes, the naturally occurring parasitoids, including encyrtids and aphelinids, and predators, such as coccinellids, lacewings, cecidomyiids, and drosophilids, play a major role in the suppression of the mealybugs. Invasive mealybugs are often being controlled excellently with the introduced parasitoids and predators. Coccinellids accept a wide range of food, but they complete the larval development and produce viable progeny only if they consume their "essential food." Four genera of Chilocorinae (*Brumus*, *Aspidimerus*, *Stictobura*, and *Orcus*) and six genera of Scymninae (*Diomus*, *Nephus*, *Sidis*, *Parasidis*, *Cryptolaemus*, and *Pseudoscymnus*) prey preferentially on mealybugs (Iperti 1999). Other important groups of predators are brown lacewings (Neuroptera; Hemerobiidae) and predatory gall midges (Diptera; Cecidomyiidae). The most well-known predator is the mealybug destroyer, *Cryptolaemus montrouzieri* Mulsant, which is native to Australia.

As sap feeders, mealybugs are not likely to be exposed to viral or bacterial infections (Moore 1988) and only a few species of entomopathogenic fungi were reported to be associated with mealybugs and confirmed to be pathogenic; they include *Aspergillus parasiticus* Speare, *Cladosporium oxysporum* (Berk and Curt.), *Hirsutella sphaerospora* H.C. Evans and Samson, and *Neozygites fumosa* (Speare) Remaudière and Keller (Browning 1994; Delalibera et al. 1997; Le Ru 1986; Moore 1988; Samways and Grech 1986).

16.6.1 Classical Biological Control

Biological control of mealybugs has been practiced for many years; it involves three main tactics, that is, classical biological control, augmentative releases, and conservation biological control. Species are considered invasive if they are transported outside their native range and become established, spread, and adversely affect the environment. Since the mealybugs are the most invasive species, classical biological control has been frequently employed against them. Moore (1988) reviewed the natural enemies used against mealybugs in biological control programs worldwide. According to Moore, more than 70 species of parasitoids have been introduced against mealybugs, and at least 16 % of the introduced parasitoids were considered to initiate substantial or complete control. Most of the introduced parasitoid species were encyrtids, but species of Aphelinidae and Platygastridae proved to be successful on several occasions. Often a single parasitoid was considered to be responsible for the success, even when more than one was introduced. Noyes and Hayat (1994) reviewed the use of encyrtids for biological control of pest mealybugs and found that out of a total of 385 importations of encyrtids, targeting 22 mealybug species, about 24 and 7 % were considered to give partial or successful control in the field and in greenhouses, respectively. With regard to predators, Moore (1988) analyzed the use of *C. montrouzieri* separately from that of other mealybug predators. This ladybeetle has been used many times against at least ten different species of mealybugs and was considered to give substantial or partial control in about 19 % of the introduced predators; on some occasions, it has been regarded as an outstanding biological control success. Of the other 46 predator species, mostly coccinellids, as well as cecidomyiids, chrysopids, hemerobiids, and lycaenids used in biological control of mealybugs, only the cecidomyiid, *Kalodiplosis pseudococci* Felt, was regarded as having given significant control, when used against *Dysmicoccus brevipes* (Cockerell) in Hawaii in conjunction with two parasitoids. Stiling (1993) showed that the major reason for the failure of introduced natural enemies to reduce the pest population is related to climate (34.5 %). Moore (1988) analyzed the reasons for the failure of both parasitoids and predators of mealybugs to become established in biological control programs. In the case of parasitoids, Moore cites the following documented reasons: (1) incorrect identification of the target mealybug species; (2) the target was a native species; (3) hyperparasitism; (4) failure of the parasitoid to adapt to unfavorable climates; and (5) other reasons, such as interference with ants, use of pesticides, and small numbers of individuals released. With regard to predators, Moore (1988) listed six main reasons for failure: (1) no adaptation of the released species to climate; (2) effect of the pesticides; (3) density of the prey; (4) effect of the host plant; (5) inability to reach the prey; and (6) effects of the other organisms. The lack of adequate food resources for natural enemies within or near to agroecosystems may limit the performance of biological control agents against mealybugs. For example, Davies et al. (2004) observed that the survival and reproduction of *Coccidoxenoides perminutus* Girault, a parasitoid of the citrus mealybug *Pl. citri*, were significantly influenced by the nature of the nectar on which the parasitoid was fed. In light of these results, it was suggested that the habitat management, for example, by providing suitable nectar sources for adult parasitoids, might be a means to conserve and enhance *C. perminutus* activity in the field. In recent years, successful classical biological control programs against mealybugs have targeted the cassava mealybug, *Phenacoccus manihoti* Matile-Ferrero in Africa (Neuenschwander 2001), the mango mealybug, *Rastrococcus invadens* (Williams) in West Africa (Bokonon-Ganta et al. 2002), the pink hibiscus mealybug, *Maconellicoccus hirsutus* (Green) in the Caribbean and California (Roltsch et al. 2006), and the papaya mealybug, *Paracoccus marginatus* Williams and Granara de Willink in Palau (Muniappan et al. 2006). It is important to note that successes were mostly achieved in tropical regions where the target area for classical biological control and the area of origin of the introduced parasitoids displayed similar climatic conditions. In a few cases, modeling has been used as a tool to analyze actual systems and to identify major constraints, in order to improve the biological control of mealybugs. For example, the model developed by Gutierrez et al. (2008a) predicted that the parasitoid *A. pseudococci* would have a larger impact on the vine mealybug *P. ficus* than either *L. abnormis* or *C. montrouzieri*, and that biological control of the mealybug in California would require additional species of natural enemies and/or could be achieved by reducing the size of the spatial-temporal refuge. In another use of a modeling approach, Gutierrez et al. (2008b) concluded that the biological control of the vine mealybug might be adversely affected by climate change. Gutierrez et al. (1993) developed a tritrophic model of the cassava system and used it to explore the basis for the successful control of the cassava mealybug *P. manihoti* in Africa by the exotic parasitoid *Epidinocarsis lopezi* (DeSantis), and also to examine the causes for the failure of the related parasitoid *E. diversicornis* (Howard) to establish itself.

16.6.2 Augmentative Control Tactics

The first known case of an augmentative biological control program dates back to before 1917 and was aimed at controlling the citrophilus mealybug *Ps. calceolariae*, a pest of citrus in Southern California, by using the coccinellid predator *C. montrouzieri* (Luck and Forster 2003; van Lenteren 2006). Since then, this Australian ladybird beetle has been commonly used in various countries on diverse crops (Copland et al. 1985; Franco et al. 2009), and is actually one of the few species of natural enemies commercially available for the biological control of mealybugs by means of augmentative tactics. Augmentative releases of *L. dactylopii* and *C. montrouzieri* against *Pl. citri* have been reported to be effective in several Mediterranean countries and in other citrus-growing areas, such as Australia and California. However, Mendel et al. (1999) released 5,000–10,000 individuals of *L. dactylopii* or 10,000–50,000 individuals of *A. pseudococci* per hectare and obtained no significant impact both on the mealybug infestation and on the fruit damage. When the mealybug population is low, the population densities of its specific natural enemies, especially the predators, are also low. Parasitoids, which are better fitted to survive at low mealybug densities, may find it difficult to reach their hosts in their most appropriate refuges, and these small colonies may also be well protected by ants. Furthermore, the parasitoids of tropical or subtropical mealybug species do not tolerate Mediterranean climate winters very well. However, inoculative or inundating releases of parasitoids may compensate for their low survival. Augmentation of the parasitoid population in spring, when mealybugs leave their typical refuges for new colonization sites on the host plant, may improve the mealybug/parasitoid ratio (Mendel et al. 1999). Since the population density during this season is low, the released parasitoids tend to disperse over a rather large area in their search for mealybug colonies (Mendel et al. 1999). The kairomonal response of the parasitoids to the mealybug sex pheromone can be utilized to keep the released individuals in the targeted area. The parasitoids search for mealybugs in the vicinity of the pheromone-release points (Franco et al. 2008); therefore, we may increase the intensity of parasitization in the treated plots. Another tactic that may be considered involves measurement of the population of natural enemies in the managed area. Advance acquisition of information should be considered in order to plan augmentation of natural enemies in the coming growing season. It is expected that if there was considerable mealybug mortality in a particular plot, it could be because of the activity of parasitoids and predators that had survived in this plot and not because of the migration of natural enemies from a long distance. Therefore, information about the natural enemy density, late in the season, may be achieved by setting up traps baited with mealybug colonies, with or without the sex pheromone (with respect to each individual case).

Application of chemicals alone does not solve the mealybug problem in many cases. Many a time, more than one control method is needed to manage the mealybugs.

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17 Insecticide Resistance and Its Management in Mealybugs

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Mealybugs throughout the world cause a variety of economic problems and are called 'hard to kill pests of fruit trees'. Insecticides also play a critical role in the management of mealybugs. Currently, a fairly broad selection of insecticides namely organophosphates, carbamates, neonicotinoids, insect growth regulators and keto-enols are being used against mealybugs. However, many insecticides are ineffective due to the cryptic behaviour of mealybug, its typical waxy body cover and clumped spatial distribution pattern. Waxy coatings protecting the eggs, nymphs and adults of mealybug make it almost impossible for insecticides to reach them, and also there is a possibility of development of insecticide resistance. Furthermore, available pesticides in the market may not be adequate to manage the mealybugs if used only once and hence pesticide applications are required to be repeated many times. This situation may lead to the development of insecticide resistance. As a result, many insecticides had failed to check the mealybugs. Further, different classes of insecticides provide various active ingredients and their efficacy may be reduced if insecticide resistance develops.

Many insecticides do not provide adequate control of mealybugs because of the inherent nature of mealybugs. Mealybugs are noted for the production of dermal wax secretions. Adult mealybugs and the nymphal instars are covered with a waxy coating. In addition, the eggs of mealybugs, protected by the waxy filamentous secretions of the ovisac, are almost impossible to reach with insecticides.

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Eggs protected with waxy ovisac

Adult mealybug covered with waxy coating

Mealybug crawlers not covered with waxy coating

The waxy secretion is the most common conspicuous trait of the mealybug family. It is a complex system that serves different functions. It is produced by the epidermal wax glands and transported to the body surface via ducts, pores and secretory setae of various types (Foldi 1983; Gullan and Kosztarab 1997). The main components of the wax of five mealybug species (*Planococcus citri* (Risso), *Pl. ficus* (Signoret), *Pl. vovae*, *Pseudococcus cryptus* (Hempel) and *Nipaecoccus viridis* (Newstead) were trialkyl glycerols and wax esters. The wax cover is believed to prevent water loss. The hydrophobic property of the wax enables the mealybugs to escape drowning or becoming swamped by water in their typical cryptic sites. They are covered with a powdery wax that repels water-based insecticide solutions. The ovisac, which is also a wax secretion, is considered to be an adaptation that protects the offspring from both wet and dry conditions, and it may also provide an attachment to the host plant. Tubular ducts and multilocular disc pores, respectively, produce long hollow and shorter curled filaments, which make up the ovisac and the male cocoon (Cox and Pearce 1983; Foldi 1983). The white wax of mealybugs is strongly light reflective and may reduce desiccation. In some cases, the wax also serves to cover the honeydew droplets and to protect the mealybugs from contamination by their own honeydew and defensive exudates (Gullan and Kosztarab 1997). Normally, chemicals are used to control the mealybugs. However, crawler stage is not covered with wax, and hence, this is perhaps one of the most susceptible stages of mealybug to chemicals. However, the crawler stage is available only for a few days. Control failure does not always imply resistance, and it is wrong to conclude that the mealybugs have developed resistance to insecticides. Mealybugs most frequently cause concern by their presence on horticultural crops destined for export markets. However, relatively few insecticides can be used on fresh fruits without exceeding residue tolerances set by those markets. This restricted range of permitted insecticides increases the risk of resistance and the potential economic impact that it could bring about. Flaherty et al.. (1982) reported that insufficient control measures and multivoltine nature of mealybugs may speed up the development of insecticide resistance. If an insecticide has provided good control sometime back but fails to effect adequate control of the mealybugs over the use of the chemical for a number of years, then it is concluded that the mealybug has developed resistance to that particular insecticide. Many a time it is not so in the case of mealybugs. Mealybugs are capable of becoming resistant to insecticides, and it should not be assumed resistant until tenfold of resistance is observed (Valles et al. 1997; Khan et al. 2013). However, documentation of insecticide resistance in mealybugs across the globe is very scanty.

17.1 Monitoring of Insecticide Resistance

While insecticides have greatly improved human health and agricultural production worldwide, the use of insecticides has been limited by the evolution of resistance in many major pests, including few that became pests as a result of the application of insecticides (Mallet 1989).

An important component of resistance management strategies is the ability to effectively monitor susceptibility levels in pest populations to insecticides. Determining dosage response of a target pest populations or species to particular insecticides would be very useful for monitoring insecticide resistance in mealybugs. In general, various metabolic resistance mechanisms work by detoxifying insecticides through oxidative or hydrolytic reactions to reduce or eliminate the toxic activity of insecticide. This is a dynamic process in insect populations where resistance levels rise and fall according to exposure regimes and selection pressures (Castle et al. 1996; Horowitz et al. 2002), which ultimately increases the resistant individuals in the field. Georghiou and Taylor (1986) suggested that a number of factors influence resistance development in pest populations including biological, ecological, genetic and operational. Regular exposure to pesticides allows selection of individuals that are naturally resistant to pesticide and develop resistance to survive. When a pesticide is used for the first time, a small proportion of the pest population may survive exposure to the material due to their distinct genetic makeup. These individuals pass the genes that are responsible for resistance to the next generation. Subsequent uses of the pesticide increase the proportion of less susceptible individuals in the population. Through this process of selection, the population gradually develops resistance to the pesticide.

Lack of systemic management plans may also account for the development of resistance (Bushra et al. 2014). Different agro-ecological factors such as the presence of refugia, which harbour less resistant or susceptible individuals, could dilute resistant gene frequencies (Sayyed et al. 2005; Khan et al. 2013). Further, knowledge of the target pest populations with respect to their susceptibility levels to different insecticides and how much they vary among locations can be taken as a clue to the genetic potential for resistance development. Hence, there is a need to document the geographical variation of natural populations of mealybug susceptibility to insecticides. Further, determining a diagnostic dose for each test insecticide from the generated baseline data is needed for facilitating future resistance monitoring of mealybug (Sanderson and Roush 1992; Denholm et al. 1996).

17.2 Dosage Mortality Test in Mealybugs

For establishing baseline data to different insecticides, different stages of mealybugs were treated as per the mode of action of each insecticide. Mixed stages including immature and adults of the mealybugs were tested for susceptibility to chlorpyrifos, dimethoate, methomyl, and imidacloprid. Only immature stages were tested with buprofezin because of its activity as a chitin synthesis inhibitor that interferes with the development of immature stages of susceptible insects (Nilima et al. 2012). There are different bioassay techniques which are followed for determining the baseline toxicity of different insecticides.

17.3 Petri Dish Bioassay

Susceptibility to contact insecticides (e.g. buprofezin, chlorpyrifos, dimethoate and methomyl) that are applied on foliar was assessed using an established petri dish technique (Prabhaker et al. 2006a, b; Nilima et al. 2012). Morishita (2006) also followed plastic petri dish technique in which first-instar nymphs of *Planococcus kraunhiae* (Kuwana) were transferred onto a kidney bean leaf on 1.5 % agar gel in a plastic petri dish. A petri dish which contained 20–40 nymphs was sprayed once with 6 ml of insecticide through a spraying tower on day 2 (first instar), day 9 (second instar), day 16 (third instar) or day 25 (adult), and examined for susceptibility to insecticide.

17.4 Systemic Bioassay Technique

To determine baseline toxicity data of imidacloprid, a systemic uptake technique was used as described by Prabhaker et al. (2006a) and Nilima et al. (2012). Discriminating doses are expected to kill 100 % of a susceptible population but 0.1 % of resistant individuals (French-Constant and Roush 1990).

17.5 Insecticide Resistance in Different Mealybugs

17.5.1 *Pseudococcus viburni*

In New Zealand, mealybugs were found to develop resistance due to extensive and regular use of insecticides. The obscure mealybug *Pseudococcus viburni* (Signoret) (=*Pseudococcus affiniss* (Maskell) was reportedly resistant to dichlorodiphenyltrichloroethane (DDT) in Hawke's Bay in 1959 (Congdon and Morison 1959). Following anecdotal records of resistance to parathion-methyl in the 1970s, resistance to chlorpyrifos was reported in the 1990s, with signs of cross-resistance to prothiofos (Charles et al. 1993). A residual bioassay was used to measure the responses to chlorpyrifos of two populations of *Ps. affinis* from pome fruit in Hawke's Bay. One population of *Ps. affinis* exhibited a 24-fold level of resistance compared with the other population (Charles et al. 1993).

17.5.2 *Pseudococcus maritimus* (Ehrh.)

The organophosphates including parathion were extensively used for the control of the mealybugs from the 1940s to the 1990s (Frick 1952; Tranfaglia and Viggiani 1981; Grimes and Cone 1985). These materials were effective; for example, rates as low as 48 g/ha (active ingredient, a.i.) of ethyl parathion provided grape mealybug control (Frick 1952). Eventually, these materials became less effective. *Ps. maritimus* developed resistance to parathion in the San Joaquin Valley, California, USA (Flaherty et al. 1982). A similar parathion resistance in the mealybugs had been reported in South Africa (Myburgh and Siebert 1964). It has been reported that there could be a potential for resistance to buprofezin and hence it is recommended for twice in a year around the world.

17.5.3 *Planococcus citri* (Risso)

A strain of *Planococcus citri* from citrus groves near Limassol, Cyprus, with a long history of spray treatments, developed a low level of resistance to several organophosphorus insecticides; this ranged from 1.6-fold to malathion and 2.8-fold to diazinon (Serghiou 1983). Further, the mealybug was reported to develop resistance to chlorpyrifos, prothiofos and kinoprene from 1991 to 1992 (Walker et al. 1993). The development of resistance to chlorpyrifos by citrus mealybug, *Pl. citri*, was reported in Israel (Mendel et al. 1999).

17.5.4 *Planococcus kraunhiae* and *Pseudococcus cryptus*

Methyl bromide fumigation was conducted for quarantine control of *Planococcus kraunhiae* (Kuw.) and *Pseudococcus cryptus* (Hempel) (*Pseudococcus citriculus* Green) on mandarins to develop a disinfestation treatment for export from Japan to the USA. Susceptibility of all stages of the pests to methyl bromide fumigation showed that all stages of *P. kraunhiae* were more resistant than those of *P. citriculus*, and that the most resistant stage was 5-day-old eggs of *Pl. kraunhiae*. LD_{50}s and LD_{95}s for 5-day-old eggs were 26.4/m^3 and 31.8 g/m^3, respectively. A fumigation standard (48 g/m^3 of methyl bromide for 2 h at 15 °C or above with 32 % or below loading) was established on the basis of the data from susceptibility tests (Misumi et al. 1994). *Planococcus kraunhiae* were collected from places with conventional insecticide spraying and an insecticide-free orchard. LC_{50} of the first-instar Hashimoto population and the resistance ratio at LC_{50} of the other populations collected from conventional spraying orchards to that of the insecticide-free orchard were, respectively, 0.637 ppm and 8.0–12.2 for cypermethrin, 1.15 ppm and 6.0–7.8 for methidathion and 0.029 ppm and 15.4–20.2 for acetamiprid. The susceptibility to prothiofos and methidathion decreased as the growth stage advanced, whereas susceptibility to acetamiprid remained high (Morishita 2006).

17.5.5 *Maconellicoccus hirsutus*

The adult pink mealybug, *Maconellicoccus hirsutus* (Green), showed resistance to lambda-cyhalothrin, pirimiphos-methyl, triazophos, fipronil and decamethrin when tested under laboratory and semi-field conditions (Anand and Ayub 2000). Eggs, crawlers, early nymphs, late nymphs and adults of the pink hibiscus mealybug, *M. hirsutus*, were tested for their susceptibility to methyl bromide in 2-h laboratory fumigations at ambient conditions (25 °C, 95 % RH). Based on probit analysis of dose–response data, no significant differences were observed among susceptibilities of the crawler, early-stage or late-stage nymphs or adults at either the LC_{50} or LC_{99} level, but late-stage nymphs were more tolerant than early-stage nymphs in a separate paired comparison test (Zettler et al. 2002).

17.5.6 *Planococcus ficus* and *Planococcus citri*

Planococcus ficus (Sign.) has the innate ability to develop resistance (Castle et al. 1996; Horowitz et al. 2002). Mansour et al. (2010) reported that methidathion was more effective against the mealybugs *Pl. ficus* and *Pl. citri* and cautioned that the mealybug is likely to develop resistance to methidathion, which was most widely used against mealybugs in Tunisian vineyards. Mixed life stages of *Pl. ficus* were tested for susceptibility to all insecticides except for buprofezin, which was measured against early and late instars (first, second and third). Variations in susceptibility to each insecticide among sample sites showed a 7-fold difference for buprofezin, 11-fold to chlorpyrifos, 9-fold to dimethoate, 24-fold to methomyl and 8.5-fold to imidacloprid (Nilima et al. 2012).

17.5.7 *Planococcus minor*

Thirumurugan and Gautam (2001) determined the LC_{50} values for different insecticides and the relative resistance of *Planococcus minor* (Maskell) (*Pl. pacificus* Cox) to various insecticides in relation to predatory beetle, *Scymnus brunnescens* (Motsch). The predators were more resistant to endosulfan (0.07 %) than mealybugs.

17.5.8 *Phenococcus solenopsis*

In Pakistan, Bushra et al. (2014) reported insecticide resistance in *P. solenopsis* (Tinsley) for selected organophosphates and pyrethroids. The resistance ratio were in the range of 2.7–13.3-fold for chlorpyrifos, 11.6–30.2-fold for profenofos, 10.6–46.4-fold for bifenthrin, 5.8–25.2-fold for deltamethrin and 4.1–25.0-fold for lambda-cyhalothrin.

17.6 Resistance Management and Prevention Strategy

Management strategies aimed at reducing or preventing resistance will help conserve existing products for ongoing use (Charles 1996, 2004). The general strategy is to reduce the selection pressure for resistance by optimum spray timing, accurate delivery of insecticides and rotation of products with active ingredients from different chemical groups and used in a planned programme. This is combined with management practices for the crop and shelter trees that aim to reduce mealybug numbers and improve insecticide coverage. Details are provided below:

- Mark 'spot' infestations of mealybugs during harvest. Confine sprays to the infested crop area: do not spray shelter or other areas around the orchard unless there is a clearly identified source of pest infestation.
- Be aware of mealybug natural enemies and take actions to protect them.
- Insecticide use must be designed to keep the mealybug population small enough to prevent significant infestation of fruit. Spray only when essential for control.
- Follow industry codes of conduct where appropriate. Comply with label rates.
- Use correct application procedures, observing correct tractor speeds and spraying conditions to obtain good insecticide coverage. Calibrate sprayers at least once per season. Follow spray programme recommendations.
- Mealybugs are difficult to kill with insecticides. They also often live deep inside cracks and crevices in trees, or inside fruit or fruit bunches where they are protected from contact with insecticides. High-volume applications of insecticides are essential for mealybug control and should be sprayed to 'run-off'. Mealybug control should not be attempted with a low-volume application technology.
- Identify mealybugs present and learn their life cycle. Apply insecticides when the most vulnerable stage (crawlers) is prevalent. To minimise this risk, use strictly in accordance with label instructions. Avoid using this pesticide exclusively all season. The potential for resistance to Applaud has been long recognised and it is generally recommended around the world that it is not used more than twice a year.
- Use a range of insecticides, especially if making more than one application per season.

Efforts should be made to determine insecticide resistance across the geographical populations and different species of mealybugs. Further, adequate in-depth research should be done on biochemical aspects especially quantification of detoxifying enzymes and molecular mechanism of resistance by detecting different insecticide resistance alleles, namely sodium-gated channel, KDR (Knock down resistance) and Ache.

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18 Mealybug Alikes

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The insects belonging to the family Pseudococcidae and Putoidae are called true mealybugs (Williams 2004). There are several insects (Coccoidea) similar in appearance, and they are to be called as mealybug alikes only. By mistake, many of the scales belonging to genera *Drosicha*, *Icerya*, *Perissopneumon* (Margarodidae) and *Pulvinaria*, *Chloropulvinaria*, *Megapulvinaria*, *Ceroplastodes* (Coccidae), *Dactylopius* (Dactylopiidae), *Eriococcus* (Eriococcidae), *Stictococcus* (Stictococcidae), etc. were quoted as mealybugs in literature. In India, *Drosicha mangiferae* (Green) belongs to the Margarodidae and is popularly called as mango mealybug, but truly speaking, it should not be called as mealybug. Many species belonging to the genus *Icerya* (Margarodidae) are also called mealybugs, like the cottony *Icerya aegyptiaca* (Douglas), and is wrongly called as breadfruit mealybug in Pacific Atolls. Another group belonging to genera *Pulvinaria*, *Chloropulvinaria*, *Megapulvinaria*, etc. are also similar to mealybugs when they produce ovisacs, and are often mistaken as mealybugs. They are also called mealy scales. Yet another group belonging to the genus *Ceroplastodes* is also being wrongly quoted as mealybug (Bhatnagar et al. 1984). The scale insect *Stictococcus vayssierei* is also commonly called as mealybug-infested cassava. The following scales are also mistaken as mealybugs and come under the category of mealybugs look-alike. *Icerya genistae* (Hempel), *Pulvinaria acericola* (Walsh and Riley), *Pulvinaria ericicola* (McConnell), *Pulvinaria psidii* (Maskell), *Pulvinaria urbicola* (Cockerell), *Neopulvinaria innumerabilis* (Rathvon), *Philephedra tuberculosa* (Nakahara & Gill), *Protopulvinaria pyriformis* (Cockerell), *Milviscutulus mangiferae* (Green), *Ceroplastes ceriferus* (Fabricius), *Ceroplastes rusci* (Linnaeus), *Ceroplastes cirripediformis* (Comstock), *Ceroplastes dugesii* (Lichtenstein), *Ceroplastodes cajani* (Maskell), *Ceroplastes floridensis* (Comstock), *Ceroplastes rubens* (Maskell), *Eriococcus azalea* (Comstock), *Eriococcus quercus* (Comstock) and *Dactylopius confuses* (Cockerell). *Gregoporia distincta* sp.n. (Eriococcidae) is wrongly named as a mealybug from material found on a grass of the cereal type in a reserve in the Western Caucasus (Dantsig 1979).

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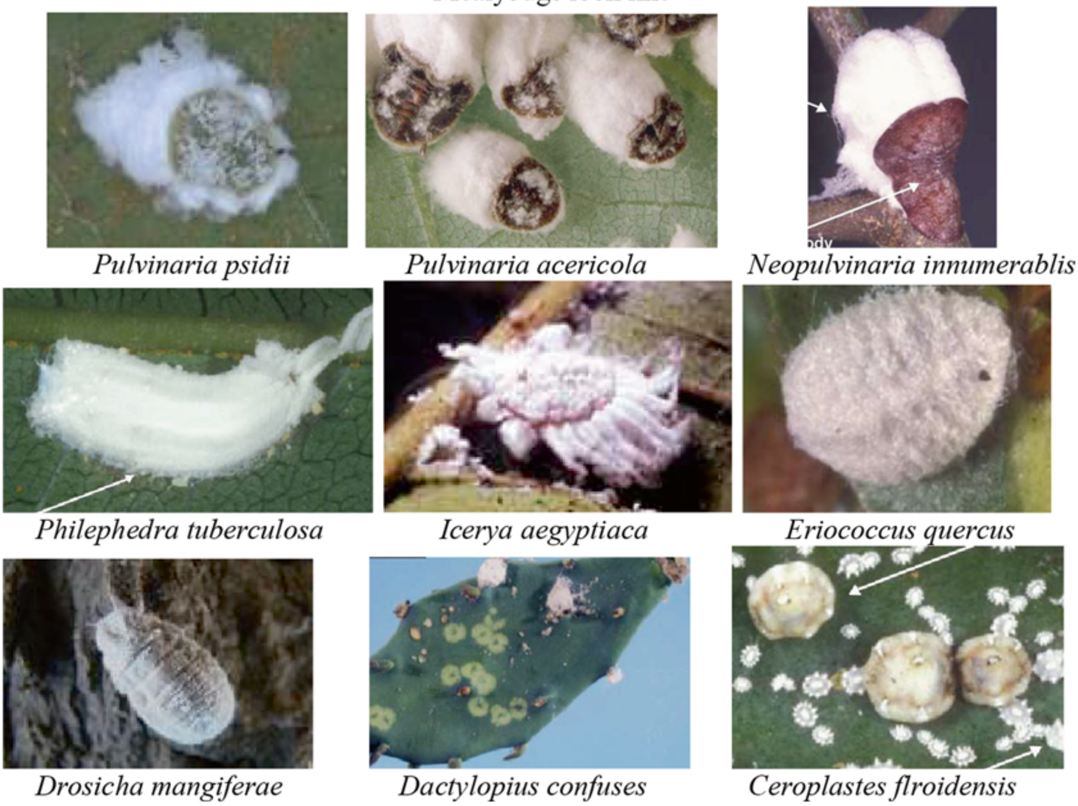
Mealybugs look like



18.1 Breadfruit Mealybug: *Icerya aegyptiaca*

Icerya aegyptiaca is quoted as breadfruit (*Artocarpus* spp.) mealybug in Pacific nations. Heavy infestations of the pest, which kills young leaves and stems, can reduce fruit yields by 50 % and may even kill mature trees. Insecticides could not be used for fear of polluting water supplies. *Rodolia cardinalis* was used to control the breadfruit mealybug, *Icerya aegyptiaca*. A predatory ladybird beetle *Rodolia limbata* (Blackburn) from Australia was introduced in the Federated States of Micronesia (FSM), where control of the mealybug was spectacular. This success was repeated in Kiribati, the Marshall Islands and Palau, where similar problems have been caused by the mealybug (Waterhouse 1991). This is also quoted as Egyptian mealybug *Icerya aegyptiaca* (Douglas) and reported several fruits and ornamental plants in India (Rao 1950). Sundararaj et al. (2006) reported *Icerya aegyptiaca* as mealybug infestation on *Santalum album.*

18.2 *Icerya seychellarum*

In Egypt, *Icerya seychellarum* (Westwood) (Margarodidae, Homoptera) was reported as common white mealybug/ornamental palm mealybug on *Cycas revoluta* Thunb (Cycadaceae). Adult female is orange red or brick red, obscured by a granular covering of waxy secretion, which may be either bright canary yellow or white, tinged with yellow. It is reported to breed on many species of *Acalypha*, *Acacia*, *Artocarpus*, *Casuarina*, *Citrus*, *Cocculus*, *Cynodon*, *Croton*, *Cassia*, *Dodonaea*, *Grevillea*, *Morus*, *Mangifera*, *Magnolia*, *Olea*, *Psidium*, *Pyrus*, *Pterospermum*, *Rosa* and sugarcane (*Saccharum officinarum*) (Rao 1950). Sundararaj et al. (2006) reported its infestation on *S. album.* The important tree species affected by this insect include *Acacia nilotica, A. tortilis, Casuarina equisetifolia, Dodonaea viscosa, Grevillea robusta, Morus alba* and *Mangifera indica* (Sundararaj and Muthukrishnan 2008).

18.3 *Perissopneumon ferox*

Perissopneumon ferox Newstead is also similar to mealybug in appearance. *Rodolia fumida* and *Leptus* sp. were recorded from Malihabad (Singh 1993). *Perissopneumon ferox* was reported as a new mealybug, *Perissopneumon ferox* (Margarodidae, Homoptera), on mangoes from Uttar Pradesh, India. Heavy infestation of the pseudococcid *P. ferox* on mango was seen in Uttar Pradesh, India. Two predators, the coccinellid *Rodolia fumida* and the Erythraeid *Leptus* sp., were seen preying on *P. ferox* (Srivastava and Verghese 1985). *Perissopneumon tamarindus* Green was also reported as a mealybug on ber and other crops in India (Butani 1973).

18.4 *Drosicha* spp.

Drosicha stebbingi Green and *Drosicha mangiferae* are popularly called mango mealybugs besides *Perissopneumon ferox*. Mealybug alikes, *Drosicha mangiferae* (Green) and *Drosicha dalbergiae* Green was recorded as mealybugs on pomegranate and papaya in India. Mealybug alikes, *Drosicha stebbingi* Green, *D. mangiferae* (Green) (Pruthi and Batra 1960), *Drosichiella tamarindus* Green and *Perissopneumon tamarindus* Green (Butani 1973) were reported as mealybugs on ber in India. *Drosicha stebbingii* Green on forest plants is reported as a mealy bug occurring throughout the sal (*Shorea robusta*) forests of north India. It was also quoted as mealybug on *Tectona grandis* and *Albizia* spp. in India (Joshi 1992). *Drosicha mangifera* was also recorded as a mealybug pest on black nightshade (*Solanum nigrum* L) and Indian gooseberry (*Phyllanthus emblica*) from Uttar Pradesh, India.

Incidence of *Drosicha mangiferae* on ashwagandha was reported as mealybug infestation in Jammu and Kashmir, India. The pinkish nymphs and female adults suck the sap from the twigs, leaf stock and also along the midrib, and the infestation was mainly concentrated on the terminal part of the shoot. *Sumnius vestita* and *Cryptochaetum* were known to attack *D. mangiferae*. In western Uttar Pradesh, *Drosicha mangiferae* has one generation a year and diapauses in the egg stage in soil for about 7 months.

The so-called mango mealybug *D. stebbingi* was predated by several coccinellids, but none of these natural enemies were found to give adequate control of *D. stebbingi* (Rahman and Latiff 1944, Wadi and Batra 1964, Singh 1993). *Beauveria bassiana* was found infecting nymphs of *Drosicha mangiferae* in the field, and the pathogen was found infecting the margarodid in orchards in five localities in India. In field trials on infested mango panicles, spray application of a suspension having 4.8 × 106 conidia/ml reduced populations of *D. mangiferae* by 33.3–100 % in 10 days (Srivastava and Fasih 1988).

An integrated approach involving cultural, mechanical and chemical methods is ideal for the management of mango mealybugs. Raking of soil four times (May, June, August and October) in Uttar Pradesh afforded the best control of egg hatching of the margarodid *Drosicha mangiferae*; 30 % of the eggs hatched, as compared with 68 % for no treatment (Chandra et al. 1989). Complete control could be obtained by the use of grease bands round the trunks from the second week of December. An alternative method proved to be banding with coal tar, which remains effective for only a relatively short period (Prasad and Singh 1976). Sticky bands were found to remain effective for only a short time (up to 15 days after application). The commonly used bands of mixture of rosin and castor oil (4:5) and coal tar and grease (2:1) prevented the nymphs from ascending for only up to 5–6 days after application. Field tests were carried out in Hissar, India, and revealed that the slippery band of alkathene sheet was most effective of all in blocking the ascending nymphs, as an average of 2.79 nymphs per sample area were able to cross it every alternate day as compared with 407.3 nymphs on untreated trees (Lakra et al. 1979). A 30-cm-wide polyethylene band tied round the tree 50–100 cm above the ground and with its lower edge plastered over with mud was sufficiently slippery to prevent the passage of *Drosicha stebbingi* nymphs and much cheaper than the conventional sticky band (Bindra and Sohi 1974). The double girdle band of alkathene was more effective as it stopped the few nymphs of *Drosicha mangiferae* that managed to cross the first band (Srivastava 1980).

Trunk sprays of quinalphos, diazinon and methyl parathion at 0.0.75–0.15, 0.05–0.1 and 0.05–0.1 % in Haryana were highly effective against ascending first instar nymphs that had collected below bands. In Bihar, alkathane banding was followed by three to four applications to the trunk of 0.04 % malathion or three of 0.03 % dimethoate, 0.03 % phosphamidon, 0.04 % diazinon or 0.05 % thiometon during January. All these insecticides were equally effective when applied to the shoots (after banding of the trunks) in late February and early March. Diazinon and thiometon were too expensive for their use to be recommended (Prasad and Singh 1976). Field tests carried out in Delhi indicated that diazinon was the most effective compound and was significantly superior to monocrotophos and chlorpyrifos, both of which, however, gave fairly satisfactory control of the pest (Srivastava 1980). Infested trees were sprayed once, with acetamiprid at 100 g/100 L of water against first instar in the second week of February in Pakistan (Karar et al. 2009). Against *Drosicha mangiferae* on guava**,** fenitrothion at 0.1 % was the most effective treatment, followed by phosalone at 0.07 %, quinalphos at 0.05 %, monocrotophos at 0.04 %, parathion-methyl at 0.05 %, and bromophos-ethyl at 0.07 % and phosphamidon at 0.03 %. Phenthoate at 0.05 %, dimethoate at 0.03 % and malathion at 0.1 % were less effective (Dalaya et al. 1983). Among 24 insecticides that were tested against *Drosicha mangiferae* in Haryana, quinalphos at 0.025 % and fenitrothion, carbophenothion and parathion-methyl, each at 0.05 %, were highly effective against gravid females of the pest. Spraying of acephate, methyl demeton, monocrotophos, quinalphos, dimethoate and phosphamidon at 0.08 % was able to keep the population of mealybug *D. mangiferae* under check.

18.5 *Stictococcus vayssierei*

Stictococcus vayssierei Richard has been reported as root mealybug of cassava (*Manihot esculenta*) in Cameroon (Ngeve 2003). The larvae and adults attack young feeder roots of germinating cuttings, causing extensive leaf-fall, wilting, tip die-back and death of plants. Plants that escape early infestation develop normally and tuberize, but the mature tuberous roots are small and become covered with the root scale, making them unattractive to market. In severe infestations, a mature tuberous root of about 40 cm long may harbour up to 500 mealybugs. It is most severe during the dry season in lateritic and clayey soils, in fields of depleting fertility and in thinly prepared land where planting has been done on the flat. The prevalence of the pest in the semi-humid forest region of Cameroon increased from 12.5 % in 1990 to 87.5 % in 1999. *S. vayssierei* infestation was more severe (30 mealybugs/hill) when cassava was planted on the flat than when planted on ridges (16 adults/hill). Plants also sprouted better (91 %) when cassava was planted on ridges than when planted on the flat (71 %). Root yields (31.4 t/ha) and root numbers (7 roots/hill) were also higher in cassava planted on ridges than in those grown on the flat (24.5 t/ha and 4.5 roots/hill, respectively). For plants grown on the flat, the improved clones suffered the least attack by *S. vayssierei*, clones 8017 and 8034 showing the most tolerance (19 and 22 females/hill, respectively) when compared with the local, Meyiboto (49 females/hill). *Stictococcus vayssierei* was more severe when cassava was intercropped; there were 40, 48 and 59 mealybug adults per hill when cassava was intercropped, respectively, with maize, groundnuts or maize and groundnuts combined. By contrast, maize suffered no yield depression when intercropped with cassava. *S.*

vayssierei is a major threat to cassava production in Cameroon and neighbouring Central African countries. It calls for emergency integrated control measures. With poorly enforced quarantine regulations, and the unrestricted movement of vegetative planting stakes from one country to the other in Africa, this pest is likely to become an epidemic if strong measures are not taken to control its spread. The effects of season, rainfall distribution and soil type on oviposition and insect development need to be further studied so as to determine whether it is the physical or chemical properties of the soil that play such differential role in pest prevalence and severity. Finally, the mechanism of cultivar tolerance to pest infestation could be studied to throw light on plant traits and cultural conditions that could be exploited in screening cassava clones for yield and pest tolerance. Such studies could lead to the early release of improved, mealybug-resistant varieties to growers. Orientations for future research are discussed. Monocropping is recommended in areas where pest impact is very severe. Also, disinfestation of cuttings with insecticidal bioproducts should be exploited to reduce pest impact. Finally, rhizosphere biocontrol agents such as endomycorrhizae should be studied to determine their usefulness in controlling the pest under farming conditions in Cameroon (Ngeve 2003).

18.6 *Pseudaspidoproctus fulleri*

Pseudaspidoproctus fulleri (Homoptera: Margarodidae), has been reported as mealybug in Mauritius. *Cynodon dactylon* was found to be the preferred food plant of the pest. Destruction of the plant where it grows as a weed with herbicides is suggested as a method of controlling the pest. The predator *Rodolia chermesina* was observed consuming large numbers of the pest, and the parasitoid *Cryptochetum monophlebi* is also mentioned as a potential biological control agent (Rajabalee and Banymadhub 1990).

18.7 *Drosicha dalbergiae*

Drosicha dalbergiae (Stebbing) has been reported as almond mealybug in Kashmir, India (Malik et al. 1972). The eggs are laid in clusters and covered with cottony ovisacs, exhibiting silky touch and appearance. The freshly laid eggs are yellowish in colour and oval shaped, which later on turns brownish in colour during hatching. The adult female of *D. Dalbergiae* is brownish grey in colour, devoid of wings, sluggish and similar in shape as it is in last nymphal instar. Its body is covered with ash white mealy powder with three pairs of small black legs. However, males are more active and smaller in size with a pair of wings. The pest passes through one complete generation in a year.

The pest feeds on both aerial and underground parts of almond plants, colonizing in the collar region of the tree in crevices and at wounded sites (Masoodi et al. 1988). On migration to the aerial parts of the plant, the pest feeds on the plant phloem and excrete honeydew that cover the leaves, trunk and fruits, thus making the fruit unmarketable due to development of black sooty mould and sickly appearance.

The management strategy involves with

- Raking of the soil around the base of the infested trees so that egg masses get exposed to the sun and get killed.
- Application of sticky bands around the tree trunk so as to check the nymphs from crawling up the trees (four parts of castor oil and five parts of resin) 0.5–1 m above the ground level during the month of May. It will remain effective for a period of 2 weeks after which it should be repeated.
- The soil application of carbaryl (10 % dust) will keep the mealybug population under check.
- Insecticidal spray of methyl-o-demeton (0.02 %) will exhibit maximum mortality of almond mealybug.
- The combined effect of carbaryl (10 % dust) and dimethoate (0.03 %) applied as soil drench

and foliar spray, respectively, plays a significant role in suppression of the pest (Shaheen et al. 2014).

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Part II

Management of Mealybugs in Agricultural and Horticultural Crops

Rice

19

Gururaj Katti

19.1 Mealybug Species

Mealybugs are injurious to rice in several countries. Among the species, *Brevennia rehi* (Lindinger) is widely distributed across the world in South and South East Asia, North America and Australasia (Table 19.1). In a recent report also, the rice mealybug has been listed as one of the important pests of rice in Bangladesh (Ahmad et al. 2011). It is found to cause heavy loss to the growers in India and Pakistan. Identification of rice mealybug species *Brevennia rehi* has undergone several modifications across space and time (CABI 2003). At first, the rice mealybug *Brevennia rehi* was recorded as *Ripersia sacchari* Green by Lefroy (1908), attacking rice in India, and later, *Brevennia rehi* was confirmed as the valid name for the rice mealybug by Miller (1975). It has become a primary pest in Bihar, and also in other rice-growing states such as West Bengal, Orissa, Bihar, Andhra Pradesh, Tamil Nadu, Karnataka, Kerala and Maharashtra (CIE 1979).

Brevennia rehi (Photo credit: Lyle Buss, University of Florida)

19.2 Damage

Both the adults and nymphs are found in sedentary colonies and suck sap from stems and leaf sheaths, resulting in yellowish curled leaves, stunting and wilting of rice plant. The mealybug populations can be easily noticed in the field as they are covered by a distinct waxy and powdery coating. Also, ants frequent the mealybug-infested plants, and sometimes carry the mealybugs to healthy plants. The insect pest attacks rice during the tillering and stem elongation

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Table 19.1 List of mealybug species recorded on rice in different regions of the world

Species	Country/Region	Reference
Brevennia rehi (Lindinger)	Israel, Iraq, Azerbaijan, Tajikistan and Brazil	Ben-Dov (2008)
Syns: *Heterococcus rehi* (Lindinger); *Heterococcus tuttlei* Miller and McKenzie; *Rhizoecus cynodontis* Bodenheimer; *Brevennia femoralis* Borchsenius	Bangladesh	Alam et al.(1979), Alam and Bhuiyan (1964)
	Nepal	Pradhan (1981)
	Taiwan	Liu and Tao (1988)
	Australia and Papua New Guinea	Williams et al. (1981)
	India	Narayan and Ram (1985), Radja (1985), Velusamy and Babu (1986), Gopalan et al. (1987a), Ghode and Mishra(1988), Lakshmanan et al. (1988), Raguraman et al. (1991), Jayarani and Velusamy (1994)
	Bangladesh, Pakistan and Philippines	Williams (2004)
	USA	Miller and McKenzie (1970)
Chlorozococcus mireorum Matile Ferren	Cameroon	Ben-Dov (1994)
Chorizococcus ilu Williams	–	Williams (1970)
	Bangladesh	Alam and Karim (1981)
Dysmicoccus boninsis (Kuwana)	Taiwan and China	Liu and Tao (1988)
	USA	Miller and McKenzie (1970)
	Bangladesh	Alam and Karim (1981)
Dysmicoccus brevipes (Cockerell)	–	Williams (1970)
Dysmicoccus oryzae (Wijati)	Java	Williams (2004)
	Bangladesh	Alam and Karim (1981)
Formicoccus lingnani (Ferris)	Malaysia and Thailand	Williams (2004)
Geococcus oryzae (Kuwana)	–	Williams (1970)
	Bangladesh	Alam and Karim (1981)
Nipaecoccus graminis (Maskell)	–	Williams (1970)
	Bangladesh	Alam and Karim (1981)
Novaniliacoccus oryzae Ghosh & Ghise	India	Williams (2004)
Paracoccus ilu (Williams)	Fiji and New Zealand	Ben-Dov (2008)
Planococcoides lingnani (Ferris)	China	Ben-Dov (2008)
	Bangladesh	Alam and Karim (1981)
Planococcus minor (Maskell)	Philippines	Williams (2004)
Pseudococcus saccharicola Takahashi	Australian and Oriental region	Ben-Dov (2008)
	Bangladesh	Pathak and Khan (1994)
	Malaysia and Thailand	Williams (2004)
Pseudorhodania oryzae Tang	China	Ben-Dov (2008)
Saccaharicoccus sacchari (Cockrell)	–	Williams (1970)
	Bangladesh	Alam and Karim (1981)
Trionymus ceres Williams	India and Pakistan	Williams (1970; 2004)
	Bangladesh	Alam and Karim (1981)

stages of the rice crop. The infested plants appear stunted and scorched. High incidence inhibits panicle emergence, and plants may even dry. Grains from mealybug-infested plants do not develop properly and have a bitter taste; if present in normal food, they spoil the flavour after being cooked. The pest is also known to transmit the virus known as chlorotic streak (Williams 2004).

Damage by *Brevennia rehi*

19.3 Factors Influencing Incidence of Mealybugs

The prevalence of dry period, presence of grassy weeds, well-drained soils and upland/rain-fed environments are major factors influencing the mealybug incidence. Increased temperature and wind velocity and decreased relative humidity have been reported to increase the incidence of *B. rehi* (Radja 1985). Also, the pest infestation is more severe in unirrigated and upland fields (Mammen 1976; Pradhan 1981). The planting dates and irrigation regimes also influenced the incidence of rice mealybugs. Early planting and continuous pounding of irrigation water at 5-cm depth throughout the growing period resulted in lower intensity of rice mealybug infestation (Gopalan et al. 1987a). Also, type and dosage of nitrogenous fertiliser applied affected infestation levels: higher levels of nitrogen increased the rice mealybug infestation, whereas the application of raw coir pith, raw sugarcane trash and farmyard manure reduced the infestation (Backialakshmi 1994). During the off season, rice mealybugs survive on a variety of grasses, later spreading into the rice nurseries, which provide the main source of infestation. The alternative hosts include *Cynodon dactylon, Cyperus rotundus*, *Echinochloa crus-galli, Echinochloa colona, Panicum repens* and *Paspalum scrobiculatum*. The mealybug damage is found mainly confined to upland and rain-fed environments, particularly in fields with uneven soil surface where the plants grow in relatively dry soil patches. It occurs in great number during the rainy season.

19.4 Extent of Losses

The rice mealybugs cause heavy losses to crops in Bangladesh, India, and Thailand. High density (>100 mealybugs/hill) causes plants to wilt and die. Despite being a traditional pest in the upland paddy in the eastern states of Orissa and West Bengal, there are few reports on the quantification of the extent of rice mealybug incidence or its damage in India. Banerjee (1956) reported incidence of mealybugs from Midnapore, Nadia, 24 Parganas, Bankura, Murshidabad and Jalpaiguri districts of West Bengal. Satpathi et al.

(2005) reported an average damage up to 7 % in the rice-growing areas of West Bengal. Ghode and Mishra (1988) reported a serious outbreak of its occurrence in Dhenkanal, Cuttack and Puri districts of Orissa state, the affected areas being 4,000 ha, 2,780 ha and 303 ha, respectively. Velusamy and Babu (1986) observed a severe attack of mealybugs in an area of 100 ha of rice in the Pudukottai district of Tamil Nadu, India. The population of adults and nymphs was 650–750/hill and the affected plants failed to produce panicles. Later in two villages of Tamil Nadu, extremely severe incidence of mealybug populations was reported up to 91.1 per tiller (Nalini et al. 2011). There was yield reduction in extremely stunted rice plants at a population level of 50 mealybugs/hill (Backialakshmi 1994). The association of high mealybug incidence with the occurrence of sheath rot disease further aggravates the yield reducing potential of this pest in rice (Alam and Karim 1981; Lakshmanan et al. 1988; 1991). Rice mealybugs are also associated with rice chlorotic streak viruses as the transmission studies with the bug were positive. There have been reports of widespread and severe outbreaks of rice mealybug infestation with association of sheath blight and sheath rot diseases in Bangladesh during the drought years of 1950, 1957, 1966, 1972 and 1979 (Alam et al. 1979). Both traditional and improved varieties showed infestation, and the crop losses were estimated at 30 % because of the combined effects of drought and mealybug. Pradhan (1981) mentioned *B. rehi* as a pest of rice in the Terai belt of Nepal which included areas of Sarlahi, Bara, Parsa, Rautahat and Dhanusha. Rice mealybug has also been reported as tuttle mealybug-infesting Bermuda grass (*Cynodon dactylon*) in USA (Ben-Dov 2012).

19.5 Management

It is difficult to control *B. rehi* because of its protective waxy covering over its entire body and a secure position in between the stalks and leaf sheath; however, early detection of the infestation in the nursery as well as pulling out and timely destroying of the infested plants are useful in preventing its spread and impact.

19.6 Varietal Resistance

Traditional/local varieties and improved cultivated varieties showed low levels of resistance (Alam et al. 1979; Heinrichs 1983). Radja (1985) and Gopalan et al. (1987b) reported varieties such as IET 8616, AS 89090 and IET 12798 with low infestation after screening them under field conditions. Mallikarjuna Rao (1987) found that TNAU 80030, TM 1087 and CO 43 were tolerant, with the outer leaf tip turning yellowish, despite high bug population, while TNAU 831520 and TNAU 831521 were found to be resistant and moderately resistant, respectively. Further studies identified more resistant sources such as Ptb 33, IR 56 and IR 58, Tending, Badal 2, Rathu Heenati, Ptb 21, Sufaida 172, IR 42 and IR 72, Senawee, Sufaida 172, DR 52 and ARC 575 (Jayarani 1992: Jayarani and Velusamy 1994: Backialakshmi 1994). The studies on resistance mechanism indicated that feeding by rice mealybug resulted in a marginal increase in total phenolic content and a large increase in total sugars, reducing sugars, non-reducing sugars, isoleucine and proline content of the rice plants (Gopalan et al. 1987c). Resistant varieties had low total nitrogen, low potassium and high calcium contents compared with the moderately resistant and susceptible varieties (Mallikarjuna Rao 1987). Antixenosis and antibiosis were also reported, resulting in low oviposition and egg hatchability, slow nymphal development, reduced adult longevity and low fecundity. Steam distillate extracts of resistant varieties adversely affected the ovipositional behaviour and were toxic to crawlers (Lakshmanan and Velusamy 1991).

19.7 Cultural Control

Removal of alternative hosts in the vicinity of the field is recommended to prevent pest multiplication (Ayyar 1939). It is also advised to infested plants at the post-panicle initiation stage, burying them in the soil and replanting to prevent further spread of the pest (Alam et al. 1979). Early planting and regular irrigation had also resulted in lower levels of mealybug infestation (Pradhan 1981; Radja 1985; Gopalan et al. 1987a). The application of organic products such as raw sugarcane trash and farmyard manure reduced the infestation (Backialakshmi 1994).

19.8 Biological Control

Few natural enemies have been recorded as potential enemies of different stages of rice mealybugs, and no field release studies have been made. The parasitoids recorded so far are *Ceraphron* sp., *Adelencyrtus* sp., *Cheiloneurus* sp., *Doliphoceras* sp., *Mayeridia* sp., *Parasyrphophagus* sp., *Xanthoencyrtus* sp., *Rhopus fullawayi, Gyranusa* sp., *Aprostocetus* sp., *Chrysochoris* sp., *Desostenus* sp., *Tetrastichus* sp., *Lymaemon* sp., *Callitula* sp., *Diparini* sp. and *Thysanus* sp., while predator species include *Anatrichus pygmaeus* Lamb, *Domomyza perspicax* (Knab), *Leucopis luteicornis* Malloch and *Scymnus* sp. (Cherian et al. 1935; Ayyar 1939; Manjunath 1968; Prakasa Rao and Das 1971; David and Ananthakrishnan 2004; Raguraman et al. 1991; Pathak and Khan 1994 and Backialakshmi 1994; CABI 2003). Recent surveys to explore parasitoids associated with *B. rehi* conducted in two villages of Tamil Nadu, India, revealed five encyrtids, among which *Rhopus nigroclavatus* (Ashmead) was dominant. Overall, the parasitisation percentage ranged from 5.09 to 39.39 %. Emergence of parasitoids per host was more from adults (17.8 %). The parasitoids were more active from the last week of July to the end of August but weakened during September due to a decline in the *B. rehi* population. The other minor parasitoids recovered were *Adelencyrtus coxalis* Hayat, *Mahencyrtus assamensis* Singh and Agarwal and *Anagyrus gracilis* (Hayat 1970).

19.9 Chemical Control

Several insecticides belonging to organophosphates - parathion (Santhanaraman 1952), carbophenothion (Basu and Banerjee 1965), parathion-methyl and demeton (Anantanarayanan and Abraham 1957), malathion (Wahed 1959; Alam 1965), demeton-S-methyl (Alam 1965; Mallikarjunaa Rao 1987), diazinon, phosphamidon, fenthion and fenitrothion (Alam 1965; Alam et al. 1979; Radja 1985; Lakshmanan et al. 1991), dicrotophos (Alam et al. 1979), dimethoate (Radja 1985; Gopalan et al. 1987d; Radja 1985), monocrotophos (Mallikarjunaa Rao 1987), Chlorpyriphos and isofenphos as seed treatment (Rajamani et al. 1987) and phorate as furrow treatment (Rajamani et al. 1987) were recommended for the control of *B. rehi*. The organocarbamate insecticides found effective included fenobucarb (Radja 1985), carbofuran and carbosulfan as seed treatments (Rajamani et al. 1987) and carbaryl as an ovicide (Gopalan et al. 1987d).

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20 Wheat

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20.1 Species

Mealybugs are injurious to wheat (*Triticum vulgare*) in Ukraine, Hungary, Italy, Tibet, California, Armenia, India etc (Table 20.1).

The mealybug species which occur in the cotton–wheat cropping system in north India are solenopsis mealybug *Phenacoccus solenopsis* (Tinsley), pink hibiscus mealybug *Maconellicoccus hirsutus* (Green) and striped mealybug *Ferrisia virgata* (Cockerell) (Jat et al. 2010). Among these, *Ph. solenopsis* is the most predominant species. The occurrence of mealybug *Maconellicoccus hirsutus* was observed on wheat–mustard cropping areas in Punjab, India, and the incidence declined by end of December, probably due to low temperature (Monga 2007). *Phenacoccus parvus* Morrison is among the plants grown close to infested *Lantana camara* in Queensland (Swarbrick and Donaldson 1991). *Phenacoccus hordei* (Lindeman) has been reported from Britain. It is a root-feeding species that occurs throughout Europe and its hosts include several important crops, such as alfalfa, barley, clover, rye and wheat (Malumphy 2011). The Haanchen barley mealybug, *Trionymus haancheni* McKenzie, has been detected in wheat in large areas of Idaho (http://www.agri.state.id.us/Categories/PlantsInsects/RegulatedAndInvasiveInsects/Documents/Haanchen%20 Barley11.pdf) (Fig. 20.1).

In India, the wheat crop of 10–30 days old was found attacked by the mealybug *M. hirsutus* (Monga 2007). The 10 ha of wheat crop in village Jodhkan, district Sirsa (Haryana), has been found infested with mealybugs. In district Fatehabad, the infestation of the mealybug was observed on wheat around which cotton stalks infested with mealybugs are kept (Monga 2007). The mealybug was seen on wheat but was not proliferating as it could not establish on the wheat crop. It was seen migrating through stubbles and heaps of cotton stalks, and even developmental stages of the mealybug were seen on wheat during December, at two places, namely, Sahidanwali (Abohar) and Katiawali (Malot) of Ferozepur district in Punjab state, India.

20.2 Management

To manage this pest, the following pest management strategy was advocated in north zone, covering the state of Punjab, Haryana and Rajasthan in India.

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Table 20.1 List of mealybugs recorded on wheat

Mealybug Species	Country	Reference
Euripersia amnicola (Borchsenius)	Ukraine	Ben-Dov (1994)
Euripersia tomalinii (Newstead)	Palaearctic region	Ben-Dov (1994)
Heterococcus tritici (Kiritshenko)	Ukraine	Ben-Dov (1994)
Peliococcus turanicus (Kritshenko)	Palaearctic region	Ben-Dov (1994)
Phenacoccus evelinae (Tereznikova)	Hungary, Italy	Ben-Dov (1994)
Phenacoccus solenopsis (Tinsley)	India	Jat et al. (2010)
Phenacoccus tergrigaorianae (Borchsenius)	Armenia	Ben-Dov (1994)
Planococcoides lindingeri (Bodenheiemr)	Egypt, Israel	Ben-Dov (1994)
Rhizoecus tritici (Borchsenius)	Ukraine	Ben-Dov (1994)
Trionymus haancheni (McKenzie)	Idaho, California	(http://www.agri.state.id.us/Categories/PlantsInsects/RegulatedAndInvasiveInsects/Documents/Haanchen%20Barley11.pdf)
Tibetococcus triticola (Tang)	Tibet	Ben-Dov (1994)
Trionymus ascripticius (Williams)	Australia	Ben-Dov (1994)
Trionymus utahensis (Cockerell)	California	Ben-Dov (1994)

Fig. 20.1 Wheat leaf damaged by the mealybug

20.2.1 Cultural

- Alternate host plants growing on field bunds, water channels and wastelands in the area are to be uprooted and destroyed during the off season of cotton.
- The uprooted infested plants in cotton fields/water channels should be thrown to far-off areas to check further spread of mealybugs.

20.2.2 Chemical Measures

The use of the following insecticides, carbaryl 50 WP (1 kg), thiodicarb 75 WP (250 g), profenophos 50 EC (500 ml), quinalphos 25 EC (800 ml), acephate 75 SP (800 g), chlorpyriphos 20 EC (2000 ml), per hectare in 125–150 l of water with manually operated knapsack sprayer or 75 l with the shoulder- and tractor-mounted sprayers for the control of mealybugs is advocated in India. It is advised to rotate the insecticides of different groups in two consecutive sprays. In case of severe infestation, the sprays at 5–7-days interval are to be repeated.

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Barley

21

M. Mani

21.1 Species

The Haanchen barley mealybug (*Trionymus haancheni* McKenzie) was first detected in Northern California as a pest of cv. Haanchen barley in the 1950s. At that time, the mealybug developed large populations on part of 15,000 acres of barley in California, causing damage and hampering harvesting operations due to the sticky honeydew (Osborn 1951). It has recently been detected in the Northern Plains and Pacific Northwest barley production areas (Alvarez 2004). Seriousness of *T. haancheni* was reported in Idaho, Montana, and Alberta. The mealybug outbreak in Idaho in 2003 caused millions of dollars in damage to barley. This insect has been detected in wheat, but it primarily damages barley. Haanchen mealybug infestations in irrigated barley have been widespread throughout many northern Montana counties in 2007. Crawlers can also be transported to other plants by wind, people, or animals. Crawlers develop through several successive nymphal instars that resemble small adults, each of which have legs and so can actively move, until the mature adult stage is reached and the cycle repeats. The number of generations in Idaho is still unknown, but all instars can be found at a single time on a plant host. Coupled with a short generation time, the ability to reproduce asexually can allow mealybug infestations to increase quickly to damaging levels (Fig. 21.1).

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21.2 Damage

These damage symptoms are caused by mealybugs injecting toxic saliva into the plant. Both nymphs and adults feed with sucking mouthparts and reduce the amount of chlorophyll in the leaves, causing extensive yellowing and browning of foliage, reduced vigor, and root damage. Heavy infestations in commercial fields eventually kill the plants. Early signs of Haanchen mealybug infestation include cottony-like wax secretions at the plant base, often accompanied by extensive honeydew deposits and black sooty mold. Abundant, sticky honeydew was the first sign of mealybug infestation when detected. The mealybug excretes honeydew, affecting grain quality and also harvesting operations. The Haanchen mealybug is apparently able to survive winter, where it is protected by soil and plant material. Mild winter conditions in southeast Idaho during the past few years perhaps explain increased population densities. One could also speculate that outbreaks are related to the elimination of mealybug parasitoids after the application of insecticides directed against other barley pests such as cereal leaf beetle, cutworms, and

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Fig. 21.1 Barley mealybug and mealybug damage in the barley field

aphids (http://www.agri.state.id.us/Categories/PlantsInsects/RegulatedAndInvasiveInsects/Documents/Haanchen%20Barley11.pdf).

21.3 Management

The concealed feeding habit of *T. haancheni*, and the fact that the eggs are protected inside the cottony ovisacs, would further complicate management attempts and limit the insecticide use in barley because insects sheltered under leaf sheaths or ovisacs would be protected from contact sprays.

The most basic elements of an integrated pest management program are lacking for this pest. Currently, no insecticides are registered for use against this mealybug on barley. However, insecticide lambda-cyhalothrin with a surfactant (Activator 80) applied at the tillering stage of barley reduced mealybug populations by 60 % when compared with an untreated control. Mealybug control in other crops typically targets the small, highly mobile crawler stage because it tends to be more vulnerable than the later, larger life stages. Applications often are timed for the week after egg laying begins so as to kill the nymphs before they develop to the egg-laying adult stage. Foliar-applied contact insecticides that also have fumigant action (so that the chemical penetrates to insects behind leaf sheaths), or systemic insecticides, perhaps might provide some control. Repeated applications are needed to reduce infestation levels.

Tillage may be a viable alternative for reducing populations of Haanchen mealybugs. Seed treatments, which include Cruiser 5 FS (0.5 oz/cwt) or Gaucho 480 F (0.75–1.0), may offer proactive control of Haanchen mealybug in future spring plantings. Proactive seed treatments should be used for insects only if you have had a history of yield loss from a particular insect. Either tillage or seed treatments should be viewed as proactive options producers may consider for future plantings against Haanchen mealybug. (http://wiki.bugwood.org/HPIPM:Haanchen_Mealybug).

Biological control with parasitoids and predators has been the most effective and long- lasting management option. Two parasites were recorded on Haanchen mealybugs at Idaho. The more dominant and numerous parasite was a *Rhopus* spp. Few predators were observed in Idaho during the outbreak of the mealybugs.

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22 Groundnut

G. Harish and M.V. Nataraja

22.1 Mealybug Species

Mealybugs are injurious to groundnut found in many countries (Nandagopal and Prasad 2004). The species of mealybugs that are known to infest groundnut in different countries are listed in Table 22.1.

22.2 Damage

The damage symptoms produced by groundnut plants due to infestation of mealybugs vary depending on the mealybug species, part of plant which it attacks, and stage of the crop. The damage symptoms for each mealybug species attacking groundnut are given below (Fig. 22.1a–f).

22.2.1 *Dysmicoccus brevipes* (Cockerell)

Dysmicoccus brevipes is commonly called as pineapple mealybug and is found on the roots of the groundnut. It lives in colonies underground, and few may be seen on foliage. If found on foliage, they can be seen infesting the under surface of the leaves (base and on either side veins). Under favorable environmental conditions, the plants were found infested by mealybugs at alarming population levels of 2–3 nymphs per nodule. They feed on nodules and cut off the nutrient supply to plants (Singh et al. 1986). In Taiwan, *D. brevipes* was discovered to infest on the basal part and roots of some groundnuts in a field near a pineapple plantation. The infested plants showed leaf yellowing and wilting, and marked growth retardation (Huang et al. 2002). All stages of mealybug were feeding on roots up to a depth of 22 cm. A symbiotic relationship was observed between mealybug and ant, *Monomorium* spp., which are found in huge numbers attending mealybugs at infestation sites (Rajagopal et al. 1982). Das and Ray (1988) reported that this mealybug can cause yield loss up to 25 % in groundnut.

22.2.2 *Ferrisia virgata* (Cockerell)

Ferrisia virgata is commonly known as striped mealybug and is found attacking groundnut (Ahmed and Hasan 2009). The mealybug was also found associated with pods, pegs, green succulent stems, and branches at the transitional zone of stems, roots, and on abaxial surfaces of lower leaves. The nymphs and adult females suck sap from underground pods, pegs, stems, and branches and underside of the lower leaves, causing enormous damage to groundnut crops (Anonymous 2003; Ahmed and Hasan 2009).

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Table 22.1 List of mealybugs reported on groundnut in different countries

Species	Region/Country	Reference
Dysmicoccus arachidis sp.n.	India	Williams (2004)
Dysmicoccus brevipes (Cockerell)	Many countries	Lepage (1938), Hosny (1940), Williams (1985), Williams and Watson (1988), Williams and Granara de Willink (1992), Ben-Dov (1994)
	Taiwan	Huang et al. (2002)
	India (Andhra Pradesh, Karnataka, Tripura)	Rajagopal et al.(1982), Singh et al. (1986), Das and Ray (1988)
Dysmicoccus lepelleyi (Betrem)	Indonesia	Williams (2004)
Dysmicoccus mallis De Lotto	Uganda	Ben-Dov (1994)
Ferrisia consobrina Williams and Watson	Australian, Ethiopian, Neotropical and Pacific region	Ben-Dov (1994)
Ferrisia virgata (Cockerell)	Asia, Africa, Australia and Pacific Islands, North, South and Central America, Bangladesh	Anonymous (1975), Williams (2004)
	India (Gujarat)	Anonymous (2003)
Formicoccus polysperes sp.n.	India	Williams (2004)
Maconellicoccus hirsutus (Green)	Caribbean, Africa, South East Asia, Northern Australia	Chang and Miller (1996), Hoy et al. (2011), Williams (1996)
	India (Andhra Pradesh)	Rao and Srinivasan (1987)
Paracoccus marginatus William and Granara de Willink	Ghana	Cham et al.(2011)
	India (Tamil Nadu)	Selvaraju and Sakthivel (2011)
Phenacoccus solenopsis Tinsley	Central America, Caribbean, Ecuador, Chile, Argentina, Brazil, and China	Lysandrou et al. (2012)
	India (Gujarat)	Unpublished
Planococcus bendovi sp.n.	India	Williams (2004)
Planococcus furcisetosus Mamet	–	Ben-Dov (1994)
Planococcus japonicus Cox	China	Ben-Dov (1994)
Planococcus lilacinus Cockerell	Asia, Africa	Hill (1975), Cox (1989), Ben-Dov (1994)
Planococcus mali Ezzat and McConnell	*Planococcus mali* Ezzat and McConnell	Williams (2004)
Planococcus minor Maskell	–	Ben-Dov (1994),
	India	Williams (2004)
Pseudococcus calceolariae Maskell	Mauritius	D'Emmerez de Charmony and Gebert (1921), Williams (1985), Ben-Dov (1994)
Pseudococcus spp.	Africa, South and Central America, and Australia	Hill (1975, 1983)

22.2.3 *Maconellicoccus hirsutus* (Green)

Maconellicoccus hirsutus is commonly known as pink hibiscus mealybug and reported on groundnut from Florida along with other host plants (Hoy et al. 2011). In groundnut, mealybug colonies are often found feeding on underground plant parts like the taproot, pegs, and pods, resulting in reduced growth and development of pods. Mealybugs pierce and suck sap from the plant tissue, resulting in stunted plant growth. In Australia, heavy mealybug infestation was observed in poorly drained areas, resulting in the collapse of

Fig. 22.1 (**a**) Roots infested with mealybugs, (**b**) Mealybugs feeding on leaves, (**c**) Mealybugs on either sides of vein, (**d**) Pegs and pods infested with mealybugs, (**e**) Mealybugs feeding on stem, (**f**) Eggs inside the protective pouch (ovisac)

groundnut kernels, and they turn into black (http://www.daff.qld.gov.au/26_14460.htm).

22.2.4 *Paracoccus marginatus* William and Granara de Willink

Paracoccus marginatus William and Granara de Willink is commonly called as papaya mealybug and is also known to infest groundnut, and its degree of infestation recorded was below 15 % in Tamil Nadu, India (Selvaraju and Sakthivel 2011). It was also reported infesting groundnut from Akraman and Nsawam regions of Ghana (Cham et al. 2011).

22.2.5 *Phenacoccus solenopsis* Tinsley

Phenacoccus solenopsis Tinsley is commonly called as solenopsis mealybug, a polyphagous pest known to multiply on different host plants, including groundnut. In Australia, it was found attacking groundnut (http://www.daff.qld.gov.au/26_14460.htm). In India, it was first time recorded infesting GG-20, a variety of groundnut during kharif, in 2012 in Junagadh district of Gujarat. These mealybugs were also found associated with pods, pegs, green succulent stems, and branches.

22.2.6 *Pseudococcus* spp.

It is found to infest foliage of groundnut in Africa, Australia, Central America, and South America (Hill 1983).

22.3 Seasonal Development

The seasonal occurrence of the mealybugs varied largely from one region to another. In Andhra Pradesh, India, *D. brevipes* was reported to occur on groundnut during September and October months (Singh et al. 1986), whereas *M. hirsutus* occurred during February and March months (Rao and Srinivasan 1987). In Gujarat, *F. virgata* was observed on harvested groundnut plants in the month of May (Anonymous 2003). In Ghana, *Paracoccus marginatus* was found infesting groundnut during July to March months (Cham et al. 2011). In Sind and Punjab provinces of Pakistan, *Phenacoccus solenopsis* peak population was observed during the first week of September on groundnut (Abbas et al. 2010; Lysandrou et al. 2012). It was also recorded during June to October (2012) in Junagadh district of Gujarat.

22.4 Management

Managing mealybugs on groundnut crop requires a holistic approach through proper integration of several pest management tactics such as cultural, mechanical, physical, biological, behavioral, and chemical measures.

22.4.1 Cultural Control

- Crop should be kept free from weeds and alternate hosts harboring the mealybugs.
- Plants should be maintained in healthy condition and avoid water stress.

22.4.2 Mechanical Control

- Ant colonies that are located near the soil surface are to be destroyed during land preparation.

22.4.3 Biological Control

- Conservation and release of the natural enemies such as coccinellids (*Cryptolaemus montrouzieri* Mulsant; *Brumoides suturalis* (Fabricius) and *Scymnus coccivora* Ramakrishna Ayyar), syrphids and lycanid, and *Spalgis epeus* (Westwood) in general for all the mealybugs, and also release of host-specific parasitoids for the respective mealybugs.

- Foliar spray of *Verticillium lecanii* (Zimmerman) or *Beauveria bassiana* (Bals.-Criv.) (2×10^8 cfu/ml) at 5 g/ml/l of water is effective during high humid months in reducing the population of mealybugs (Tanwar et al. 2007).

22.4.4 Chemical Control

- Chemicals such as pirimiphos-methyl or triazophos are effective against first instar mealybugs (Persad and Khan 2000). Soil application of aldicarb at 1 kg a.i./ha 15 days after sowing, followed by a spray of chlorpyriphos at 0.5 kg a.i./ha at the base of the plants was also recommended (Das and Ray 1988). Use dichlorovos (0.2 %) in combination with fish oil rosin soap (25 g/l) as the spray helps to control the mealybugs (Tanwar et al. 2007).
- Drenching with chlorpyriphos 20 EC at 2.5 ml/l, or apply 5 % malathion dust at 25 kg/ha, is also advised to control the mealybugs on groundnut.

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23 Sunflower

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In recent years, the mealybugs are found to infest sunflower crop in different sunflower-growing regions. *Phenacoccus solenopsis* (Tinsley) (Basappa 2007; Jagadish et al. 2008), *Maconellicocus hirsutus* (Green) (Basappa 2008; Rathod et al. 2008) and *Paracoccus marginatus* (Williams and Granara de Willink) (Jagadish et al. 2010) are known to attack sunflower in *India*. In Australia also, *Ph. solenopsis* was found attacking sunflower (http://www.daff.qld.gov.au/2614460.htm). *Phenacoccus madeirensis* (Green) is also known to infest sunflower (Bend-Dov 1994).

Phenacoccus solenopsis is the major mealybug species attacking sunflower particularly grown nearer to cotton in India. It is found severe on sunflower in different parts of Karnataka (Bengaluru, Chitradurga, Bellary, Haveri, Bagalkot, Koppal and Gadag districts), Andhra Pradesh (Nandyal, Kadri, Anantapur, Karimnagar, Gouraram, Ranga Reddy and Hyderabad), Maharasthra (Akola, Aurangabad and Jalna districts) and Tamil Nadu (Coimbatore, Tirupur, Erode, Salem and Namakkal districts). There is a likelihood of severe incidence of this mealybug on sunflower crop in Punjab, Haryana and Gujarat whenever this pest causes severe damage to cotton crop (Basappa 2008).

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23.1 Bionomics

The total developmental period of egg to adult *P. solenopsis* on sunflower was completed in 20–30 days and the fecundity of female was about 500–650 nymphs (Basappa 2008; Chandrashekar 2011; Anonymous 2011). Around Bengaluru, India, the mealybug infestation initially appeared in the first week of January and gradually increased as the season advanced. Then it increased abruptly to reach 156.20 in the 15th standard week (9–15 April). Later, the mealybug population declined gradually and reached 113.78 in the 18th standard week (30 April–5 May). The mealybug population remained nil during kharif and rabi seasons (June–December) (Chandrashekar 2011). It was significantly positively correlated with maximum temperature (0.870**) and sunshine hours (0.509**) and negatively correlated with rainfall (–0.177) and morning (–0.627**) and evening (–0.743**) relative humidity. The population of the encyrtid parasitoid (*Aenasius bambawalei* Hayat) was also significantly positively correlated with *P. solenopsis* population (0.985**) and weather parameters, namely maximum temperature

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(0.845**) and sunshine hours (0.493). The regression coefficient of the mealybug and its parasitoid with weather parameters indicated that the population dynamics of mealybug and parasitoid was dependent on weather parameters to the extent of more than 70 % (Chandrashekar et al. 2012).

At Raichur in Karnataka, India, peak infestation of *P. solenopsis* was observed from October to November, while no incidence was found from June to September (Anonymous 2011). At Hyderabad, India, maximum population of mealybug was noticed on sunflower from April to August (Basappa 2008). High temperatures along with low humidity are congenial for rapid growth and multiplication of *P. solenopsis*, while high-intensity rains and wet spells adversely affect its infestation (Saini et al. 2009).

23.2 Ant Association with Mealybugs

Ten species of ants, namely *Paratrechina longicornis* (Latreille), *Myrmicaria brunnea* (Saunders), *Monomorium pharaonis* (Linnaeus), *Tapinoma melanocephalum* (Fabricius), *Camponotus sericius* (Fabricius), *Solenopsis geminata* (Fabricius), *Anoplolepis gracilipes* (Smith), *Camponotus compressus* (Fabricius), *Monomorium latinode* (Mayr) and *Oecophylla smaragdina* (Fabricius), were found attending to the mealybug *P. solenopsis* in sunflower (Jagadish et al. 2008; Chandrashekar 2011; Basappa 2008). Different ant species were found to transfer *P. solenopsis* from one sunflower plant to another, and also found to provide protection to the mealybug from predators, parasitoids and other natural enemies (Chandrashekar 2011). Ants were responsible for quick colonization of *P. solenopsis* to newer areas (Saini et al. 2009) (Fig. 23.1).

23.3 Damage

Incidence of *Ph. solenopsis* is observed on sunflower a week after germination onwards, up to maturity stage, but the level of damage varies with different phenological stages of the crop. Sunflower is highly susceptible to mealybug attack in the seedling stage. One adult can cause typical symptoms of curling of leaves, stunted growth, deformation and death of plants, within 30 days of germination. At this stage, it could cause 100 % crop loss. If infestation occurs at vegetative stage, symptoms of curling of leaf, stunted growth and deformation without death of plant were observed, but the plant could not produce flowers; however, it could cause 100 % loss in patches. If incidence is at the reproductive stage of the crop, it affects flower buds and flowers, leading to deformation of head without seed set. In some cases, partial seed setting is also noticed with about 50 % yield loss (Anonymous 2011; Basappa 2008; Chandrashekar 2011; Rathod et al. 2008). The overall appearance of

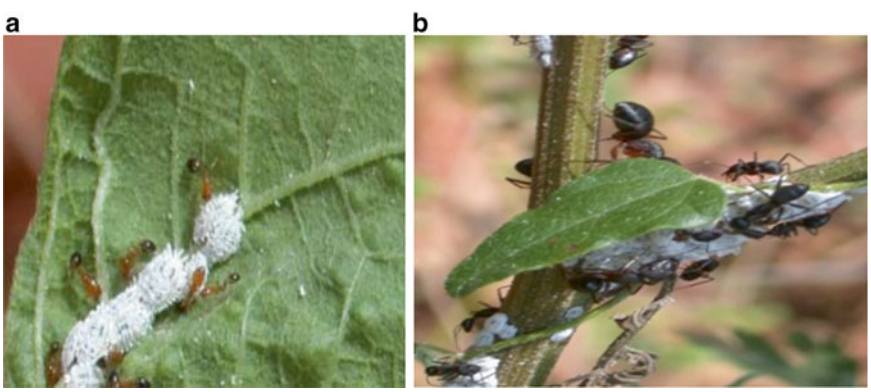

Fig. 23.1 Ants attending to the mealybugs (**a**) *Monomorium pharaonis* (**b**) *Camponotus compressus*

the plant was bushy and stunted, with the infested plants showing a reduction in their height, as compared to the uninfested plants (Jagadish et al. 2009). Sunflower yield in Tamil Nadu slipped to 700 kg/acre from the normal yield of 1000–1200 kg/acre, mainly due to the mealybug infestation in the entire growing belt (Anonymous 2009; Suresh et al. 2010). At Akola, Maharashtra, 60 % reduction in sunflower seed yield was reported in the case of Morden variety due to mealybug attack by Rathod et al. (2008) (Fig. 23.2).

23.4 Natural Enemies

Among the natural enemies, the parasitoid *Aenasius bambawalei* Hayat found an important one, commencing its activity from the second fortnight of January onwards and the parasitization was observed up to last week of June. No parasitization was recorded from first week of July up to second week of January. Parasitization percentage ranged between 0.00 and 52 % (Chandrashekar 2011; Basappa 2008). Seven predators, namely *Cryptolaemus montrouzieri* (Mulsant), *Brumoides suturalis* (Fab.), *Cheilomenes sexmaculata* (Fab.), *Scymnus coccivora* (Ayyar), *Spalgis epeus, Coccinella transversalis* (F.) and *Chrysoperla zastrowi*, were found attacking *Ph. solenopsis* (Basappa 2008; Chandrashekar 2011; Anonymous 2011; Joshi et al. 2010; Jagadish and Shadakshari 2009). Peak activity of predators was observed from February to April around Bangalore (Chandrashekar 2011). Activity of natural enemies associated with mealybug was more during April to June 2008, and later its population was reduced to minimum around Hyderabad (Basappa 2008). *Lecanicillium lecanii* (Zimm.) Zare & Gams was found to be highly pathogenic to *P. solenopsis*. At an initial inoculum of 1×10^4 conidia mL^{-1}, lethal time (LT50) was 3.77 and 2.51 days for nymphs and adults, respectively (Gulsarbanu et al. 2009) (Figs. 23.3 and 23.4).

23.5 Management

23.5.1 Under Glasshouse Conditions

Profenophos 50 EC (0.05 %) and buprofezin 25 SC (0.025 %) were significantly superior in reducing the population of mealybug on sunflower under glasshouse condition (Chandrashekar 2011). Methomyl was also found effective against mealybugs with lowest population, followed by dichlorvos, dimethoate, acephate, azadiractin and malathion (Anonymous 2011). Basappa (2008) also reported that dichlorvos (2 ml/L), chlorpyriphos (2 ml/L) and profenophos (1 ml/L) gave more than 80–90 % reduction in the mealybug population at 3 and 7 days after treatment. Proper preparation of spray solution and coverage are more important in the effective management of mealybug on sunflower.

Fig. 23.2 *Phenacoccus solenopsis* on sunflower

Fig. 23.3 *Aenasius bambawalei*

Fig. 23.4 Cocoons of *A. bambawalei*

The fungal pathogen *Verticillium lecanii* was able to bring about 50 % reductions in the mealybug population. Biopesticides may be effective under moderate levels of incidence along with natural enemies (Basappa 2008).

23.5.2 Under Field Conditions

Profenophos 50 EC (0.05 %), methomyl 40 SP (0.04 %), dimethoate 30 EC (0.06 %) and dichlorovos 76 WSC (0.15 %) were found to be most effective in controlling the mealybug on sunflower under field conditions (Chandrashekar 2011; Anonymous 2011). The insecticides can be used after initiation of mealybug attack, and second spray can be applied after 10 days of first application if the pest population persists (Anonymous 2011). Methomyl 40 SP (0.04 %) and profenophos 50 EC (0.05 %) recorded maximum net returns of Rs. 10,230 and Rs. 10,119, respectively. Dimethoate recorded higher cost-to-benefit ratio (1:24.37), followed by profenophos (1:22.19), acephate (1:20.69) and methomyl (1:14.21). Based on the incremental cost-to-benefit ratio, dimethoate, profenophos, acephate and methomyl were suggested for the management of *P. solenopsis* in sunflower (Chandrashekar 2011).

Aenasius bambawalei is a potential of the encyrtid parasitoid which can be exploited in managing *Ph. solenopsis*.

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Pulses 24

S.K. Singh, S.D. Mohapatra, and P. Duraimurugan

24.1 Pigeon Pea

24.1.1 Species

Mealybugs are found to infest pigeon pea (red gram) (*Cajanus cajan*) in India, Trinidad, Africa and Ghana (Table 24.1). Several scale insects have been misquoted as mealybugs of pigeon pea in India (Bhatnagar et al. 1984; Shaw et al. 1999; Singh 2004).

24.1.2 Bionomics

Mode of reproduction of *Planococcus cajani* is sexual and oviparous. Incubation period of eggs is 5.2 days. The female and male nymphs moult thrice and four times, respectively, in 18.41 and 16.26 days at 28.1–29.9 °C and 84–93 % relative humidity (RH). *Coccidohystrix insolita* caused damage to pigeon pea in Gujarat and Tamil Nadu, India. The eggs were off-white, oval and found within the protective cottony ovisac. The male and female bugs passed through four and three nymphal instars, respectively. It takes 42.14 and 59.49 days for males and females at the field temperature of 24.94 ± 2.27 °C with 70.11 ± 13.10 % relative humidity, respectively. The sex ratio of male to female was 2.07 in the field (Borad and Bhalani 1997). *Coccidohystrix insolita* attained major pest status in pigeon pea with the introduction of new varieties and necessitating management practices (Ganapathy et al. 1994). The mealybug was found infesting leaves, flowers and pods. The mealybug was found more devastating in Vamban, Tamil Nadu, India.

The damage caused by *Coccidohystrix insolita* was characterised by the presence of large congregation of nymphs and adults with their body covered with white mealy coating on the under surface of the leaf. The affected leaflets turn yellow and drop off. The plant becomes stunted initially. Severe incidence causes wilting and drying of plants. The movement of ants and development of sooty mould were observed on the mealybug-infested plants (Durairaj and Ganapathy 2000). *Maconellicoccus hirsutus* has been reported to cause 15 % plant infestation on pigeon pea in Gujarat, India.

Mealybug crawlers were observed on the lower surface of leaves, causing damage by sucking the cell sap. In severe infestation, the pest was found covering the whole leaf surface. Severely affected plants were stunted. Honeydew excreted by nymphs and adults supported the growth of sooty moulds on leaves and shoots, giving blackish appearance to leaves (Patel et al.

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Table 24.1 List of mealybugs recorded on pigeon pea

Mealybug Species	Country/Region	References
Coccidohystrix insolita (Green) (*Centrococcus insolitus* (Green))	India	Nair (1975), Atwal (1976)
	Gujarat, India	Patil et al. (1985), Rai et al. (1988)
	Tamil Nadu, India	Durairaj and Ganapathy (2000)
Dysmicoccus brevipes (Cockerell)	India	Rajagopal et al. (1982)
Ferrisia virgata (Cockerell)	Haryana, India	Gautam and Saxena (1986)
Paracoccus marginatus Williams and Granara de Willink	Ghana	Cham et al. (2011), Shylesha et al.(2011)
	Karnataka, India	Tanwar et al. (2007)
Maconellicoccus hirsutus (Green)	Gujarat	Patel et al. (1990), Rajadurai and Thyagarajan (2003), Persad and Khan (2006)
Nipaecoccus viridis (Newstead)	–	Ben-Dov (1994)
Nipaecoccus filamentosus (Cockerell) Syn: *Pseudococcus filamentosus* Cockerell	India	Nair (1975)
Phenacoccus madeirensis Green	–	Ben-Dov (1994)
Phenacoccus solenopsis Tinsley	India	–
Planococcus cajani Mukherjee and Mukhopadhyay	India	Mukhopadhyay and Mukherjee (2005)
Planococcus minor (Maskell)	Trinidad	Francis et al. (2012)
Planococcus kenyae (LePelley)	Africa	http://www.infonet-biovision.org/default/ct/94/pests
Rastrococcus iceryoides (Green)	India	Williams (2004)

1990). *Paracoccus marginatus* was reported to cause 25 % damage to pigeon pea in Tamil Nadu. In Haryana, nymphs and adults of the mealybug *Ferrisia virgata* were found mainly on the inflorescences, causing withering and dropping of flowers. On heavily infested plants, the population of *F. virgata* ranged from 1 to 2/leaf, 2 to 3/flower and 10 to 13/inflorescence (Gautam and Saxena 1986). In Bangalore, India, *Dysmicoccus brevipes* was found infesting the root nodules of red gram in southern India There were two to three mealybugs per nodule. All stages of the mealybug were observed, and infestation was noted at the depth of up to 22 cm. More than 80 % of the plants were infested. The ant *Monomorium* sp. was found to be attracted to sites of mealybug infestation (Rajagopal et al. 1982) (Fig. 24.1).

24.2 Chickpea

Ferrisia virgata was found damaging chickpea *Cicer arietinum* by sucking the sap of the leaves.

24.3 Mung Bean

Geococcus coffeae Green was found sucking the leaves, stem and pods of mung bean (green gram) (*Vigna radiata*) (Kooner 2006). Root mealybugs *D. brevipes* and *Geococcus coffeae* have been reported to cause damage to green gram in India.

24.4 Cowpea

Dysmicoccus brevipes (David and Ananthakrishnan 2004), *Maconellicoccus hirsutus* (Persad and Khan 2006) and *Geococcus* spp. (Mathew et al. 2011) are known to infest cowpea (*Vigna unguiculata*) in India.

24.5 Beans

Paracoccus maraginatus was found infesting beans (*Phaseolus vulgaris*) in Ghana (Cham et al. 2011), Florida (Walker et al. 2003), Sri Lanka (Galanihe et al. 2010), Palau (Muniappan et al. 2006) and Hawaii (Ronald et al. 2007).

Fig. 24.1 Mealybug damage to pigeon pea: (**a**) *P. solenopsis* on pigeon pea, (**b**) *P. marginatus* on pigeon pea and (c) *P. maraginatus* on *Phaseolus vulgaris*

24.6 Blackgram

Dysmicoccus brevipes was known to infest black gram (*Vigna mungo*) in India (David and Ananthakrishnan 2004).

24.7 Management

24.7.1 Chemical Control

Monocrotophos (0.04 %) + kerosene oil (0.05 %) + soap (0.02 %) and ethion were found to be highly effective in controlling *Coccidohystrix insolita* in pigeon pea in South Gujarat (Rai et al. 1988). More than 95 % reduction in field population of *C. insolita* was observed with applications of lambda-cyhalothrin, dichlorvos and profenophos in Tamil Nadu (Durairaj and Ganapathy 2000). Methyl parathion (0.03 %), quinalphos (0.05 %), monocrotophos (0.04 %), cypermethrin (0.009 %), endosulfan (0.075 %), diazinon (0.05 %), chlorpyrifos (0.05 %) and decamethrin [deltamethrin] (0.00125 %) caused 89.2, 88.1, 68.0, 33.9, 32.1, 30.5, 30.0 and 7.9 % mortality of *C. insolita*, respectively, on the treated leaves (Patel et al. 1989).

24.7.2 Biological Control

There are many parasitic wasps and various predatory insects that feed on mealybugs. *Cryptolaemus montrouzieri* can be used to control the mealybugs in general. Host-specific parasitoids are available for the control of mealybugs. For example, *Acerophagus papayae* Noyes and Schauff for *P. marginatus* can be used to control the *P. marginatus*.

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25 Soybean

M. Mani

Mealybugs are reported to be injurious to soybean in India, Kentucky (USA), Sri Lanka, Indonesia, and so forth (Table 25.1).

Pseudococcus sorghiellus has been found in association with fields that exhibit symptoms similar to potassium deficiency (yellowed leaf margins and stunted plants), often in fields that recently hosted alfalfa. It seems that this mealybug species is fairly common on other plant species, reported from Indiana, Illinois, and Pennsylvania. The mealybug species is often found to be tended by ants, which eat the honeydew excreted by the mealybugs and in turn protect the mealybugs from predators. Similar to other mealybugs in appearance, these small, whitish insects live beneath the soil surface and feed on plant juices. These whitish crawlers are seen attached to the roots (http://extension.entm.purdue.edu/pestcrop/2011/issue14/index.html).

Planococcus citri was known to suck the sap from stem at pod formation stage in Maharashtra, India (Jadhav et al. 1996). The development of *Pl. citri* and the parasitoid *Anagyrus pseudococci* (Girault) was better on soybeans than on *Streptocarpus hybridus* or *Aeschynanthus ellipticus* (Copland et al. 1993). The average developmental periods of males and females of *N. vasatator* on soybean were 15.46 and 14.62 days, respectively. The average preoviposition, oviposition, and fecundity were 7.66 days and 78.67 eggs on soybean (Saha and Ghosh 2001).

Pseudococcus sorghiellus on soybean

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Table 25.1 List of mealybugs recorded on soybean

Mealybug species	Region	Reference
Dysmicoccus brevipes (Cockerell)	–	Ben-Dov (1994)
Ferrisia virgata (Cockerell)	Singapore	Williams (2004)
Geococcus coffeae Green	–	Ben-Dov (1994)
Maconellicoccus hirsutus (Green)	Indonesia	Williams (2004)
	India	Rajadurai and Thyagarajan (2003)
Nipaecoccus vastator (Mask.)	Madhya Pradesh, India	Srivastava (1972)
Nipaecoccus viridis (Newstead)	Sri Lanka	Williams (2004)
Planococcus citri (Risso)	Maharashtra, India	Jadhav et al.(1996)
	Sri Lanka	Williams (2004))
	UK	Copland et al. (1993)
	India	Williams (2004)
Planococcus minor (Maskell)	–	Ben-Dov (1994)
Pseudococcus cryptus Hempel	Sri Lanka	Williams (2004)
Pseudococcus maritimus (Ehrhorn)	USA	Gimpel and Miller (1996)
Pseudococcus sorghiellus (Forbes)	Kentucky, Ohio, and Iowa (USA)	Tooker (2011)
Pseudococcus sociabilis Hambleton	Neotropical region	Ben-Dov (1994)

Potassium deficiency symptoms could be a sign of mealybugs below
(Photo credit: Ohio State University)

Mealybugs, soybean root

Dysmicoccus sp. was found to suck the sap from root and rhizome nodules of soybean grown in sandy soil in Karnataka. The infestation on nodules and taproot began during second fortnight of September and continued up to the last week of October. The population of mealybugs ranged from 6 to 25 per plant. Severely affected plants showed stunted growth (Thippaiah and Kumar 1999).

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26 Cotton

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26.1 Mealybug Species

Mealybugs are injurious to cotton in India, Pakistan, China, Brazil, Australia, Ethiopia, USA, Emerald and so on. (Table 26.1). Among the mealybug species, the solenopsis mealybug *Phenacoccus solenopsis* Tinsley was found to cause severe economic damage in all nine major cotton-growing states of India, resulting in loss worth of US $16–20 million while reducing yields up to 50 % in the affected fields in 2007 (Nagrare et al. 2009). *Paracoccus marginatus* Williams and Granara de Willink also caused havoc on cotton around Coimbatore district of Tamil Nadu. Besides these two mealybugs, *Nipaecoccus viridis* (Newstead), *Maconellicoccus hirsutus* (Green), *Ferrisia virgata* Cockerell, *Ferrisia malvastra* (Mc Daniel) in central India and *Rastrococcus iceryoides* (Green) in south India were also reported on cotton in traces.

26.2 Damage

Mealybugs are small sap-sucking insects that cause severe economic damage to cotton. They attack different parts of the growing cotton plant, namely main stem, branches and underdeveloped flowers that produce bolls of smaller size. The boll opening when adversely affected result in serious reduction in yield. Excretion of honeydew attracts ants and also contributes to the development of black sooty mould. Plants severely affected with sooty mould have the appearance of burn symptoms.

An infested cotton plant shows the symptoms such as white fluffy mass on underside of leaves, near growing tips, along leaf veins and on stem, distorted or bushy shoots. Plants infested by mealybugs during vegetative phase exhibit symptoms of distorted, bushy shoots, crinkled and/or twisted bunchy leaves and stunted plants that dry completely in severe cases.

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Table 26.1 Mealybug species recorded on cotton in different regions of the world

Species	Region/Country	References
Ferrisia consobrina Williams and Watson	Australia, Ethiopia, Neotropical and Pacific region	Williams (2004)
Ferrisia malvastra (Mc Daniel)	India	Jhala et al. (2008), Suresh and Kavitha (2008a)
Ferrisia virgata Cockerell	India	Saminathan and Jayaraj (2001), Suresh (2008), Vennila et al. (2010a), Anonymous (2010), Nagrare et al. (2011), Tanwar et al. (2011), Nagrare et al. (2012), Anonymous (2013b)
	Brazil	Torres et al. (2013)
	Cambodia	Williams (2004)
Maconellicoccus hirsutus (Green)	India	Misra (1920), Dhawan et al. (1980), Muralidharan and Badaya (2000), Suresh (2008), Nagrare et al. (2009), Pinjarkar et al. (2009), Vennila et al. (2010b)
Nipaecoccus viridis (Newstead)	India	Misra (1920), Vennila et al. (2010b), Nagrare et al. (2011), Thomas and Ramamurthy (2011)
Paracoccus burnerae (Brain)	Ethiopian region	Ben-Dov (1994)
Paracoccus marginatus Williams and Granara de Willink	India	Anonymous (2008), Amutha et al. (2009), Banu et al. (2010), Dharajothi et al. (2010), Tanwar et al. (2010), Jeyarani et al. (2011), Nagrare et al. (2011), Sakthivel et al. (2012)
	Argentina	Granara de Willink (2003)
Paracoccus solani Ezzat and McConnel	Australia, Peru and Costa Rica	Ben-Dov (1994)
Phenacoccus madeirensis Green	India	Shylesha and Joshi (2012)
Phenacoccus solenopsis Tinsley	China	Wang et al. (2009), Wu and Zhang (2009), Zhang et al. (2010)
	India	Dutt (2007), Hodgson et al. (2008), Jhala et al. (2008), Thomas et al. (2008), Anonymous (2009), Bhosle et al. (2009), Dhawan and Saini (2009), Dhawan et al. (2009), Hanchinal et al. (2009), Kumar et al. (2009a), Monga et al. (2009), Nagrare et al. (2009), Saini et al. (2009), Bisane et al. (2010), Suresh et al. (2010), Vennila et al. (2010b), Hanchinal et al. (2011), Kumar et al. (2011), Tanwar et al. (2011)
	Pakistan	Zaka et al. (2006), Muhammad (2007), Hodgson et al. (2008), Abbas et al. (2009), Afzal et al. (2009), Abbas (2010), Abbas et al. (2005), Abbas et al. (2010), Ashfaq et al. (2010), Khuhro et al. (2011), Sahito et al. (2011)
	Brazil	Silva (2012)
	Ethiopia	Anonymous (2013a)
	USA	Fuches et al. (1991)
	Australia	Admin (2010), Charleston and Murray (2010), David and Charleston (2010), IPPC (2010)
	Emerald and Burdekin	Admin (2010)
	Nigeria	Akintola and Ande (2008)
	Sri Lanka	Prishanthini and Laxmi (2009)

(continued)

Table 26.1 (continued)

Species	Region/Country	References
Peliococcus turanicus (Kritshenko)	Palaearctic region	Ben-Dov (1994)
Planococcus minor Maskell	–	Ben-Dov (1994)
Pseudococcus neomaritimus Beardsley	Kiribati and Marshall Islands	Ben-Dov (1994)
Rastrococcus iceryoides (Green)	India	Suresh and Kavitha (2008b), Anonymous (2012)
Rhizoecus macgregori Hambleton	Mexico	Ben-Dov (1994)
Spilococcus eriogoni (Ehrhorni)	California, Mexico	Ben-Dov (1994)

P. soleneopsis

P. marginatus

F. virgata

26.2.1 Mealybug Damage to Cotton Plants

Late-season infestations during reproductive crop stage result in reduced plant vigour and early-crop senescence.

26.3 Varietal Resistance/Susceptibility

In Pakistan, there was a highly significant variation in the population of mealybug on 15 varieties of cotton crop, namely Cris-134, Chandi, FH-901, CIM-473, CIM-499, Shahbaz, TH-57/96, NIAB-111, CIM-496, Hari dost, Okra leaf, Sindh-1, NIAB-78, Bt cotton and Okra desi. The peak populations were recorded on 8 June 2008 (8.80 on TH-57/96), 23 June (43.20 on NIAB-111), 7 July (57.00 on Cris-134), 21 July (20.40 on Bt), 5 August (36.00 on Sindh-1) and 18 August (72.60 also on Sindh-1), 3 September (148.30 on FH-901), 17 September (141.10 on Chandi) and 30 September (189.10 on NIAB-78). However, the highest overall mean population (62.34) was recorded on variety NIAB-78 (Sahito et al. 2011).

26.4 Seasonal Incidence

Phenacoccus solenopsis appeared on cotton crop 1–2 months after sowing and remains till harvest of the crop in Pakistan (Sahito et al. 2011). In Pakistan, maximum mealybug population (*Ph. solenopsis*) was recorded when the temperature was in the range of 30.5–39.5 °C (Khuhro et al. 2011). In Punjab, India, the highest field infestation recorded was mostly in the 30th meteorological week with 14.9, 31.5 and 26.9 % in Bathinda, Muktsar and Ferozepur districts, respectively. In Faridkot, the highest field infestation of 10.2 % was recorded in the 34th meteorological week. Mealybug infestation was positively

Ph. solenopsis

Pa. marginatus

N. viridis

correlated with temperature, whereas negative correlation was observed with relative humidity and rainfall (Dhawan et al. 2009).

It appeared that high rainfall has washed away all the small crawlers. Moreover, the high rainfall has favoured the growth of entomopathogens on the mealybugs. It is evident that enough humidity favours the multiplication, but the intense rainfall adversely affects the spread and reduces the intensity (Jeyakumar et al. 2009). In Raichur, Karnataka, India, mealybug infestation started appearing in September and gradually increased as the crop growth advanced. The population was 0.50/10-cm apical shoot in the 38th meteorological week and progressively increased throughout the season. The population reached to 115.42/10-cm apical shoot in the third week of January and thereafter increased suddenly to reach 180.42/10-cm apical shoot in the seventh meteorological week. Later on, the infestation of mealybug declined gradually and reached to 146.64/10-cm apical shoot in the 14th meteorological week. In general, predator population was low during the cropping season. Maximum population of coccinellids, chrysopids and spiders were 0.14, 0.13 and 0.16 per plant, respectively, during the season. Parasitoid cocoons ranged between 0.52 and 20.02 %. The activity of the parasitoid *Aenasius bambawalei* started during the 44th meteorological week and later on increased gradually to reach the peak during seventh to ninth meteorological weeks. Highest parasitoid (20.65 %) was recorded during the seventh meteorological week, which coincides with the higher population of mealybug. Mealybug population was significantly and positively correlated with maximum temperature (0.775) and negatively correlated with other parameters. Among predators, chrysopids were significantly correlated with relative humidity (0.289) and others were non-significant. The mealybug parasitoid cocoons were positively correlated with maximum temperature (0.421) but negatively correlated with other meteorological parameters (Hanchinal et al. 2010).

26.5 Natural Enemies

26.5.1 *P. solenopsis*

26.5.1.1 Parasitoids

The encyrtid parasitoid *Aenasius bambawalei* Hayat was recorded on *Ph. solenopsis*-infesting cotton and other crops in India (Hayat 2009). It was reported from north and central India (Tanwar et al. 2011), Haryana (Ram Pala et al. 2009), Punjab (Dhawan et al. 2011), Tamil Nadu (Sankar et al. 2011; Amutha et al. 2009), Karnataka (Hanchinal et al. 2009), all in India, Pakistan (Arif et al. 2011a) and China (Chen Hua-Yan et al. 2010). The parasitoid seems host specific, having excellent searching ability in attacking mealybugs in colonies as well as those present solitarily on different host plants of mealybug (Ram Pala et al. 2009). The parasitoid took 12–14 days to complete its development in the host. A female parasitoid parasitized 38–163 mealybugs during its life of 11–35 days. Third instar nymph of *Ph. solenopsis* is found suitable for the breeding of *A. bambawalei.* In progeny, the male and female ratio was 1:2 (Fand et al. 2011).

26.5.1.2 Predators

Chrysoperla carnea (Stephens) was also known to feed on mealybug crawlers. In Pakistan, *Cheilomenus sexmaculata, Coccinella septempunctata, Brumus suturalis* and *Hippodamia convergens* were found as potential predators of *Ph. solenopsis* (Arif et al. 2011b). Six species of coccinellids, i.e. *Scymnus coccivora* Ayyar, *Nephus regularis* Sicard, *Brumoides suturalis* Fabricius, *Hippodamia variegata* Goeze, *Cheilomenes sexmaculata* Fabricius and *Coccinella septempunctata* L., were associated with *Ph. solenopsis* in and around Hisar, Haryana (Kedar et al. 2011). In Tamil Nadu, the lycaenid predator *Spalgis epeus* was found associated with cotton mealybugs (Suganthi et al. 2009). The Australian ladybird beetle *Cryptolaemus montrouzieri* (Mulsant) was found to feed on colonies of *Ph. solenopsis. C. montrouzieri*, having a remarkable predatory potential, can be used for suppressing the population of mealybug *Ph. solenopsis* (Nagrare et al. 2009; Ghafoor et al. 2011; Solangi et al. 2012).

26.5.1.3 Pathogens

Cadavers of *Ph. solenopsis* infected with *Fusarium pallidoroseum* (Cooke) Sacc were collected from Haryana and Punjab during 2007–2010. In the laboratory, *F. pallidoroseum* caused 80–95 % mortality of *Ph. solenopsis* (Monga et al. 2010). The fungal pathogen *Lecanicillium* (*Verticillium*) *lecanii* was found to be pathogenic to *Ph. solenopsis* in Tamil Nadu (Banu et al. 2009). Entomopathogenic nematode *Steinernema thermophilum* was known to cause 83 % mortality of mealybugs within 72 h after inoculation at 50 IJ/ml and 100 % mortality of mealybugs within 48 h after inoculation at 500 IJs/ml (Kumar and Sudershan 2011).

26.5.2 *M. hirsutus*

In central India, *M. hirsutus* was found parasitized by *Encyrtus aurantii* (Geoffroy), *Anagyrus dactylopii* (Howard) and *Anagyrus mirzai* Agarwal and Alam (Pinjarkar et al. 2009).

26.5.3 *Paracoccus marginatus*

On the papaya mealybug *Paracoccus marginatus*, the local predator *Spalgis epeus* being the dominant predator feeds efficiently on the ovisacs, nymphs and adult mealybugs (Nagrare et al. 2011).

Aenasius bambawalei Hayat, *Anagyrus kamali* Moursi, *Cryptolaemus montrouzieri* (Mulsant), *Chrysoperla carnea* (Stephens), *Verticillium lecanii* (Zimmermann) and *Beauveria bassiana* (Vuillemin) are potential natural enemies of *Ph. solenopsis* (Joshi et al. 2010).

26.5.4 *Other Mealybugs*

Cacoxenus perspicax Knab, *Cheilomenes sexmaculata, Scymnus* sp., *Nephus regularis* etc. are present on *N. viridis* in different ecosystems that feed on naturally occurring mealybug infestation. These predators and parasitoids have to be conserved and used for effective pest management so that the indiscriminate use of insecticides can be avoided.

26.6 Management

26.6.1 Chemical Control

Organophosphates, such as chlorpyriphos and profenophos, resulted in 100 % wipeout of *P. solenopsis* population followed by triazophos 40 % emulsifiable concentrate (EC) (98.99 %), dimethoate 30 % EC (97.43 %), ethyl parathion 50 % EC (97.09 %), quinalphos 25 % EC (96.26 %) and acephate 75 % soluble powder (SP) (96.26 %). Nitrosoguanidines, such as thiodicarb (95.05 %), acetamiprid (86.06 %), thiomethoxam (78.21 %) and imidacloprid (74.00 %), also gave better control of mealybugs. Neem oil 0.03 % EC (77.13 %) and a herbal product (Cal-MB) (72.00 %) comparatively performed well, whereas *Verticillium lecanii* (61.20 %), *Beauveria bassiana* (55.02 %) and the insect growth regulator (IGR) Buprofezin 25 % suspension concentrate (SC) (64.32 %) showed moderate mortality. Synthetic pyrethroid cypermethrin 10 % EC (60.00 %) showed moderate mortality, whereas fenevelerate 20 % EC (35.00 %) and deltamethrin 2.8 % EC (29.82 %) were least effective (Nagrare et al. 2011). Kumar et al. (2009a) also stated that profenophos at 1,250 ml, monocrotophos at 1,250 ml, chloropyriphos at 3,000 ml, quinalphos at 2,000 ml, acephate at 2,000 g, thiodicarb at 624 g and carbaryl WP at 2,500 g/ha were found effective as spot sprays against *Ph. solenopsis.* The insecticides acephate and chlorpyriphos proved effective in reducing the population of *Ph. solenopsis* by 72.34 and 68.60 % respectively after three spray applications (Kumar et al. 2012). Surulivelu et al. (2010) reported that imidacloprid, acetamiprid, thiomethoxam, dimethoate, trizaophos, fipronil and acephate applied at 37, 51, 65 and 98 days after sowing had effectively controlled *Pa. marginatus* population in south India. Most of the effective organophosphates are extremely to moderately toxic according to World Health Organization (WHO) classification and are detrimental to several important natural enemies. Biorationals, such as neem oil, *Verticillium lecanii*, *Beauveria bassiana*, buprofezin and slightly-to-moderately hazardous insecticides (according to WHO classification), such as acephate and buprofezin, can be a part of mealybug management strategy in light of ecological safety.

26.6.2 Biological Control

26.6.2.1 *Phenacoccus solenopsis*

The parasitoid *A. bambawalei* is able to keep *Ph. solenopsis* under check in India, Pakistan and China. Its natural parasitization on *Ph. solenopsis* could reach more than 90 % at many locations, and this is the most successful example of fortuitous biological control of *Ph. solenopsis* in India (Gautam et al. 2009; Tanwar et al. 2011). It has played a very significant role in keeping mealybug population under control. Natural parasitization of more than 90 % at many locations in India plays a key role in reducing the mealybug infestation in north and central India (Tanwar et al. 2011; Pinjarkar et al. 2009). During 2008 in Haryana state, due to the activity of *A. bambawalei*, the mealybug population was reduced significantly, and its parasitism went up to 64 % (Ram Pala and Saini 2010; Kumar et al. 2009b; Ram et al. 2009). The extent of mealybug parasitization by *A. bambawalei* in cotton was 25.78–55.87 % in Punjab (Dhawan et al. 2011; Sharma et al. 2010). In cotton fields of Gujarat, *A. bambawalei* was observed on *Ph. solenopsis* with average parasitization 37 % during August–September 2008 (Jhala et al. 2009). In Tamil Nadu, *A. bambawalei* was found causing up to 76 % parasitism on *Ph. solenopsis* (Amutha et al. 2009; Sankar et al. 2011). *A. bambawalei* was the dominant parasitoid on *Ph. solenopsis* in the cotton-growing areas of Karnataka (Hanchinal et al. 2009). In Andhra Pradesh, parasitization by *A. bambawalei* was in the range of 8–26 % (Saroja 2009).

In Pakistan, *A. bambawalei* was found parasitizing *Ph. solenopsis* up to 48 % (Arif et al. 2011a). In Pakistan, the parasitism ranged between 79 and 93 % in pesticides-free cotton fields, whereas the parasitism did not exceed 8 % (Solangi and Mahmood 2011) in pesticide-applied cotton fields. *A. bambawalei* was reported on *Ph. solenopsis* in Guangdong and Hainan Provinces, China (Chen Hua-Yan et al. 2010). In the areas where the parasitoid is absent, culturing and release of *A. bambawalei* is advocated for the suppression of *Ph. solenopsis.*

At Mahatma Phule Krishi Vidyapeeth (MPKV), Rahuri, the treatment with *Metarhizium anisopliae* at 2,000 g/ha was observed to be most effective by recording a minimum of 87.46 mealybugs/5-cm shoot tip length/plant as compared to 322.06 mealybugs/5-cm shoot tip in untreated control. The higher seed cotton yield of 1,521 kg/ha was obtained in a treatment with *M. anisopliae* at 2,000 g/ha as compared to 913 kg/ha in the untreated control (Kharbade et al. 2009).

26.6.2.2 *Paracoccus marginatus*

Acerophagus papayae Noyes and Schauff was found to be highly effective against *P. marginatus* on cotton in south India (Dharajothi et al. 2011).

26.6.2.3 Other Mealybugs

Release of *Cryptolaemus montrouzieri* is recommended for the control of other mealybugs such as *M. hirsutus* and *F. virgata.*

26.7 Sustainable Mealybug Management

Detail packages of practices have been developed by Kranthi et al. (2011) available at http://www.cicr.org.in/PDF/Packageof practicesformanagingmealybugoncotton.pdf. Mealybug crawlers spread through human interventions such as spraying, irrigations and frequent movement through the infested area. Therefore, disturbing mealybug-affected plants should be avoided. It is important to remember that young cotton plants can overcome mealybugs and it is better not to resort to chemical sprays on young plants that have slight infestation of the mealybugs in early vegetative stages of the crop. It has been observed that the mealybugs were unable to establish colonies on the cotton crop during early vegetative and peak vegetative stages. All over the country, several parasitoids, predominantly *A. bambawalei*, and coccinellid predators are now found to keep mealybug populations under control, thereby preventing spread and damage. Insecticides such as profenophos, chlorpyriphos and monocrotophos, which are being commonly used for mealybug control, destroy the parasitoids and predators and can result in mealybug outbreaks. Therefore, insecticide applications should be avoided until peak boll formation stage, so as to allow further establishment of the parasitoid and predator complex in the ecosystem. Eco-friendly insecticides such as neem oil-based botanicals and insect growth regulator buprofezin can be used, if necessary, in the initial stages so as to keep mealybugs under check while causing minimum disturbance to the ecosystem.

However, during peak boll formation stage, mealybugs can establish colonies but are initially restricted to a few plants along the border rows, adjacent to the source of infestation and thus can be effectively managed through early detection and initiation of interventions to control early stages of infestation. If timely scouting and appropriate control measures are not initiated, cotton crop is likely to be severely damaged with mealybugs. The package involves with

- Regular monitoring for incidence of the mealybugs is to be done.
- Removal of the weeds that grow on field bunds, water channels and wastelands.
- Border crops like pigeon pea/sorghum/maize are to be raised around cotton fields and cropping as a strip after five to six rows of cotton may also prevent mealybug infestation and spread.
- Removal of mealybug-infested cotton plants with more than one twig infested and destruction by burning.
- Conservation and release of parasitoids *A. bambawalei* and *A. papayae*, which has a good potential in the control of the *Ph. solenopsis* and *Pa. marginatus*, respectively, in cotton ecosystem.
- The entomopathogenic fungi, *Metarhizium anisopliae, Beauveria bassiana, Verticillium lecanii* and *Fusarium pallidoroseum* are to be tried against *Ph. solenopsis*.
- If more than 20 plants/acre exceed Grade II (at least one stem completely colonized with mealybugs) by mealybug infestation, chemical control measures may be initiated.
- The insect growth regulator buprofezin is effective in control. Insecticides such as acephate can be used as soil application near the root zone.
- Insecticide application should start first on the neighbouring plants and then as spot application near the root zone, base of the plant and other infested parts.
- Avoidance of application of hazardous insecticides such as methyl parathion (classified by the WHO as Class 1a: extremely hazardous), monocrotophos, dichlorvos, methomyl, triazophos and methyl demeton (Class 1b: highly hazardous).

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27 Jute and Allied Fibre Crops

M. Mani and S. Satpathy

27.1 Mealybug Species

Mealybugs are injurious to fibre crops such as jute (*Corchorus capsularis and Corchorus olitorius*), mesta (*Hibiscus sabdariffa and Hibiscus cannabinus*), roselle (*Hibiscus sabdariffa* var. *altissima*), sorrel (*Hibiscus sabdariffa*) and kapok/silk cotton (*Ceiba pentandra*).

In India, the mealybug species *Ferrsia virgata* (Cockerell), *Nipaecoccus viridis* (Newstead), *Pseuducoccus filamentous* (Cockerell) and *Phenacoccus solenopsis* (Tinsley) are known to attack jute. *Maconellicoccus hirsutus* (Green) and *Ph. solenopsis* are also reported on mesta (Kundu et al. 1959; Ghose 1961; Tripathy and Ram 1971; David and Ananthakrishnan 2004; Satpathy et al. 2009). *Maconellicoccus hirsutus* was reported on *H. cannabinus* and *H. sabdariffa* in Egypt (Hall 1921). *Paracoccus marginatus* has been reported on silk cotton in south India (Tanwar et al. 2010). In the Caribbean islands, sorrel (*Hibiscus sabdariffa*) have been reported to be damaged by mealybugs (Pollard 1995). Mealybug infestation was also observed on jute in Dacca. In Bangladesh, *F. virgata* is known as a pest of jute (*Corchorus olitorius*), causing the formation of barky fibre. *Nipaecoccus viridis* is also known to infest *Corchorus capsularis* (white jute) (http://www.plantwise.org/KnowledgeBank/Datasheet.aspx?dsid=36335.). Kapok (*Ceiba pentandra*) is a large deciduous tree, best known for the fibre produced by its fruit (Table 27.1).

Rastrococcus iceryoides is a serious pest of Kapok trees, in Tanganyika. No reports followed a record of introduction of *C. montrouzieri* in Tanganyika (Ritchie 1935). *Planococcus lilacinus* (Cockerell), *Paraccocus marginatus* Williams and Granara de Willink *Maconellicoccus hirsutus, Rastrococcus iceryoides* and *Planococcoides njalensis* (Laing) are also known to infest attack Kapok trees**.** *Rastrococcus invadens* was also recorded on *Ficus* sp. in Sri Lanka (Galanihe and Watson 2012).

27.2 Damage

The mealybug infestation in India went up to 80 % in case of jute with average intensity of 2–3 in 0–4 scale. The plant infestation in mesta was 60 % with average intensity of 4 in the 0–4 scale.

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Mealybugs on roselle plant

P. marginatus on Silk cotton

Table 27.1 List of mealybugs recorded on Kapok in different countries

Mealybug Species	Country	Reference
Deltococcus tafaensis (Strickland)	Ghana	Ben-Dov (1994)
Maconellicoccus hirsutus (Green)	Thailand	Williams (2004)
Planococcus citri (Risso)	–	Ben-Dov (1994)
Planococcus indicus (Avasthy & Shafee)	India, China	Ben-Dov (1994)
Planococcoides nijalensis (Laing)	–	Ben-Dov (1994)
Parcoccua marginatus Williams and Granara de Willink	India	Mani et al (2012)
Planococcus lilacinus (Cockrell)	Indonesia	Williams (2004)
Rasrococcus iceryoides (Green)	Thailand	Williams (2004)

In *M. hirsutus*-infested roselle (*Hibiscus sabdariffa* var. *altissima*) plants, the number of pods averaged 13.43/plant, the number of seeds 10.57/pod and the percentage germination of the seed 78.61, as compared with 24.40 pods/plant, 27.83 seeds/pod and 87.63 % germination in uninfested plants (Ghose 1971). *Maconellicoccus hirsutus* is emerging to be a major pest of mesta, particularly in the peninsular India. It causes bunchy top which is a serious malady of mesta crop. The fibre crops *Hibiscus sabdariffa* var. *altissima* (roselle), *H. Cannabinus* and *Boehemeria nivea* have been reported to be the major hosts of mealybugs in West Bengal, India, and Bangladesh (Ghose 1972a; Singh and Ghosh 1970). The reduction in fibre yield of roselle is to the extent of 21.4 % (Ghose 1971) to 40 % (Raju et al. 1988). The salivary toxin injected during feeding causes characteristics distortion of leaves, shortening if internodes and bushy top symptom (Singh and Ghosh 1970; Ghose 1972b; Williams 1996). Infestation by mealybug, *M. hirsutus*, reduces the linear growth of the stem and petiole and markedly reduces the size, distort the mesta leaves, causing 'bunchy top' symptoms (Dutta et al. 1951), causing 15–20 % reduction in fibre yield (Das and Singh 1986). Its infestation causes damage to both fibre and seed crop. *Ferrisia virgata* has also been reported to induce stiffness of the ramie plants which makes the extraction of fibres by machine very difficult. In Bangladesh, it caused 65–70 % infestation of mesta plants (Jalil and Kabir 1971). There was an outbreak of *Ph. solenopsis* in jute and mesta in West Bengal. The plant infestation in jute (cv. JRO524) was 60–80 % with an average intensity of 2–3 in 0–4 scale, while it was 60 % and 40 %, respectively, in the case of mesta (cv Local). Analysis of weather factors indicated that the warm and dry weather condition during summer might be the predisposing factor for the mealy outbreak in jute and mesta (Satpathy et al. 2009).

27.3 Natural Enemies

The coccinellid predators *Brumoides suturalis* (F.) and *Scymnus nubilus* (Muls.) and the encyrtid parasite *Anagyrus* sp. are the important natural enemies on *M. hirsutus*. Six species of ants were found attending *M. hirsutus* in West Bengal, India (Ghose 1970a). In Andhra Pradesh, India, *Spalgis epeus* (Westwood), *Hyperaspis maindroni* Sicard, *Autoba silicula* Swinhoe and *Brinckochrysa scelestes* Banks were found preying on eggs and nymphs of *M. hirsutus*, an important pest of kenaf (mesta) (Rao et al. 1984).

27.4 Management

Sprays of methyl demeton at 0.2 % were found highly effective in controlling populations of *M. hirsutus* on roselle *Hibiscus sabdariffa* (Ghose 1970b). The chemicals have limited effectiveness against *M. hirsutus* because of its habit of feeding in inaccessible parts and waxy covering of the body (Williams 1996). Any pesticide used against *M. hirsutus* should be carefully selected to avoid injury to its natural enemies, since they are likely to be important in helping to keep populations at low levels in the long term. The farmers used wide array of insecticides without any appreciable result against *Ph. solenopsis*. On the other hand, insecticide spray suppressed the natural enemy activity, resulting in build-up of the mealybug population (Satpathy et al. 2009). *Cryptolaemus montrouzieri* is a very good candidate for the biological control of *M. hirsutus* and *F. virgata*, and this predator can be utilised for the suppression of mealybugs. *Acerophagus papayae* can be utilised for the control of *P. marginatus* and so also *Aenasius bombavale* for *Ph. solenopsis* in fibre crops.

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28 Sugarcane

R. Jayanthi, J. Srikanth, and S.N. Sushil

28.1 Mealybug Species

Mealybugs are widespread throughout the sugarcane-growing tracts of the world but all of them seldom attained major pest status (Tohamy et al. 2008). According to Williams (1970), 30 species of mealybugs are known to attack sugarcane in different regions of the world (Table 28.1). Nine species of mealybugs are known to occur in India. A detailed compendium on the Indian species of sugarcane mealybugs with respect to their biology, factors influencing their buildup, crop damage, and management aspects has been documented by Jayanthi (1986). The pink mealybug *Saccharicoccus sacchari* (Fig. 28.1a) is the most ubiquitous species in India. Outside India, *S. sacchari* on sugarcane was reported from Alexandria and Egypt (Hafez and Salama 1969; Mesbah et al. 1976). It may be native to Eastern Africa but was also reported to occur in Formosa, Malaysia, Philippines, Java, Hawaii, Samoa, Australia, Syria, Egypt, Madeira, Argentina, Peru, British Guiana, Mexico, Caribbean Islands, Mauritius, South Africa and East Africa (Clausen 1978). *Kiritshenkella sacchari* was reported for the first time in Cuba along with observations on three other species, including *S. sacchari* (Williams et al. 2001). *Kiritshenkella sacchari* (Fig. 28.1b–c) and *Antonina graminis* are also commonly encountered in Tamil Nadu, India. The incidence pattern of these three species revealed that *K. sacchari* has the potential to emerge as an important pest, especially under drought conditions. While *Dysmicoccus carens* (Fig. 28.1d–e) was observed infesting the foliage of sugarcane hybrids, *Pseudococcus* sp. was observed on sugarcane rootlets (Jayanthi et al. 1995). *Pseudococcus saccharicola* was reported from south Andaman on sugarcane leaves (Veenakumari and Mohanraj 1995). *Dysmicoccus carens* was recorded in Andhra Pradesh by Rao et al. (2008).

28.2 Damage

Nymphs and adults suck the sap from leaves, nodes, and internodes of canes. Severe infestation results in yellowing of leaves, stunting of canes and poor germination in the case of *S. sacchari* attack.

Loss of sap may kill the young shoots in the case of *Ps. saccharicola* or may result in a marked setback in cane growth, ultimately leading to total drying of the crop as evident in instances of *Ph. saccharifolii* infestation. The stalks on which the mealybug colonies have fed and perished can

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Table 28.1 List of mealybugs recorded on sugarcane in different regions of the world

Mealybug species	Region/Country	Reference
Antonina graminis (Maskell)	–	Williams (1970)
	Hawaii	Pemberton (1938)
	India	Ahmad (1942)
	Sri Lanka	Kumarasinghe (2003)
	Texas	Riherd (1950)
Cannococcus ikshu Williams and Watson	Papua New Guinea	Ben-Dov (1994)
Chorizococcus rostellum (Lobdell)	–	Williams (1970)
Chorizococcus talipikanus Williams and Watson	Papua New Guinea	Ben-Dov (1994)
Dysmicoccus boninsis (Kuwana)	Indonesia and Sri Lanka	Williams (2004)
Dysmicoccus brevipes (Cockerell)	India	Williams (2004)
Dysmicoccus carens sp.n.	India	Williams (1970)
Dysmicoccus cryptus (Hempel)	–	Williams (1970)
Dysmicoccus trispinosus (Hall)	–	Williams (1970)
Eumyrmococcus smithii Silvestri	China and Japan	Williams (2004)
Exallomochlus hispidus (Morrison)	Indonesia, Java and Malaysia	Williams (2004)
Formicococcus lingnani (Ferris)	Indonesia	Williams (2004)
Ferrisia virgata (Cockerell)	–	Williams (1970)
Heliococcus summervillei Brookes	Australia and Pakistan	Ben-Dov (1994)
Kiritshenkella sacchari (Green) [= *Ripersia sacchari* (Green)]	Cuba	Williams et al. (2001)
	India	Ayyar (1919)
	Pakistan	Ali (1995)
	Bangladesh, Burma, India, and Pakistan	Williams (2004)
Maconellicoccus hirsutus (Green)	–	Williams (1970)
Madagasia cincinnata sp.n.	–	Williams (1970)
Mizococcus sacchari Takahashi	–	Williams (1970)
	Taiwan	Williams (2004)
Neoripersia ogasawarensis (Kuwana)	Ogasawara Islands	Ben-Dov (1994)
Paracoccus eastopi Williams	Nigeria	Williams (1970); Williams (2004)
Paracoccus spinulosus (De Lotto)	–	Williams (1970)
	Uganda	Ben-Dov (1994)
Phenacoccus hargreavesi (Laing)	–	Williams (1970)
	Ethiopia	Ben-Dov (1994)
Phenacoccus parvus Morrison	Ethiopian, Neotropical, and Pacific region	Ben-Dov (1994)
Phenacoccus saccharifolii (Green)	–	Williams (1970)
	India	Green (1908), Isaac and Misra (1933)
	India, Nepal, and Pakistan	Williams (2004)
Planococcus citri (Risso)	–	Williams (1970)
Planococcoides lindingeri (Bodenheimer)	Egypt and Israel	Ben-Dov (1994)
Planococcoides lingnani (Ferris)	China	Ben-Dov (1994)
Planococcus minor (Maskell)	Trinidad	Francis et al. (2012)

(continued)

Table 28.1 (continued)

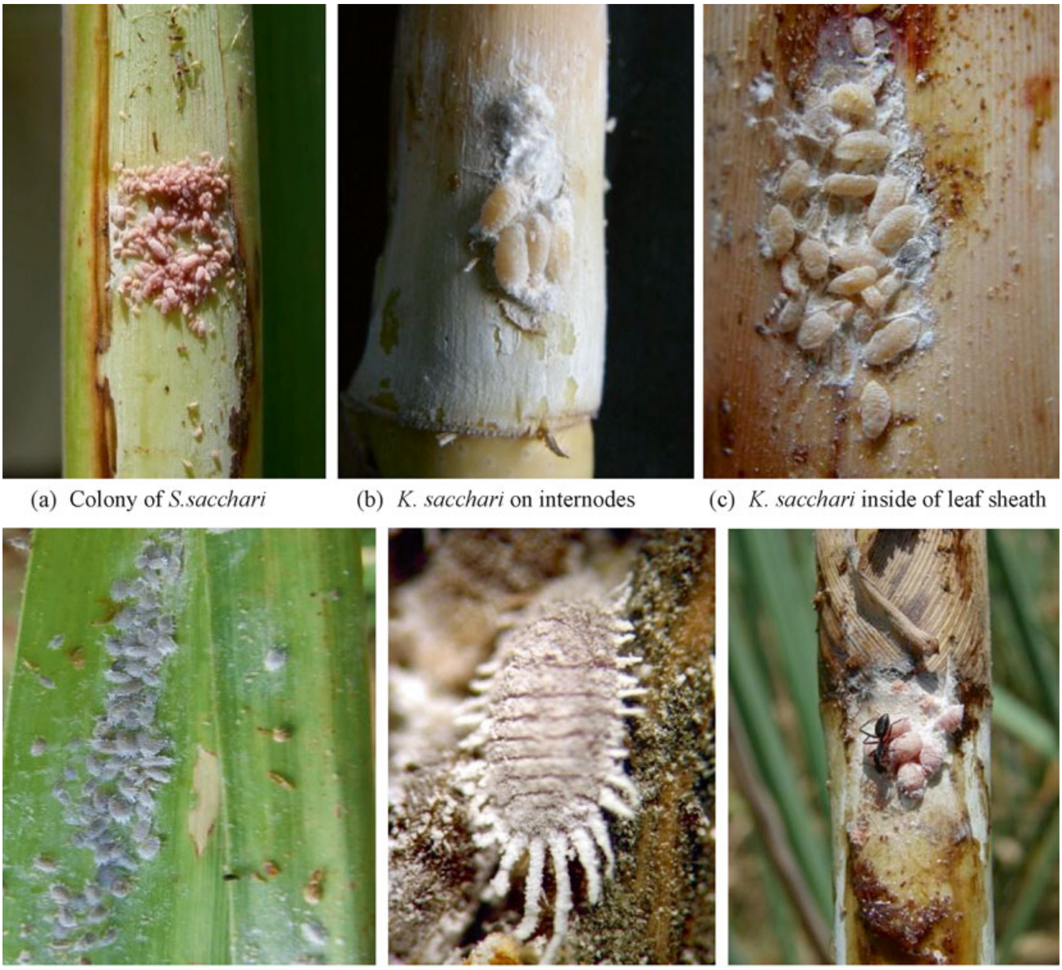
Mealybug species	Region/Country	Reference
Planococcus variabilis (Hall)	–	Williams (1970)
Pseudococcus longispinus (Targioni Tozzetti)	–	Williams (1970)
Pseudococcus saccharicola Takahashi	Australian and Oriental region	Ben-Dov (1994)
	British Virgin Islands	Wheeler et al. (2010)
	India	Ahmad (1942) Pruthi and Rao (1942)
	Bangladesh	Williams (2004)
Rhizoecus albus James	–	Williams (1970)
Rhizoecus epicopus (Williams)	Barbados	Ben-Dov (1994), Williams (1970)
Saccharicoccus sacchari (Cockerell)	Australia	Mungomery (1932)
	Barbados	Bovell (1921)
	British Guiana	Bodkin (1913)
	Costa Rica	Anonymous (1912)
	Cuba	Hutson (1918)
	Egypt	Hall (1922)
	India	Isaac and Misra (1933)
	Jamaica	Gowdey (1926)
	Madagascar	Frappa (1935)
	Mexico	Van Zwaluwenburg (1926)
	Porto Rico	Van Dine (1913)
	Samoa	Swezey (1924)
	South Africa	Dick (1953)
	Uganda	Hancock (1926)
	–	Williams (1970)
	India, Indonesia, Pakistan, Sri Lanka, and Malaysia	Williams (2004)
Trionymus ceres Williams	India and Pakistan	Williams (1970), Williams (2004)
Trionymus internodii (Hall)	Egypt and Israel	Williams (1970)
Trionymus pygmaeus De Lotto	Asia	Williams (1970)
Trionymus radicicola (Morrison)	Columbia and Jamaica	Ben-Dov (1994), Williams (1970)

be recognized by residues of wax, honeydew, and sooty mold that persist for months (Jayanthi 1986.

Severe infestation of *S. saccchari* in canes reduced sucrose content by 24.1 % and brix by 16.2 % (Kalra and Sidhu 1964). Varietal reaction in terms of infestation levels and yield and quality parameters due to *S. sacchari* infestation have been elucidated by Jayanthi (1991). In Uttar Pradesh, India, *S. sacchari* infestation reduced sugar brix, sucrose, purity, and available sugar content by 10.64, 16.44, 6.14, and 12.92 %, respectively but did not affect the volume of cane juice significantly in cv. Co 1148 (Atiqui and Murad 1992).

28.3 Factors Influencing Buildup

Agroclimatic conditions and crop management factors are known to have impact on the mealybug abundance, both positively and negatively. While dry conditions generally favor mealybugs, rainfall exerts a negative influence, apparently by dislodging colonies in detrashed crop and promoting the growth of entomopathogenic fungi.



(a) Colony of *S.sacchari* (b) *K. sacchari* on internodes (c) *K. sacchari* inside of leaf sheath

(d) *Dysmicoccus carens* (e) *D. carens* (f) *S . sacchari* with ant

Fig. 28.1 Mealybugs of sugarcane

However, *Ph. saccharifolii* was observed to multiply rapidly with the onset of monsoon (Mohammad Ali 1962). In general, conditions that are least favorable for the vegetative growth of the sugarcane plant appear to be most favorable for the increase of *S. sacchari*. Reduction in *S. sacchari* populations was observed with enhanced levels of irrigation in drip-irrigated plots (Parsana et al. 1994). Ratoons were not susceptible as a general rule; on the other hand, the plant crop of some commercial hybrids was more susceptible than the ratoon counterparts (Jayanthi 1991). *Saccharicoccus sacchari* outbreak occurred in years of moderate temperature during March–April, and temperature had a positive correlation with incidence in Andhra Pradesh, India. Water stress conditions, small dry spells, neglected ratoons and repeated ratooning enhanced infestation (Rao et al. 2009). Mealybug abundance is also known to be influenced by plant factors such as the nature of leaf sheath. Varieties with loose clasping leaf sheath harbor higher levels of mealybug populations than those with tight clasping leaf sheath. Self-stripping varieties are less prone to mealybug infestation. According to Jayanthi (1991) and Jayanthi et al. (1994), stem hardness was not found to influence colonization by *S. sacchari*; some biochemical parameters were related to infestation by *S. sacchari*. Ants, generally found associated with mealybugs, have been shown to interfere with predator activity (Srikanth et al. 2001), thereby possibly enhancing the mealybug density.

28.4 Varietal Susceptibility

No truly resistant varieties are available because mealybugs are capable of infesting any sugarcane genotype. However, higher levels of infestation are often observed in genotypes with loose clasping leaf sheath. The commercial varieties CoC 671 and CoA 7601 with tight clasping leaf sheath always registered low incidence of *S. sacchari* (Sithanantham 1973; Mehta et al. 1981). The genotypes Co 740, Co 6806, Co 8014, CoC 671, and CoA 7601 showed tolerance to *S. sacchari* (Anonymous 1992). In Assam, the varieties CoBLN 9101, 9102, 9103, Co 6806, C0Jor-1, C0Jor-2 and Co 740 were relatively resistant to *S. sacchari* (Borah and Dutta 1995). Although none of the 24 sugarcane varieties screened were free from nymphs of *S. sacchari*, lowest densities of nymphs/internode were found on CoN 84136 and CcN 84134, while the highest were on Co 87004 (Parsana et al. 1995). Similarly, none of the 17 genotypes evaluated against borers and sucking pests in Maharashtra, India, were found to be resistant to *S. sacchari* (Hole et al. 2009). The sugarcane cultivars Q 63 and Co 6501, categorized as being lightly infested by *S. sacchari* and scale, showed higher quantities of phenols at harvest compared to the other heavily infested cultivars, namely Co 671, Co 6806, Co 740, and G 229 (Jayanthi and Goud 2001). Differential biological parameters of *D. carens* observed on the sugarcane genotypes Co 740, Co 7704, C 6806, CoC 671, and Co 6907 under laboratory conditions indicated differential susceptibility of the genotypes to the mealybug (Razak et al. 1994). Nine promising clones and a commercial cultivar were considered susceptible to *S. sacchari* in Bangladesh. Lower infestation levels in clones I 155-91 and I 209-91 indicated that these might be chosen as promising material to develop commercial cultivars (Taleb and Rahman 2004). Mealybug-tolerant clones were identified in a series of other screening studies with clones and standard varieties at different locations (Abdullah 2009; Abdullah et al. 2006a, b, 2010). In studies with 43 germplasms against *S. sacchari* in Egypt, C 46-117, Co 237, Co 290, Co 997, CP 31-294, CP 34-38 and CP 52-43 were classified as resistant (Solouma 2002). The varieties Giza 96/74 and Ph 8013 were less susceptible to *S. sacchari* based on percent infested internodes and number of mealybugs per stalk (Tohamy et al. 2008).

28.5 Natural Enemies

About 16 parasitoids, 13 predators and the entomopathogenic fungus *Aspergillus parasiticus* were recorded in different parts of India (Jayanthi 1986). The encyrtid *Anagyrus punctulatus* Agarwal was found to be the most important parasitoid in regulating the pest population in Gujarat; the parasitoid showed positive results in augmentative studies (Kapadia et al. 1995). The activity of the parasitoid was noticed to be highest in July and lowest during November–December (Parsana et al. 1996). In Maharashtra, *Chilocorus nigrita* (F.) was found attacking *S. sacchari* (Dorge et al. 1972). In Uttar Pradesh, six parasitoids and four predators, including *Batrachedra* sp. near *psilopa* Meyrick (Lepidoptera: Momphidae), were reported on *S. sacchari* (Nigam 1983; Singh et al. 1997). The cecidomyiid predator *Dicrodiplosis* sp. was also recorded on *S. sacchari* in Andhra Pradesh (Reddy and Aziz 2000). The natural enemies of *S. sacchari* found in the neighboring Sri Lanka were listed by Rajendra (1974). Of these, the predatory drosophilid *Gitonides* (*Gitona*) *perspicax* Knab, larvae of the nitidulid *Carpophilus marginellus* Motsch. and five encyrtid parasitoids of a genus near to *Microterys* were important in controlling mealybug populations in the field. The rat *Millardia meltada meltada* gnawed through the lower dry leaf sheaths and devoured the mealybugs at the nodes (Rajendra 1974).

28.6 Management

Mealybugs assume pest status sporadically, apparently under localized favorable conditions, some of which are elucidated above. Unlike other sucking pests such as woolly aphid, scale or pyrilla, outbreaks of mealybugs have rarely been encountered in proportions that warranted systematic and organized control measures. However, control methods have been evaluated under specific situations which when practiced as a package (Srikanth et al. 2012) would be useful in containing them.

28.6.1 Cultural Control

Routine adoption of certain cultural practices such as avoidance of overdoses of nitrogenous fertilizers, planting of uninfested setts, clean cultivation, removal of known alternative hosts near sugarcane fields and detrashing in severely infested grown-up crop ensures reduction in mealybug proliferation and perpetuation (David et al. 1986). In Egypt, increasing the row spacing had resulted in a decrease in the population of *S. sacchari*. Ratoon crops harbored greater levels of mealybug infestation. Burning of dry leaves left in the field integrated with flood irrigation after harvesting sugarcane significantly reduced percent infested internodes and number of mealybugs per plant (Tohamy et al. 2008).

28.6.2 Chemical Control

Application of 0.05–0.1 % ethyl parathion (Kalra and Sidhu 1964), malathion (Singh and Avasthy 1973) and phosphamidon at 3 kg a.i./ha (Shah et al. 1977) after detrashing of leaves has been reported effective in the suppression of the mealybugs. Subsequently, monocrotophos, dichlorvos, demeton-S-methyl, malathion and quinalphos were 1.09, 1.09, 1.89, 2.39 and 3.05 times, respectively, as toxic as endosulfan based on LC_{50} values (Duhra and Singh 1986); carbofuran 3G at 1 kg a.i./ha was found to minimize the incidence of *S. sacchari* (Pandya 1997); fenvalerate 0.4 % and malathion 10 % as dust formulation significantly reduced *S. sacchari* populations (Deka et al. 1999); spraying of phosphamidon (0.05 %) or dimethoate (0.05 %) during the seventh and eighth months of crop growth was effective against *S. sacchari* (Thirumurugan et al. 2002). High mortality of *S. sacchari* was observed when infested plants were treated with acephate (95.00 %) and acetamiprid (96.66 %) (Tewari and Yadav 2005). The plant product PLEXIN, a mixture of plant oils and tobacco decoction, at 1 % concentration was superior to other lower concentrations in controlling the sucking pests of sugarcane, including mealybugs (Chelvi and Kandasamy 2010). In Sri Lanka, dipping cane setts in 0.1 % gamma benzene hexachloride (BHC) before planting failed to control *S. sacchari* (Rajendra 1974). Among six insecticides, methomyl 90 % soluble powder (SP) was effective in reducing the joints per stalk infested by *S. sacchari* in Egypt (Ebieda et al. 1998). Malathion applied 30 days after the release of *Trichogramma evanescens* (Westwood) effectively controlled both *Chilo agamemnon* and *S. sacchari* and reduced the incidence of infested joints and dead tops (Khewa et al. 2006).

28.6.3 Biological Control

Two releases of the predator *Chrysopa scelestis* Banks at 10,000 eggs/ha at a 15-day interval resulted in the highest predation rates of *S. sacchari* (Chelvi and Kandasamy 2009).

Augmentation and/or introduction of natural enemies, particularly the predatory coccinellid *Cryptolaemus montrouzieri* Mulsant, were resorted to in several countries for the control of *S. sacchari* with positive and negative results. It was the principal natural enemy of *S. sacchari* in Costa Rica but did not survive the cold winter (Anonymous 1912); it played an active role in keeping down the mealybug population in the Malay States (Malaysia) (Muir and Swezey 1917). However, attempts to control *S. sacchari* in Egypt in 1922–1924 through its releases were not successful (Hall 1927). Imported from Egypt in 1933, the predator was ineffective in

Somalia (East Africa) as it failed to penetrate under leaf sheaths where the mealybugs congregate (Chairamonte 1933). In Hawaii, some control of *S. sacchari* was achieved with its introduction in 1893 (Pemberton 1948, 1964). When *C. montrouzieri* was introduced with two other predatory coccinellids, namely *Hyperaspis* sp. and *Nephus* sp., from India in 1968–1969, and the encyrtid *Anagyrus saccharicola* Timberlake (Hymenoptera: Encyrtidae) was introduced from East Africa in 1970 against *S. sacchari* in Barbados, only the parasitoid had been recovered. Rapid spread, aided by additional releases, led to 8.3–9.7 % parasitism in differential rainfall areas by 1972 (Alam 1972). Interference by the attendant ant *Camponotus compressus* F. (Fig. 28.6f) through physical removal of stages of *C. montrouzieri* (Srikanth et al. 2001) could be one of the reasons for the predator's limited success. *Anagyrus saccharicola* Timberlake releases against *S. sacchari* in five governorates of upper Egypt during 1999–2000 led to the parasitoid's rapid establishment and spread with considerable increase in the rates of parasitism (Abd-Rabou 2002; Tohamy et al. 2008).

The imported *C. montrouzieri* and *Aphycus terryi* Full. were undoubtedly responsible for a large measure of control of gray sugarcane mealybug *Dysmicoccus boninensis* in Hawaii (Williams 1931). When introduced into Guam from Hawaii in 1926, the predator was occasionally found to feed on *D. boninensis* (Swezey 1940). In British Guiana, the predator was introduced for trials against the mealybug misidentified as *Pseudococcus calceolariae* (Bodkin 1913). The preceding examples illustrate the necessity and usefulness of identification and introduction of candidate biological control agents not only across nations or continents but also within the country for effective control of mealybugs.

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29 Fruit Crops: Apple

M. Mani

29.1 Species

Mealybugs have been reported to cause damage to apples in New Zealand, South Africa, Japan, New York, Florida, and California (Table 29.1).

29.2 Seasonal History

The apple mealybug *Phenacoccus aceris* Sig. overwinters as a second-instar nymph in a cocoon under scales or in cracks of the bark. Feeding is done by inserting the proboscis into plant tissues (bark or leaves) and sucking the plant sap. They emerge from overwintering sites very early in the spring, feed on twigs, mature to the adult stage (male and female), and mate. They begin to lay eggs in early May in central Washington. Only one generation was observed in a year.

29.3 Damage

Mealybugs take shelter in leaf axils, under bark, and in the calyx of the fruit. Sucking sap will to some extent devitalize the tree. In addition, the apple mealybug can directly infest and feed on fruit, possibly becoming a direct pest or a quarantine concern. Besides, the pest excretes a honeydew substance, which can then be a suitable source for sooty mold to develop. It is this sooty mold that can result in rejection or downgrading of the fruit. It is also known to transmit little cherry disease (Raine et al. 1986; Eastwell and Bernardy 2001). The presence of *Phenacoccus graminicola* Leonardi under the calyxes of apple and pears grown for export has caused concern in Australia and New Zealand (Ward 1966).

29.4 Natural Enemies

The parasitoid *Pseudaphycus flavidulus* (Brèthes) from Argentina and Chile has been collected in apple orchard infested with *Ps. viburni*. Other natural enemies observed are *Pseudaphycus maculipennis* (Mercet), *Anagyrus pseudococci* (Girault), *A. novickyi* Hoffer, *A. punctulatus* Agarwal and Alam [*A. diversicornis* (Howard)], *Leptomastix epona* (Walker), *Chartocerus* sp., and *Pachyneuron* sp. (Kreiter et al. 2005).

The obscure mealybug *Pseudococcus viburni*, a polyphagous cosmopolitan pest, probably got introduced to New Zealand through commercial trade. Natural enemies included *Ophelosia bifasciata* Girault and *O. charlesi* Berry (Hymenoptera: Pteromalidae) and the predatory larvae of *Cryptoscenea australiensis* (Enderlein) (Neuroptera: Coniopterygidae) (Charles et al. 2004).

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Table 29.1 List of mealybug species infecting apple in different regions of the world

Mealybug species	Region/Country	Reference
Pseudococcus maritimus (Ehrhorn)	New Zealand	McKenzie (1972)
Pseudococcus fragilis Brain, *Pseudococcus obscurus* Essig.	South Africa	Myburgh et al. (1975), Swart (1977)
Pseudococcus viburni (Signoret)	South Africa	Stokwe and Malan (2010)
	France	Kreiter et al. (2005)
	New Zealand	Charles et al. (2004)
Pseudococcus longispinus (Targioni Tozzetti)	South Africa	Stokwe and Malan (2010)
	Japan	Morimoto (1976)
Pseudococcus calceolariae (Maskell)	South Africa	Stokwe and Malan (2010)
	Japan	Morimoto (1976)
Pseudococcus comstocki (Kuwana)	Japan	Morimoto (1976)
	New York and California	–
Planococcus citri (Risso)	Florida	–
Phenacoccus aceris Sig.	Nova Scotia	Gilliatt (1935/1936)
	British Columbia	Madsen and Proctor (1982), Marshall and Pickett (1944); Marshall (1953), Kozar et al. (1989)
Dysmicoccus debregeasiae (Green)	Bangladesh	Williams (2004)
Maconellicoccus hirsutus (Green)	–	Ben-Dov (1994)
Phenacoccus mespili (Signoret)	France and Russia	Ben-Dov (1994)
Phenacoccus graminicola Leonardi	Australia and New Zealand	Ben-Dov (1994)

Mealybugs on the calyx of the fruit

Sooty mold on apple

Anagyrus pseudococci

Leptomastix epona

29.5 Monitoring

There are no formal schemes for monitoring the apple mealybugs. When they are abundant, the egg sacs are quite apparent and will give an indication if control is required later. In some cases, only a few areas in an orchard may have sufficiently heavy populations to merit control.

29.6 Management

29.6.1 Chemical Control

Mealybugs appear to emerge in the spring and move onto young developing shoots to feed. As the fruit develops and the leaves toughen up (if not controlled), they can move into the calyx of the fruit and then into the heart of the apple. They need to be controlled before they are able to move into the calyx of the fruit. Aminocarb (Matacil 75 % wettable powder (WP)) at 1.5 lb/100 gal was best, followed by phosmet (Imidan) at 1 lb against *Ps. maritimus* in New Zealand. Nine applications of each insecticide tested were made between petal fall and harvest (McKenzie 1972). In S. Africa, although the mealybugs were present in many orchards, they were well controlled in most of the cases, and serious infestations were associated with inefficient or infrequent spraying. Mealybugs *Ps. fragilis* and *Ps. viburni* appeared to be under good control through intensive spray regimes (Myburgh et al. 1975). A description is provided for ten recommended insecticides on their formulations, concentrations, dosages, times of application, and withholding periods (Swart 1977).

If mealybug is a cause for concern, then monitoring can be a valuable tool. Monitoring can assist managers to make decisions on the timing of sprays when thresholds are exceeded. If insecticides are required, they are best applied early in the season when the mealybug crawlers and nymphs emerge. Clothianidin is one of the few registered products for control of mealybugs in apples. Dormant, petal-fall, summer, and postharvest sprays for *Ph. aceris* are recommended in British Columbia. Dormant or delayed dormant sprays should reduce the population if they have emerged from their overwintering sites. The period of crawler emergence in early to mid-June is likely another vulnerable point in the life cycle. Conventional insecticides and insect growth regulators used against the grape mealybug *Ps. maritimus* are likely effective. In organic orchards, the neem insecticides, timed for crawler emergence, appear to provide some control. Spray practices (e.g., high gallonage) that cover the undersides of the leaves and crevices in the bark will likely be more effective. Once they begin feeding, mealybugs are not very mobile, and they will not move around to contact a sparsely applied spray. Avoiding pesticides that destroy parasitoids should also help keep this species at a low level.

29.6.2 Biological Control

29.6.2.1 *Phenacoccus aceris*

Parasitoids are likely the most effective biocontrol agents of the apple mealybug *P. aceris*. The best-known parasitoid is *Allotropus utilis* Muesbeck, a platygastrid wasp discovered and named in 1939 in Nova Scotia (Gilliatt 1939; Muesbeck 1939). This species was exported to British Columbia where it became well established. This was considered one of the outstanding successes of classical biological control. In Washington, the parasitic wasp *Anagyrus* sp. was found attacking a heavy infestation of apple mealybug in an organic orchard. A high percentage of the overwintering generation was parasitized. In S. Africa, *Pseudaphycus malinus* Gah., a good host-searching parasitoid, was released by pinning sheets of paper bearing parasitized mummified mealybugs produced in the laboratory to the fruit trees; about 2000 adult parasites emerged per sheet, and three sheets were usually required for each moderately infested apple tree and two sheets per pear tree. The best time for application of the sheets proved to be during the second- and third-nymphal instars of the pest in the spring; this method was found to control even heavy infestations in orchards when used for two successive seasons, and chemical applications could be reduced gradually from the third season onwards. Since *Pseudaphycus malinus* is highly susceptible to chemical insecticides, these should not be applied within 10 days before or 15 days after releasing the parasitoid (Morimoto 1976).

29.6.2.2 *Pseudococcus viburni*

Five primary hymenopteran parasitoid species were reared from *P. viburni*-infesting apples. *Pseudectroma* sp. was the predominant parasitoid species recovered, accounting for 84.3 % of the total number of primary parasitoids reared. No predators were recovered from the infested apple fruit in S. Africa. In Western Cape Province, South Africa, an isolate of *Heterorhabditis zealandica* Poinar was found to cause mortality of *P. viburni* up to 80 % after 48 h. The life cycle of *H. zealandica* was completed in a period of 8–10 days, during which relatively few nematodes penetrated the mealybugs. This can be attributed to the relatively small size of the adult female mealybug (6×3 mm) in comparison with that of the nematode (0.7×0.03 mm). Once penetrated inside the mealybug, the nematode can grow within a few days to the same length as, and even longer than, the mealybug. All stages of *P. viburni* beyond crawlers appeared to be susceptible to nematode infection. Hence, control in the field should take place when the intermediates and adults are most abundant (Stokwe and Malan 2010).

In New Zealand, *Ps. viburni* probably might have got introduced through commercial trade. It has been an important pest of pipfruit (the term "pipfruit" refers to apples and pears, because of the small hard seeds (pips) in the centre of the fruit) in Hawke's Bay for at least 50 years (Charles 1989). *Pseudaphycus maculipennis* (Mercet) (Hym: Encyrtidae) is host-specific and an internal parasitoid of *Ps. viburni*, and has reportedly provided good control of obscure mealybug in France and the Republic of Georgia. It is a facultatively gregarious endoparasitoid; it is a koinobiont, ovipositing in one developmental stage of the mealybug (usually the third-instar female, although second instars and adult females are also attacked) and emerging from the next (usually the adult). Male and female wasps often emerge from the same mealybug.

Pseudaphycus maculipennis

The first release into New Zealand was made in February 2001 when it became the first biocontrol agent to be released under the Hazardous Substances and New Organisms (HSNO) Act 1996 (Charles 2001).

Approximately 750,000 *P. maculipennis* were released in 41 pipfruit orchards in Hawke's Bay, Nelson/Motueka and Auckland, and to the Wellington Botanic Gardens between 2001 and 2004. At least a year later, mealybug infestation was controlled with a recovery rate of 83 % in Hawke's Bay and 60 % in the Nelson orchards and from the Wellington Botanic Gardens, indicating that the parasitoid has a solid foothold in New Zealand. *Pseudaphycus maculipennis* have dispersed since their release at a natural rate of about 200 m/year (Charles et al. 2004). In New Zealand, the parasitoid *Pseudaphycus maculipennis* was attracted to the synthetic sex-pheromone-baited traps. The presence of *P. maculipennis* in pheromone traps suggests recognition of the host female sex pheromone as kairomone. The finding of the kairomonal activity in the parasitoid has simplified monitoring to determine the post-introduction establishment of the biological control agent (Bell et al. 2006).

29.6.2.3 *Pseudococcus maritimus*

The impact of native natural enemies on populations of the grape mealybug *Pseudococcus maritimus* (Ehrhorn) in apple and pear orchards was assessed using a combination of techniques, including exclusion cages, limb-banding, and visual inspection of shoots and fruits. The complex of native natural enemies (which included two encyrtid parasitoids, namely *Pseudaphycus websteri* Timberlake and *Mayridia* sp.), a coccinellid beetle (*Hyperaspis lateralis* Mulsant), and a chamaemyiid fly (*Leucopis verticalis* Malloch) provided a reasonably good control in orchards that had not been treated with insecticides for 1–2 years. However, surveys indicated that most of these species were absent from orchards regularly sprayed with pesticides (Grasswitz and Burts 1995).

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30 Fruit Crops: Pears

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30.1 Species

Mealybugs are injurious to pears in Korea, Tasmania, New York, Australia, New Zealand, Chile, China, Washington, Yakima and so forth (Table 30.1). *Pseudococcus longispinus* (Tar-Toz.) and *Pseudococcus viburni (Ps. obscurus* Essig.) have been reported in commercial pear orchards of South Africa (Myburg et al. 1975; Swart 1977).

30.2 Damage

The Comstock mealybug *Pseudococcus comstocki* (Kuwana) poses two major concerns for pear processing industry of New York. First, the emergence of crawlers and adult females from the calyx of pears at packhouses creates a nuisance to workers. Second, pears to be made into puree typically are not peeled or cored by the processors, so infestations can result in unacceptable contamination of the product. Another cause of concern to pear growers is that honeydew secreted by crawlers is a substrate to sooty molds growing on the fruit surface. These molds result in downgrading of the fruit and therefore an additional cause of economic loss. In Japan, *Ps. comstocki* has become the most regularly occurring pest in pear orchards because of the destruction of its natural enemies by the frequent application of organochlorine and organophosphorus insecticides (Morimoto 1976).

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30.3 Management

Although mealybugs were present in many orchards, they were well controlled in most cases, and serious infestations were associated with inefficient or infrequent spraying. *Pseudococcus viburni* (*P. obscurus*) appeared to predominate under intensive spray regimes, whereas the proportions of *P. longispinus* increased under light or no-spray programs (Myburg et al. 1975). *Pseudaphycus malinus* Gah., a good host-searching parasitoid, was released during the second and third nymphal instars of the pest in the spring; this method was found to control even heavy infestations in orchards if used for two successive seasons, and chemical applications could be reduced gradually from the third season onwards. Around 2000 adult parasites emerged per sheet, and two sheets were usually required for each moderately infested pear tree (Morimoto 1976). Notes are provided for each of the ten recommended insecticides, and their formulations, concentrations, dosages, times of application, and withholding periods are given for the control of mealybugs (Swart 1977).

Heterorhabditis zealandica Poinar was known to cause mortality on *Pseudococcus viburni* in

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Table 30.1 List of mealybugs recorded on pears in different countries

Mealybug Species	Region, Country	References
Crisicoccus matsumotoi (Siraiwa)	Korea	Park et al. (2010)
Dysmicoccus prochilus Williams	Tasmania	Ben-Dov (1994)
Dysmicoccus wistariae (Green)	New York and China	Ben-Dov (1994)
Maconellicoccus hirsutus (Green)	–	Ben-Dov (1994)
Phenacoccus aceris (Signoret)	Nearctic and Palaearctic region	Ben-Dov (1994)
Pseudococcus viburni (Signoret)	Australia, South Africa, New Zealand, and Chile	Furness (1976), Stokwe and Malan (2010), Charles (1993), Curkovic et al. (1995)
Pseudococcus comstocki (Kuwana)	Korea, New York, USSR, and Japan	Seo et al.(2010), Agnello et al.(1992), Dantsig and Shtundyuk (1975), Morimoto (1976)
Planococcus citri (Risso)	Florida	–
Pseudococcus calceolariae (Maskell)	New Zealand and South Africa	Charles (1993), Wakgari and Giliomee (2004)
Planococcus kraunhiae (Kuw.)	Korea	Park et al.(2010)
Pseudococcus longispinus (TargioniTozzetti)	India	Williams (2004)
	South Africa	Myburg et al.(1975), Swart (1977)
Pseudococcus maritimus (Ehrhorn)	Washington and Yakima	Miller et al.(1996), Warner (2000)

South Africa up to 80 % after 48 h. All stages of *P. viburni* beyond crawlers appeared to be susceptible to nematode infection. Hence, control in the field should take place when the intermediates and adults are most abundant (Stokwe and Malan 2010).

Acceptable control of *Pseudococcus comstocki* in pears grown for processing in New York could be attained with one or two sprays of parathion-methyl, diazinon, or methomyl, timed to coincide with each generation of larvae; double-sided tape traps on the scaffold branches are the recommended monitoring tactic for the timing of sprays. Heavily infested orchards with no history of control measures may initially require a total of three or four insecticide applications, but this number can be reduced in subsequent years (Agnello et al. 1992).

The appearance of grape mealybug *Ps. Maritimus* in stone fruit orchards in the Yakima area is reported. Best control results are achieved by applications of organophosphate and oil at the delayed dormant to prepink stage and imidacloprid at petal fall. Green lacewing can be used for biological control (Warner 2000).

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Fruit Crops: Plum

31

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31.1 Species

Pseudococcus viburni (Signoret) is reported as pest of plums in Chile (Gonzalez et al. 1996) (Fig. 31.1). In Porterville, Tulare County, California, *Pseudococcus comstocki* (Kuw.) has been reported from a total of 65 food plants, including plum (Meyerdirk and Newell 1979). The Comstock mealybug *P. comstocki* was also observed in the Odessa region of the Crimea (USSR) on plum (Romanchenko and Bel'skaya 1981). In Apsheronsk Peninsula, Azerbaijan SSR, USSR, *Phenacoccus mespili* Sign. was shown to be a pest of many fruit crops, including cherry plum. In Chile, plums were found infested with *P. viburni* and its associated ant, *Iridomyrmex humilis* (Mayr) (Curkovic et al. 1995). *Dysmicoccus brevipes* (Cockerell) was found in a plum orchard in Auckland, New Zealand, in November (Richmond and Cowley 1998). *Rhizoecus kondonis* Kuwana is a subterranean pest of plums and other crops, primarily in the Sacramento Valley of California. Significantly, more *R. kondonis* were found 15.2–45.7 cm deep in the soil (averaging 8.3/1240 cm^3 soil core sample) compared with depths of 0–15.2 cm (averaging 2.2/sample) (Godfrey and Pickel 1998).

Fig. 31.1 *Pseudococcus viburni* as pest of plums in Chile

31.2 Damage

In Chile, obscure mealybug *P. viburni* in plums and apples move into the fruits during a long migratory process that precludes a proper control timing (Gonzalez and Volosky 2004).

31.3 Management

31.3.1 Chemical Control

Pseudococcus viburni is reported as pest of plums in Chile. Corrugated trap bands attached to the trunk were necessary to monitor the incidence of mealybugs. The insecticides were evaluated mostly as postharvest treatments: chlorpyrifos,

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chlorpyrifos-methyl, diazinon, dimethoate, mixture of dimethoate and methidathion, fenamiphos, imidacloprid, methidathion, omethoate, oxydemeton-methyl, parathion, profenofos, and prothiofos. Postharvest treatments as high-volume sprays (handguns) significantly reduced insect populations. However, survival rates under bark as well as on plum roots made it necessary to apply complementary sprays in October and in December–January, both periods corresponding to extensive migratory flows to the bunches and fruits. In this context, the control of *P. affinis* with trunk and soil applications of chlorpyrifos proved necessary (Gonzalez et al. 1996). Application of sprays of diazinon, methidathion, and profenofos after the fruit harvest against *Pseudococcus viburni* (*P. affinis)* was evaluated on table grapes and plums in Chile. These treatments considerably reduced pest population levels. Nymphal mortality was greater than mortality of mature females (Gonzalez et al. 1995). In Chile, a new approach to minimize risks is suggested through control programs against *P. viburni* in plums starting at the postharvest season, followed in the next early spring season with the chitin inhibitor buprofezin. The use of neonicotinoid insecticides is also under development to include acetamiprid, imidacloprid, thiacloprid, and thiamethoxam (Gonzalez and Volosky 2004). The efficacy of spring and postharvest treatments of insecticides (chlorpyrifos, ethoprophos, and carbofuran) against *P. viburni* in plum orchards (cv. Larry Anne) in Chile is also discussed (Gonzalez et al. 2001).

31.3.2 Biological Control

31.3.2.1 California

In California, exotic parasitoids *Allotropa burrelli* Mues., *A. convexifrons* Mues., and *Pseudaphycus malinus* Gah were found to be successfully established on *Ps. comstocki* (Meyerdirk and Newell 1979).

31.3.2.2 Crimea (USSR)

In the Odessa region of the Crimea (USSR), for control of the Comstock mealybug *Ps. comstocki* on plum, *Pseudaphycus* was introduced from the Uzbekistan laboratory, reared locally, and distributed in the Odessa region. This parasitoid had been already observed in Odessa, but it multiplied slowly, and regular releases were necessary during the period of appearance of the second instar nymphs of each generation. Mass releases of parasites had begun in 1977, and the effectiveness reached 76.8–96.8 % in 1978. No releases or other control measures were undertaken in 1979, and infestation declined rapidly, parasitism being 98 %. Subsequent observations showed that *Pseudaphycus* readily became established in the Odessa area and provided sufficient control for artificial rearing and release to be discontinued. Since the outbreak appeared to have been due to the importation of infested pomegranates, quarantine measures were taken to ensure that such imports were free from the mealybug (Romanchenko and Bel'skaya 1981).

31.3.2.3 Azerbaijan SSR, USSR

In Apsheronsk Peninsula in the Azerbaijan SSR, USSR, *Phenacoccus mespili* Sign was shown to be a pest of peach, apricot, quince, cherry plum [*Prunus divaricata*], cherry, bird cherry, apple, pear, and ash [Fraxinus]. The pest had two complete generations and a partial one per year. The first generation developed in about 65 days and the second in about 45.2 days. The most important natural enemy was the encyrtid *Pseudaphycus phenacocci* Yasnosh that parasitized about 73.8 % of the pest population in late August and September. Other parasitoids recorded were *Aphycus hadzibejliae* Trjapitzin and *Allotropa mecrida* (Walker), while the predators were *Chilocorus bipustulatus* L., *Chrysoperla carnea* (Stephens), and *Leucopis alticeps* Czerny (Ibadova 1985).

31.3.2.4 Chile

Pseudococcus viburni (*Ps. affinis*) has become an economically important pest of Japanese plums in Chile. At harvest, a higher number of fruits are infested inside the pedicel cavity. Mid-to-late season cultivars are often infested, and ovipositing females occur on fruits from mid-January. Postharvest treatments with chlorpyrifos, methidathion, and a mixture of dimethoate and chlorpyrifos are recommended for control of the mealybugs (Gonzalez 1991).

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32 Fruit Crops: Peaches

M. Mani

Comstock mealybug, *Pseudococcus comstocki* (Kuwana), has been reported on peaches in Illinois. Egg masses are commonly present on fruits, limbs, and bases of new shoots. *Phenacoccus mespili* Sign. is known to be a pest of peaches in the Azerbaijan SSR, USSR (Ibadova 1985).In Apsheronskiy Peninsula in the Azerbaijan SSR, USSR, the pest had two complete generations and a partial one per year. The first generation developed in about 65 days and the second in about 45.2 days. The most important natural enemy was the encyrtid Pseudaphycus phenacocci Yasnosh which parasitized about 73.8 % of the pest population in late August and September. Other parasitoids recorded were Aphycus hadzibejliae Trjapitzin and Allotropa mecrida (Walker), while the predators were Chilocorus bipustulatus L., Chrysoperla carnea (Stephens) and Leucopis alticeps Czerny (Ibadova 1985).

Mealybug on fruits

Mealybug on shoot

Reference

Ibadova SI (1985) The apple mealybug *Phenacoccus mespili* Sign., and its natural enemies in the Apsheronskiy Peninsula [Russian]. Izvestiya Akademii Nauk Azerbaidzhanskoi SSR Biologicheskikh Nauk 1:32–36

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33 Fruit Crops: Persimmon

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33.1 Species

In Japan, *Planococcus kraunhiae* (Kuw.) and *Phenacoccus pergandei* Ckll. were present on the buds in a concentrated distribution in a persimmon orchard (Ueno 1971). *Pseudococcus viburni* (Signoret) (*P. obscurus* Essig) is known to attack persimmon in southern France and Italy (Tranfaglia 1972–1973). In Israel, *Planococcus citri* (Risso) settles under the sepal and the connection between fruit and leaves. It sucks the fruits, and the honeydew causes black knots. Ants are the main transferring factor of the mealybugs, and they protect them against predators and parasitoids (Izhar 1999; Dunkelblum et al. 2002). There was an outbreak of mealybug *Planococcus kraunhiae* (Kuwana) on persimmons treated with a synthetic pyrethroid cypermethrin (Morishita 2005a, b). Recently, the damage caused by *Pl. kraunhiae* is increasing on persimmons. This might be due to the development of resurgence that occurred when natural enemies' population decreased with the use of synthetic pyrethroids (Tsutsumi 1997). In New Zealand, *Pseudococcus longispinus* (Targioni-Tozzetti) and *Ps. calceolariae* (Maskell) were reported on persimmons (Charles 1993). Prestidge et al. (1989) surveyed pest incidence on persimmons and found that a range of mealybug species were present on the fruit at harvest in New Zealand. *Pseudococcus longispinus* is a potential quarantine pest of persimmons, for example, on New Zealand fruit exported to Japan (Steven and Sale 1985). In Chile, *Pseudococcus viburni* is known to infest persimmons (Curkovic et al. 1995).

Planococcus kraunhiae

In Japan, persimmons infested by *Pl. kraunhiae* and *Phenacoccus pergandei* Ckll., overwintered individuals of both species were present in early spring on the buds, those of the first species were significantly more abundant on the topmost buds of the twigs than on those lower down, while those of the second were

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distributed more or less evenly on all buds. Over the whole orchard, the frequency distribution of immature individuals appeared to correspond to a concentrated distribution. Within a tree, the frequency distribution of the number of individuals per bud varied with density; when it was low, it corresponded to Poisson's curve, but when it was high (more than about 0.5/bud), it could be fitted to the concentrated type. The same trend was observed in both species (Ueno 1971).

Ferrisia gilli, Gill's mealybug, is a newly described species of mealybug that is spreading throughout California, infesting many stone fruits and also persimmons (Gullan et al. 2003).

Parasitoids that include wasps in the genera *Pseudaphycus*, *Chrysoplatycerus*, and *Anagyrus* have been shown to effectively reduce Gill's mealybug populations on persimmon crop systems where pyrethrin-based insecticide use is very limited.

33.2 Management

Application of chlorpyrifos (5 %) and diazinon (4 %) applied around the trunk gave excellent results against ants. All the treatments greatly reduced the population of mealybug *P. citri* (Izhar 1999). There are three generations of Japanese mealybug, *Planococcus kraunhiae*, on persimmons each year. Chemicals are to be applied usually in June and August when first instar nymphs, the most susceptible to insecticides, appear. The density of Japanese mealybug, *Planococcus kraunhiae*, on Japanese persimmon fruit was higher in plots frequently treated with cypermethrin than that in the untreated plot. The number of mealybugs found on "Fuyu," a non-astringent cultivar, was higher than that on "Hiratanenashi," an astringent cultivar. The following additional control measures should be taken in heavily infested orchards: (1) eliminating overwintering nymphs by scraping away the tree bark, (2) spraying the tree with petroleum oil in winter, and (3) applying pesticides from late April to early May when overwintering nymphs move to the top of shoots (Morishita 2005a, b). Neonicotinoids were the most toxic to the *Pl. kraunhiae* on persimmon, followed by organophosphates, while the synthetic pyrethroids were less effective in Japan (Morishita 2006).

A mean LT 99 of *Ps. longispinus* at 44 °C was 74.2 min, which decreased to 15.1 min at 54 °C. Hot water immersion appeared to be a potentially useful disinfestation method. The mortality response of *Ps. longispinus* on persimmons to hot water immersion treatments between 44 and 54 °C was examined. The calyx of the persimmon was found to offer thermal protection for *P. Longispinus*, resulting in lower insect mortality under the calyx compared to that on the outside of the fruit (Lester et al. 1995). Koide et al. (2009) predicted the hatch timing of the mealybug *Pl. kraunhiae* in persimmon orchards using the effective accumulated temperature calculation simulation of the JPP-NET in Aichi.

Hot air treatment of *P. longispinus* on persimmons achieved 99 % mortality of the mealybug with 12.4 h at 44 °C, which reduced to 4.5 h at 47 °C and 3.8 h at 50 °C (Dentener et al. 1996). Treatment at a 47 °C-persimmon flesh temperature for up to 3 h after a 2-h warm-up period, followed by immediate cold storage, has the beneficial effect of delaying the onset of chilling injury in persimmons while causing only slight internal and external damage to the fruit (Woolf et al. 1997). Therefore, a combined heat-to-cold storage treatment may be effective for disinfestations of *P. longispinus* on persimmons. An estimated treatment time of 3.3 h (including a 2-h warm-up period) at 44 °C, followed by a 40-day cold storage at 0 °C, was needed to achieve 99 % mortality (Dentener et al. 1997).

Cryptolaemus montrouzieri was introduced into Japan for the control of *Planococcus kraunhiae* on persimmon (Ishi 1940).

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34 Fruit Crops: Passion Fruit

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34.1 Species

Planococcus citri (Risso) was recorded on passion fruit in Queensland, Australia. Numbers of *P. citri* were lowest in September, increasing to peak populations in January–June (Murray 1978). *Maconellicoccus hirsutus* (Green) was reported on passion fruit in Florida (Hodges et al. 2005).

34.2 Natural Enemies

Cryptolaemus montrouzieri Muls. was the most abundant predator on *P. citri* in Australia. *Harmonia octomaculata* (F.), *Chrysopa* sp. and *Oligochrysa lutea* (Wlk.) were less common passion fruit mealybugs. Parasite activity was insignificant on *P. citri*. Attack by a fungus similar to *Entomophthora fumosa* caused up to 58.1 % mortality of third instar nymphs and adults in a period of high rainfall and humidity in the wet season in January (Murray 1978).

Mass of mealybugs on passion fruit

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35 Fruit Crops: Apricot

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35.1 Species

Pseudococcus maritumus (Ehrhorn) is a problem on apricot in the USA (Anonymous 1980). *Phenacoccus mespili* (Sign.) is known to be a pest of apricot in the Azerbaijan SSR, USSR (Ibadova 1985). *Phenacoccus aceris* (Signoret) is also known to attack all deciduous fruit and nut trees, including apricots in Nearctic and Palaearctic regions (Ben-Dov 1994). *Ferrisia virgata* (Cockerell) is also known to attack apricots in Egypt.

Pseudococcus maritumus

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35.2 Damage

The damage caused to apricots is due to excretion of honeydew by *Ps. maritumus*. Colonies are formed in the depression around the stem end of the fruits, and honeydew produced run over sides of apricots. The black smut fungus that grows in the honeydew gives the fruit an unsightly appearance. In addition, the honeydew gives the fruit a reddish tint. As apricots are picked relatively ripe, it is not possible to remove the honeydew by the normal washing procedure. The fruit is not suitable for fresh shipment, and processors of unpeeled halves consider the contaminated fruit as culls.

35.3 Seasonal Development

Pseudococcus maritimus on apricots over winter act as crawlers within white cottony egg mass deposit by adult females. These egg masses are found on the trunk and main limbs of the tree in protected places such as cracks and depressions in the bark. During spring, shortly after the tree blooms, the crawlers become active and leave their overwintering quarters. Newly hatched mealybug crawlers are about 0.06 in. long, pink to salmon colored, coated with a white powder wax, and very mobile. The crawlers usually congregate the base of the young shoots at this time, apparently feeding on tender tissue. Sedentary

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nymphs are pink to purple with waxy filaments giving them a whitish cast. Adult females resemble nymphs and are about 0.19 in. long and quite mobile. Later in the season, mealybugs may produce copious amounts of honeydew. They reach maturity by May–June. Receptive females release a pheromone to attract males. Adult males appear first, mate with last instar nymphs or adult females and die, and females deposit eggs in the cracks of the bark. The eggs hatch and crawlers of the second generation move to both foliage and fruit during June and early July. It is at this time that the mealybugs colonize around the stem end of the fruit. Apricots are usually harvested in July, and after the fruit is picked, the mature, mated females migrate to sheltered areas, lay eggs, and die in the egg sac. The eggs hatch in September, but the crawlers remain within the old egg mass until the following spring (Madsen and McNelly 1959).

35.4 Management

Treatments timed to the spring emergence of crawlers were effective and were preferred to fall or winter sprays. Diazinon was found to be effective against the mealybug on apricots. Weekly sprays of horticultural oil, neem oil, and use of insecticidal soap work well against mealybugs. As dormant spray, horticultural mineral oil is recommended at 1–2 gal/100 gal water (4–8 gal/a) + diazinon (Diazinon AG500) at 1 pint/100 gal water (1.5–3 pints/a) for control of mealybug. A prebloom spray application of insecticides diazinon (50 W) at 1 lb/100 gal water (4 lb/a) and phosmet (70 W) at 0.75–1 lb/100 gal water (4.25 lb/a) is given before leaves begin to curl, and before petal fall. Diazinon (50 W) at 1 lb/100 gal water (4 lb/a) and imidacloprid (1.6 F) were recommended at 2 fl oz/100 gal water (4–8 fl oz/a) is recommended as petal fall spray for the control of mealybugs (Madsen and Mcnelly 1960).

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36 Fruit Crops: Pistachio and Almond

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36.1 Pistachio (*Pistacia vera*)

Gill's mealybug Ferrisia gilli Gullan is a primary pest of pistachio in California. Mealybug infestation causes a decrease in nut quality because of increased shell staining and possibly smaller kernel size. Mealybug populations are at their highest at the time of harvest. Ferrisia gilli is a relatively large mealybug that feeds by sucking plant juices of almond in California. Mealybug control is achieved through a dormant or June application of buprofezin, which is highly effective against immature stages and can reduce mealybug populations in a manner that is relatively safe to predators and parasites. Alternatively, chlorpyrifos provided excellent control when sprayed in the dormant season and would likely do the same in season. Parasitoids include wasps in the genera Pseudaphycus, Chrysoplatycerus and Anagyrus. These parasitoid species have been shown to effectively reduce Gill's mealybug populations where pyrethrin-based insecticide use is very limited.

36.1.1 Damage

Mealybug feeding results in the production of large amounts of honeydew that acts as a substrate for black sooty mold. Stems, leaves, and clusters in trees are often covered in honeydew and sooty mold. Thick layers of sooty mold on leaf surfaces reduce photosynthesis. Mealybugs have a great affinity for feeding within the pistachio cluster. They use piercing–sucking mouthparts to suck out plant juices, extracting carbohydrates and other nutrients intended for nut development. This causes a decrease in nut quality because of increased shell staining and possibly smaller kernel size. During the late spring through harvest, mealybug is particularly found feeding within the cluster where they cause losses in quality and possibly yields. Harvesting is also affected when severe hull damage causes nuts to dry up and shrivel on the tree.

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Adult female mealybug

Fruit infestation

Mealybug infestation of nut clusters

36.1.2 Seasonal Development

Gill's mealybug has three generations per year in California. After harvest, adult female mealybugs migrate to the main tree scaffolds and trunk where they aggregate and give the wood a white, bearded appearance as if draped in cotton candy. Then they produce crawlers that seek out protected places in cracks and crevices to overwinter. During budbreak, the overwintering nymphs migrate to the swelling buds and begin to feed. They continue feeding at the interface between the previous year's wood and the current year's growth until May, when the overwintering mealybugs reach maturity and move to the rachis. Between late May and mid-June, the adult females give live birth to crawlers of the first of two in-season generations that feed on the pistachio hull. The first generation is present from early June through mid-July and the second from mid-July through harvest. Whereas the overwintering generation has low survival rates throughout the winter, the two in-season generations are noted for their exponential growth rates such that one mealybug per cluster in May can result in hundreds of mealybugs per cluster at harvest.

Mealybugs on buds

Aggregation of mealybugs on tree trunk

36.1.3 Management

36.1.3.1 Stopping the Spread

Mealybug populations are at their highest at the time of harvest. A lot of equipment is moving through orchards, and that equipment is typically moved locally from orchard to orchard and from county to county. Growers and harvesters are to be educated on turn to advice their equipment operators to recognize infested orchards and wash down the equipment prior to leaving infested sites. Tarping loads coming from infested orchards are needed to keep the infested leaf trash from blowing out during transport.

36.1.4 Cultural Control

There are no cultural controls known to affect the density of Gill's mealybug or the damage it causes to pistachios. However, cultural controls such as washing equipment (especially harvest equipment) when leaving infested orchards is essential for decreasing the rate of orchard-to-orchard spread of this new pest.

36.1.5 Chemical Control

Monitoring of mealybugs on the trees is an important step to make treatment decisions. At budbreak, search for mealybugs is to be done at the bases of new buds on trees known to be previously infested. Treatment decisions are to be made by determining the number of adult female mealybugs per cluster in late May. An average of three mealybugs per cluster in May is sufficient to cause a 15 % reduction in the value of the crop at harvest. It is advised to look for mealybug infestations in fall after harvest, and mark areas in the orchard where they occur so that their populations can be monitored the following spring. If adult females are found in clusters in May, a treatment aimed at crawler emergence may be warranted.

The best time to find new mealybug infestations is the period from early fall through midwinter when populations are at their highest. Before trees become dormant, it is advised to look for sooty mold on leaves and for mealybugs within the clusters. Once the leaves have fallen, look for white aggregations of mealybugs on the trunks and undersides of main scaffolds. If mealybugs are found, mark and follow up on these locations the following spring.

The most effective timing for insecticides is when most mealybugs are in the crawler stage of the first generation, which for the lower San Joaquin Valley is around early to mid-June. Be sure to monitor clusters to determine crawler emergence. Applications later in the season are more variable in effectiveness. Postharvest treatments are not recommended because this is when biological control is most active, no damage occurs to the crop in winter, and there is already high winter mealybug mortality. The insecticide buprofezin 34.5 oz is very effective when used while mealybugs are in the crawler stage of the first in-season generation. Acetamiprid 2.3–4.1 oz is effective against second-generation crawlers in mid-to-late July.

36.1.6 Biological Control

Several species of predators and parasitoids can suppress Gill's mealybug densities. Predators include green lacewings and a small brown coccinellid (ladybird) beetle whose larva mimics the appearance of a mealybug. Parasitoids include wasps in the genera *Pseudaphycus*, *Chrysoplatycerus*, and *Anagyrus.* These parasitoid species have been shown to effectively reduce Gill's mealybug populations where pyrethrin-based insecticide use is very limited.

Parasitized mealybug

Predatory larva on the mealybug

36.2 Almond (*Prunus dulcis*)

Ferrisia gilli is a relatively large mealybug that feeds by sucking plant juices of almond in California. Feeding on almonds causes sufficient stress to induce midsummer defoliation of trees. Large amounts of honeydew, which acts as a substrate for sooty mold, can also damage trees by blackening the surfaces of leaves, and thereby rendering them photosynthetically inactive. Due to the rapid spread of this mealybug to numerous counties in California, *Drosicha dalbergiae* (Stebbing) has been wrongly reported as almond mealybug in Kashmir, India (Shaheen et al. 2014).

F. gilli primarily overwinters in the immature stages in cracks and crevices under bark on the trunk and main scaffolds of the tree. Smaller numbers were also found hiding underneath the bark of limbs and underneath bud scales. Mealybugs appeared to be in the second instar stage. The percentage of spurs infested with mealybugs started to decrease from January through the first of March. During this time, the mealybugs were still in their overwintering sites under bark on the trunk and other parts of the tree. Sometime during the early weeks of March, the mealybugs migrated out of their overwintering sites, resulting in 40 % of the spurs being infested with at least one mealybug on the 18 March evaluation date. At this time, most mealybugs were medium-sized nymphs. After 18 March, mealybug populations began to decrease as mealybugs became more evenly distributed in the tree, and the mealybug populations were reduced by predation, parasitism, and other natural causes of mortality. By late June and early July, mealybugs had developed into the adult stage and began to reproduce. Soon thereafter, and without the influences of any insecticides, the mealybug populations disappeared such that we did not find a single mealybug during the remainder of the year.

Aggregation of mealybugs on the trunk of almond

36.2.2 Biological Control

Biological control was the primary cause of the mealybug disappearance. Bark samples from the trunk during the winter showed a combination of parasitoids and predators. These included at least two species of parasitoid wasps, lacewing larvae, and a predatory beetle. The two species of wasps were reared repeated times from mealybug mummies from October 2004 through spring 2005. Parasitoids appear to overwinter inside mealybug mummies on the bark of the tree, and then emerge as temperatures warm up in the spring. Parasitoids include wasps in the genera *Pseudaphycus*, *Chrysoplatycerus*, and *Anagyrus* and have been shown to effectively reduce Gill's mealybug populations on almond–grape crop systems where pyrethrin-based insecticide use is very limited. They found the mealybugs on their own (indicating that they are something already established), that they survive the winter, and that each parasitoid is capable of producing multiple offspring from each mealybug. The predatory beetle found was a small, mottled brown coccinelid. Larval stages mimic mealybugs due to white fibrous secretions that cover their bodies. The California gray ant (field ant) also interacts heavily with *F. gilli*. Field ants are attracted to mealybugs and were often found in close association with them. It is likely that predation on the crawler stages that appeared in mid-June could explain the abrupt disappearance of the mealybugs for the remainder of the season, especially since there were lots of field ants, no insecticides were used, and there were no mealybug “mummies” left behind that would indicate populations were reduced through parasitism.

36.2.3 Chemical Control

Trees treated with chlorpyriphos were the only trees to have significant reductions compared to the untreated control. During April and May, once overwintering mealybugs had molted, it resulted in an excellent control of the pest by buprofezin, followed by chlorpyriphos. Mealybug control is achieved through a dormant or June application of buprofezin, which is highly effective against immature stages and can reduce mealybug populations in a manner that is relatively safe to predators and parasites. Alternatively, chlorpyrifos provided excellent control when sprayed in the dormant season and would likely do the same during in-season. Dormant treatments, however, would be preferred since they should be relatively safe to parasitoids due to their state of dormancy inside of mealybug “mummies.”

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37 Fruit Crops: Strawberry

M. Mani

37.1 Species

The mealybugs *Pseudococcus viburni* (Maskell) and *Heliococcus bohemicus* Sulc are known to attack strawberries in Southern France (Kreiter et al. 2004; 2005). Strawberries are known to be damaged by *Planococcus citri* (Risso) in Florida. Mealybugs (*Pseudococcus* spp.) have been shown to be primarily responsible for symptoms which for a number of years have been appearing on strawberry plants grown in the greenhouse, and which in certain respects bear a strong resemblance to those of plants affected with the viral disease. The symptoms not only occur on younger leaves of small, circular to irregularly shaped translucent spots with more intensely chlorotic central portions, but also in the unevenly chlorotic character and malformation of older leaves and in the ultimate general dwarfing of heavily infested plants. The roots of strawberry plants were known to be infested with the mealybug *Rhizoecus kondonis* (Kuwana) in California (McKenzie 1967). *Puto pilosellae* (Sulc) is known to infest strawberries in Central Europe (Kosztarab and Kozar 1988).

Pseudococcus viburni on strawberry

C. montrouzieri on *Ps. viburni*

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37.2 Management

Cryptolaemus montrouzieri was used to control the mealybugs *Pseudococcus viburni* and *Heliococcus bohemicus* on strawberries in Southern France (Kreiter et al. 2004).

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38 Fruit Crops: Grapevine

M. Mani and U. Amala

Mealybugs have been reported as serious pests in North America, South America, Canada, Mexico, USSR, France, South Africa, Australia, Italy, New Zealand, Chile, Middle East countries, etc. (Table 38.1). Economic losses resulting from mealybug infestations on grapes have dramatically increased in India. As many as seven species are known to attack grapevine in India (Mani et al. 2008). Mealybugs are considered to be the most important pests of grapevine in India particularly in Maharashtra, Andhra Pradesh, Tamil Nadu and Karnataka.

Historical perview on mealybugs in India that the pink hibiscus mealybug *Maoconellicoccus hirsutus* (Green) as *Phenacoccus hirsutus* (Green) was first reported on grapes in 1919 (Fletcher 1919, 1923), spherical mealybug *Nipaecoccus viridis* (Newstead) as *Pseudococcus corymbatus* (Green) in 1932 (Fletcher 1932) and also *as Pseudococcus filamentosus* (Cockerell) in Punjab in 1946 (Anonymous 1946), striped mealybug *Ferrisia virgata* (Cockerell) in Tamil Nadu in 1958 (Raman 1958), *N. viridis* in 1965 (Subba Rao et al. 1965) and *Pseudococcus* sp. in Andhra Pradesh in 1974 (Tejkumar et al. 1977) and *Planococcoides robustus* sp.n. (Ezzat and McConnell) in Karnataka in 1976 (Puttarudraiah and Murthy 1976). Prior to 1980, occasional losses occurred as a result of localized infestation, and usually disappeared in the following year. But in the early 1980s, economic losses on grapes in Andhra Pradesh, Maharashtra, Karnataka and to some extent in Tamil Nadu led to the rediscovery of pink hibiscus mealybug, which was also reported on a wide range of host plants in peninsular India. From the mid-1980s onwards, mealybugs have become persistent pests in peninsular India (Satyanarayana 1981; Mani 1986; Reddy and Narayana 1986; Azam 1983; Srinivasan 1987). Extensive use of insecticides in vineyards might have resulted in the outbreak of mealybugs in the late 1980s (Manjunath 1985). Grape production is often adversely affected due to the mealybugs, with the extent of damage being as much as 90 % in extreme cases. Apparently, it could be due to the disruption of natural enemies of mealybugs by broad-spectrum insecticides. In fact, mealybug infestation increased with the increased use of insecticides, particularly organophosphates.

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Table 38.1 Mealybug species recorded on grapevine in different regions of the world

Species	Region	Reference
Asterococcus muratae (Kuw.)	USA	Lambdin (1983)
Dysmicoccus brevipes (Ckll.)	Brazil	Daane et al. (2012)
	India	Mani (1986)
Ferrisia malvastra (McDaniel)	S. Africa	Walton and Pringle (2004); Iordanou (1974)
	Argentina	Tryapitzyn and Tryapitzyn (1999)
Ferrisia gilli (Gullan)	USA	Gullan et al. (2003)
Geococcus coffeae (Green)	–	Ben-Dov (1994)
Heliococcus bohemicus (Šulc.)	Hungary	Jakab and Szendrey (1989)
	Italy	Camporese (1994)
	France, Germany	Sforza et al. (2003)
	Switzerland	Kozar et al. (1994)
Macoonellicoccus hirsutus (Green)	India	Reddy and Narayana (1986)
Nipaecoccus viridis (Newstead)	India	Mani (1986)
Peliococcus turanicus (Kritshenko)	Palaearctic region	Ben-Dov (1994)
Phenacoccus aceris (Sign.)	Italy	Jablonowski (1917)
Phenacoccus hystrix (Baer)	Germany	Wunn (1928); Zillig and Neimeyer (1929)
Phenacoccus madeirensis (Green)	Yemen	Marotta et al. (2001)
Phenacoccus solani (Ferris)	S. Africa	Walton and Pringle (2004); Iordanou (1974)
Planococcus citri (Risso)	Egypt	Bodenheimer (1944)
	France	Bonnemaison (1962)
	Hungary	Anonymous (1917)
	Italy	Jablonowski (1917)
	Israel	Avidov and Swirski (1950)
	Spain	Ruiz Castro (1938); Cabaleiro and Segura (1997)
	S. Africa	Joubert (1943)
	Turkey	Aykac and Erguder (1972)
	UK	Brotherston (1914)
	USA	
	California	Golino et al. (2002)
	USSR	Pintz (1932); Chochiya (1941); Rozanov and Loseva (1963); Niyazov (1969); Kurdyukov and Alan (1973)
	Brazil	Morandi Filho et al. (2007); Cabaleiro and Segura (1997)
	Chile	Gonzalez (2003); Artigas (1994)
	Australia	CSIRO (2001)
Planococcus ficus (Sign.)	France	Panis and Trevillot (1975)
	Italy	Transfaglia (1976); Forte et al. (2008)
	S. Africa	Whitehead (1961); Walton and Pringle (2004b)
	USSR	Dantsig (1977)
	Yemen	Marotta et al. (2001)
	Iran	
	Iraq, Israel, Lebanon, Libya, Egypt	
	Tunisia	Mahfoudhi and Dhouibi (2009)
	Turkey	Kaydan and Klncer (2005)

(continued)

Table 38.1 (continued)

Species	Region	Reference
	Brazil	Foldi and Kozar (2006)
	Argentina	Cordo et al. (2004); Manuel de Borbon et al. 2004)
	California	Gutierrez et al. (2008); Daane et al. (2011)
	Mexico	Gutierrez et al. (2008); Daane et al. (2011)
	Uruguay	Willink et al. (1997)
	Chile	Gonzalez (2003)
	Transcaucasus	Rzaeva (1985)
	Apsheronskiy Peninsula	Ibadova (1985)
Planococcus vitis (Nied.)	Argentina	Stanzin (1916)
	Egypt	El Sayed et al. (1962)
	France	Bernard (1914)
	Germany	Thiem (1925)
	Italy	Lotrionte (1920)
	Israel	Berlinger (1977)
	S. Africa	Niedielski (1969)
	USSR	Afanassiev (1915)
Planococcus kraunhiae (Kuw.)	Japan	Shraiwa (1935)
Planococcus bakeri (Essig.)	California	Flebut (1922)
Planococcus lilacinus (Cockrell)	India	Williams (2004)
Planococcus minor (Maskell)	India	Williams (2004)
Planococcoides robustus (Ezzat and McConnel)	India, Bangladesh, Pakistan	Williams (2004)
Pseudococcus cryptus (Hempel)	Sri Lanka	Williams (2004)
Pseudococcus comstocki (Kuw.)	USA	Flaherty et al. (1976)
Pseudococcus longispinus (Tar–Toz.); *P. adonidum* (L.)	Australia	De Castella and French (1929); CSIRO (2001)
	New Zealand	Cox (1977); Charles (1981)
	S. Africa	Joubert (1943); Walton and Pringle (2004b); Iordanou (1974)
	UK	Brotherston (1914)
	USSR	Fedorov (1926)
	Chile	Gonzalez (2003); Artigas (1994)
	California	Golino et al. (2002); Daane et al. (2008a)
Pseudococcus maritimus (Ehrh.)	S. Africa	Joubert (1943)
	Chile	Gonzalez (1982); Gonzalez (2003)
	California	Frick (1952); Flaherty et al. (1976); Golino et al. (2002)
Pseudococcus viburni (Sign.)	New Zealand	Fisher (1983); Cottier and Jacks (1952); Daane et al. (2007)
Pseudococcus obscurus (Essig.)	Chile	Artigas (1994); Gonzalez (2003)
	South Africa	Myburg et al. (1973); Walton and Pringle (2004); Iordanou (1974)
	Australia	CSIRO (2001)
	California	Golino et al. (2002); Daane et al. (2008a)
	Australia	Gullan (2000)
Rastrococcus iceryoides (Green)	–	Ben-Dov (1994)
Rhizoecus falcifer (Kunkell)	USA	
Xenococcus annandalei (Silvestri)	India	Williams (2004)

In the mid-1990s, the spherical mealybug *Nipaecoccus viridis* (Newstead) was also reported to cause occasional losses in some vineyards in South India. A localized infestation of *Xenococcus annandalei* (Silvestri) in 1996 was also reported in North Bangalore (Rajagopal et al. 1997) and *Planococcus minor* (Maskell) (*Planococcus pacificus* (Cox) in Punjab (Batra et al. 1987). But in mid-2000, citrus mealybug *Planococcus citri* (Risso) was reported to cause severe losses in Maharashtra and Karnataka parallel to *M. hirsutus* (Mani and Kulkarni 2007). Due to awareness on the use of harmful broad-spectrum insecticides by farmers, increased use of selective chemicals and biopesticides, grape mealybug populations decreased noticeably in late 2000 in India. Although individual vineyards suffered losses due to mealybugs, the problem became considerably less severe, and in many cases treatments were reduced or eliminated. Still, individual vineyards suffer from mealybugs, which require treatments.

38.1 Damage

Mealybugs are phloem feeders that use long, slender mouthparts to suck the sap from the trunk, cordons, buds, spurs, aerial roots, leaves, shoots, nodes, flower panicles and bunches. Infestation of the growing point, especially with the pink mealybug, results in malformation of leaves and shoot tips. As the mealybugs feed, they excrete carbohydrate-rich honeydew that also serves as a substrate for the growth of sooty mould on leaves, shoots and bunches. Sooty mould inhibits photosynthesis and affects the growth and development of vine. Second, it adversely affects the fermentation process and subsequently taints the wine. The damage produced by mealybugs is due to the presence of one or more of the following: the cottony ovisac, eggs, nymphs, adults, honeydew or sooty mould. Honeydew often drips onto the fruit from the mealybugs feeding on the foliage above the clusters. Honeydew is colourless and syrupy when first exuded; it later becomes darker because of the sooty mould. Grape berries in an infested bunch do not develop normally and are shrivelled. Bunches having sooty mould-coated berries will be unsightly, thereby losing its market value due to cosmetic damage to the grape clusters; they are poor in quality and unfit for human consumption. The grape mealybug alone caused 50–100 % yield losses in the field (Azam 1983). The pest attack weakens the grown-up vines. The mere presence of mealybug colonies and sooty mould causes cosmetic damage to grape cluster. In case of severe mealybug infestation, young vines often die. Difference in the amount of damage caused by each species is often related to population size, preferred feeding locations and temperature tolerances.

Symptoms of Mealybug Damage

P. citri leaf damage

Pink mealybug shoot damage

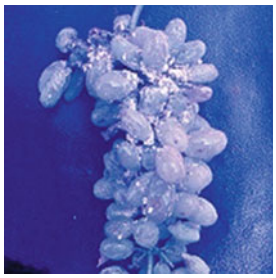
Mealybugs on nodes


Spherical mealybug egg mass on the bark of the trunk


Pink mealybugs


Mealybugs on aerial roots


Bunch damage


Honeydew on berries

Honeydew can be dissolved by light rain and will dry in warm temperatures; however, when infestations are very severe, it can accumulate to form a hard, wax-like layer that covers the infested plant material and results in defoliation, and repeated annual infestations result in vine death. Fruit clusters in direct contact with spurs or trunk are more likely to be damaged. Generally, the table grapes suffer very heavily in comparison with raisin and wine grapes. The table grape vineyards are usually more easily infested because of the greater use of pesticides to ensure clean fruits. This sometimes interferes with natural control factors. Area under wine grapes has started increasing recently in India. The mealybug also poses a serious threat to wine grapes. It is very difficult to process the fruits for raisin and wine if the bunches are heavily infested with mealybugs. The root mealybugs *Xenococcus annandalei* and *Planococcoides robustus* in India also cause damage occasionally by sucking the sap from roots; and the affected vines show reduced vigour, shortening of fruit-bearing canes and reduction in size of fruit bunches and yield.

Like most other grape pests, grape mealybugs prefer vigorous vines. Thus, vines most likely to be infested are outside rows, since these are normally the most vigorous. Weak vines may harbour mealybugs, but heavy populations are normally found mainly on fairly vigorous vines. In general, the mealybug infestations are confined to few vines, while others are clean. But when there is outbreak, all the vines are likely to be infested. Many a time, the infestation is localized. In a given area, one vineyard may be heavily infested while many others may be completely free from mealybugs under the same conditions. Grape bunches that touch old wood have significantly higher damage and mealybug densities. The majority of mealybugs are always found in protected locations (under the bark of the trunk, spurs or canes), indicating the need for chemical or biological controls that can penetrate these refugia (Chris and Kent 2001). Mealybugs are also known to transmit Grapevine-leafroll-associated virus (GLRaV) on grapevine in many countries. Recently, the diseases have been found damaging wine grapes in peninsular India. The vine mealybug as a vector of GLRaV is yet to be established in India.

38.2 Seasonal Development

In India, the mealybug occurs on the grapevine throughout the year. Seasonal development of mealybugs depends on the phenology of the crop. Development of mealybug population can be related to vine development. After pruning in September–October (fruit pruning), the mealybugs remain low on the trunk, cordons and stem up to the first fortnight of December. In general, the mealybug population starts increasing from mid-December onwards. During January, they migrate from the trunk, cordons and shoots to flower panicles and then developing berries. It attains its peak population before the harvest of bunches during March–April. The grapevine is pruned usually in April–May (foundation pruning) (Fig. 38.1). Mealybugs remain on the leaves, stem and trunk from April to September. The mealybug population is usually low from June to September coinciding with the rainy season. In the absence of rains, there is a sudden spurt in the mealybug population in July–August (Mani 1986; Balikai 1999b).

The seasonal incidence of mealybug was expressed in terms of standard weeks. A population of 25.0 colonies per vine was observed during the 14th standard week, and thereafter it declined and reached to a minimum of 7.4 colonies during the 22nd standard week due to April pruning effect. From the 24th standard week, again it started increasing and reached to a peak during the 36th standard week (14.5 colonies/vine). From the 39th standard week, it again started declining and reached to a minimum of 5.0 colonies during the 44th standard week due to September pruning effect and once again started increasing steadily in the fruiting season and reached a peak of 32.4 colonies per vine during the 10th standard week (Katke 2008) (Fig. 38.2). A similar type of seasonal development of *M. hirsutus* was observed on grapes in Andhra Pradesh (Azam, 1983: Babu and Azam 1987) and also in Maharashtra (Anonymous 1992; Koli 2003). The development of other important mealybugs like *Planococcus citri* and *Nipaecoccus viridis* also follows a similar pattern in south India.

Fletcher (1919) reported that *M. hirsutus* had ten generations per year in India. The number of generations of the mealybug varies with the species, locality and climatic factors. There is also variation in seasonal feeding, location and

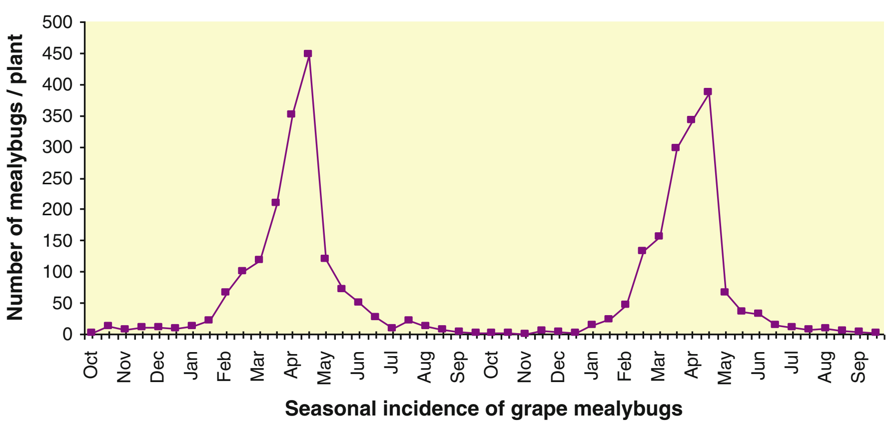


Fig. 38.1 Seasonal Incidence of grape mealybugs in India

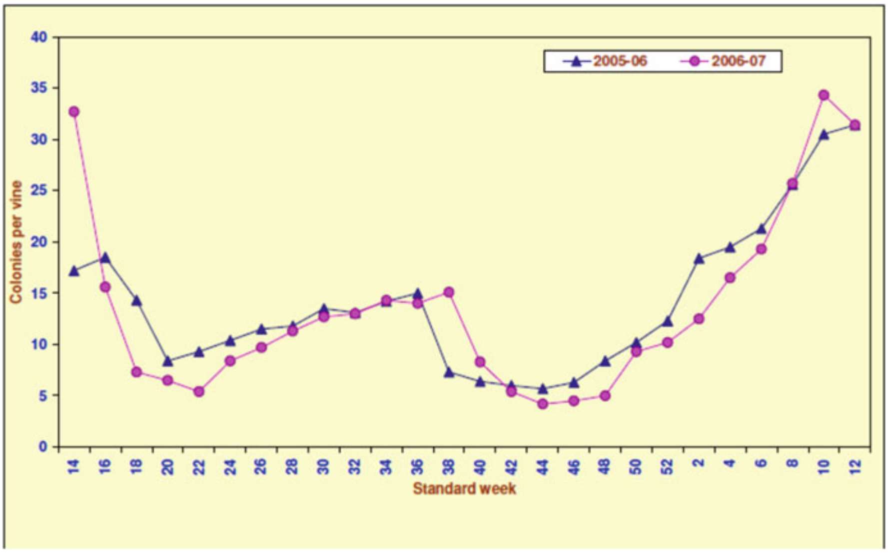


Fig. 38.2 Seasonal incidence of grape mealybug in Bijapur

movement on the vine among species and within species depending on regional temperatures and vineyard management practices. There is no diapause, and slow development may occur during the winter months under south Indian conditions. Temperature is the driving force for mealybug development (e.g., Chong et al. 2008), although development times and temperature thresholds differ among the species. Heavy sporadic rains and cool temperatures of less than 20 °C result in temporary reduction in the mealybug population. The pest population build-up coincides with high temperature of 30–40 °C, low humidity (less than 40 %) and berry development.

The population is low in winter and rainy seasons and higher in summer months (Reddy and Narayana 1986; Babu and Azam 1987; Mani and Thontadarya 1987a, b; Manjunath 1985). There was a highly significant positive correlation of maximum and minimum temperature and highly significant negative correlation of morning and evening relative humidity and non-significant negative correlation of rainfall with mealybug population in vineyards (Mani and Thontadarya 1987a, b; Koli 2003). They manage to survive under loose bark, feeding at bases of spurs, callus tissue at the site of girdles in the off season.

38.3 Varietal Susceptibility

Grape varieties that produce clusters close to the base of shoots so that the fruit touches the old wood are likely to have more heavily infested clusters than varieties where clusters hang more freely. Early-maturing varieties are much less likely to have serious fruit damage than the late-maturing varieties. Cane-pruned varieties are a little less likely to be infested seriously than spur-pruned canes. Among commercial grape varieties, none was found free from its attack. Seedless cultivars with tight filling of the clusters have more infestation than the seeded and loosely filled clusters. Raman (1958) observed more incidences of mealybugs in Pachadraksha (Bhokri) and Thomspon in seedless ones but less incidence in Black Prince, Phakdi, Anab-e-Shahi and Bangalore Blue. More or less incidence of mealybug in different varieties could also be a chance factor.

38.4 Monitoring

The control strategy of this pest requires an effective monitoring of the population dynamics, which is affected by various abiotic and biotic factors. There are no defined effective methods to visually monitor the vineyards. Most of the mealybugs have a clumped distribution pattern within the vineyard, often being found on a small percentage of vines initially. Many mealybugs are present under the bark, on the leaves. Presence of ants is the indication of the sucking pests including the mealybugs that are closely associated with ants. Second, the honeydew, which is clear, sticky, glistening in appearance, is deposited in small drops. Later, as the mealybugs grow, droplets of honeydew become larger and sooty mould begins to grow on the honeydew. Early detection is important. The suggested procedure is to examine the leaves and trunk of grapevine plants in the areas that are likely to be infested based on previous experience.

Mealybug reproduction can be quite variable. For some vineyard mealybugs, mating may be observed, but not mandatory always. In those cases of sexual reproduction, a specific faster sampling method is the use of sticky traps baited with sex pheromone to lure in and trap the adult winged males. Researchers have shown that trap counts can be used to predict damage in vineyards (Walton et al. 2004) and, in some instances, population density (Francis et al. 2007). It has long been known that sexually mature female mealybugs may emit a sex pheromone to attract the winged adult male mealybugs (Rotundo and Tremblay 1972; Rotundo et al. 1979) and these pheromones can be synthesized and used in the field to attract males, as was shown with *P. citri* (Bierlleonhardt et al. 1981; Rotundo and Tremblay 1982). Numerous sex pheromones have recently been identified in the mealybugs including *M. hirsutus* and *P. citri* (Zhang et al. 2004) and are being tested; and management tools to detect vineyard mealybug populations have been devised. Some of these synthetic sex pheromones are commercially available; however, both conventional sampling and pheromone trapping have advantages and disadvantages and, for that reason, both methods should be used.

38.5 Management

Mealybugs are hard-to-kill pests on several crop plants. Good decision to manage the grape mealybugs depends on the knowledge about previous history of mealybug damage in any given vineyard. Sometimes, infestations develop rapidly with little warning. Sound decisions also depend on close monitoring of potentially damaging populations.

Prevention is better than cure. This principle is highly applicable in the management of grape mealybugs. Chemical control at crawler stage (mobile) could be appropriate, as they do not have waxy coating and are exposed during their migration. However, they are slow in their movement and almost stationary on the vines in the later stages. Since the adult bugs hibernate in the bark, cervices and collar region of the vines, mechanical control could be quite effective as they are more amenable for mechanical and biological control.

Repeated insecticide use also adversely affects the mealybug natural enemies (Walton and Pringle 1999). For these reasons, effective species-specific work and environmentally safe control tools to work in combination with or as on alternative to insecticide programme need to be developed (Daane et al. 2008b).

Biological control is the only answer for adult mealybugs as they develop the waxy coating. In the chemical control programme, specific insecticides that only kill mealybug crawlers or early-instar nymphs, but not their predators, should be included. Cultural, mechanical, biological and chemical methods of control have to be integrated to manage the mealybug population, thus preventing the loss caused by mealybugs.

38.5.1 Cultural Control

A number of cultural controls are practised, which vary greatly among the regions, and a few have been sufficiently evaluated. Compact bunches are likely to get heavily damaged. Thinning of fruits is followed to remove the clusters that come in direct contact with the trunk or cordon. Removal of leaves covering the bunches to prevent the movement of mealybugs from leaf to bunches is necessary. Similarly, trellising systems for cane-pruned cultivars result in grape clusters that hang away from the trunk and cordons, and this reduces cluster infestation. Harvest date also has an impact on the mealybug infestation levels, which can be higher in cultivars harvested later in the season because of greater exposure time to the later mealybug broods. Early pruning of grapes in August-September in India helps them to escape from the mealybug attack in the fruit season coinciding with the winter month, December. Removal of remaining mealybug-infested fruits after harvesting helps to reduce the population of mealybugs. Farmers heap the pruned materials infested with mealybugs near the grape gardens for fuel purposes. After drying, mealybugs migrate from the pruned materials to the main plants. Then all the pruned materials from mealybug-infested gardens are collected and destructed in April/May and again in October. Overly vigorous vines can increase mealybug populations in two ways. First, excess nitrogen has been shown to increase the size of mealybug females and the number of eggs in each ovisac. Second, the increased foliage associated with overly vigorous vines provides better shelter for mealybugs by reducing temperatures inside the vine-leaf canopy and may reduce the amount of applied foliar insecticide that reaches the mealybug. Hence, proper irrigation scheduling and nutrient application are to be done for maintaining the required growth at least not to increase the mealybug population. Weedy vineyards are most likely to contain more mealybugs. Hence, weeds and alternate host plants acting as a source of mealybugs inside and nearby outside the vineyard should be removed.

38.5.2 Mechanical Control

Debarking and rubbing the vine stems with a stiff cloth soon after October pruning and pasting them with a mixture of copper oxychloride and chlorpyriphos can minimize the mealybug population. Debarking to remove the mealybugs alone is known to reduce 40 % damage in the fruiting season. Chemicals applied without debarking do not control the mealybugs effectively. Application of a sticky substance ‘tacktrap’, containing 76 % polyisobutylene, to the shoot on either side of the cluster peduncle to a length of 5 cm, was found to reduce the mealybug infestation by 50 %. Another sticky material, ‘bird tangle foot’, was known to reduce the percentage of infested bunches from 30.5 to 14.5 (Reddy and Narayana 1986). These sticky materials prevented the crawlers of mealybug reaching the bunch.

38.5.3 Chemical Control

Control measures must be applied when the mealybugs are small, to kill a high proportion of them. If the treatment is delayed, the percentage of reduction becomes smaller and smaller. Once half grown, controls are not believed worth applying. The majority of mealybugs are always found in protected locations (under the bark of the trunk, spurs or canes), indicating the need for chemicals that can penetrate these refugia.

Historically, pesticides have been a large part of vine mealybug control. Early programmes included potassium cyanide, sodium cyanide and sulphur fumigation (Nougaret 1920; Shafik and Husni 1939), which gave way to the chlorinated hydrocarbons (e.g., dichlorodiphenyltrichloroethane (DDT)) and organophosphates (e.g., parathion) from the 1940s to the 1990s (Frick 1952; Tranfaglia and Viggiani 1981; Grimes and Cone 1985b). These materials were effective; for example, rates as low as 48 g (a.i.) per ha of ethyl parathion provided grape-mealybug control (Frick 1952). Eventually, these materials became less effective (Flaherty et al. 1982) and many were ultimately banned from use.

Many organophosphates are still effectively used (Gonzalez et al. 2001; Walton and Pringle 2001; Sazo et al. 2008). Newer materials, with more novel modes of action, have also gained popularity and include neonicotenoids, insect-growth regulators, botanicals and biosynthesis inhibitors (Daane et al. 2006; Sunitha et al. 2009; Lo and Walker 2010). A major difference between the older and new materials is coverage. As mentioned, a portion of the mealybug population is often under the bark and, for some species, on the vine roots. Many of the older foliar sprays do not effectively contact and kill mealybugs in these more protected locations. The more novel materials have systemic properties, applied either through the irrigation system or as a foliar. For organic or sustainable farming programmes, neem, light mineral oils, lime sulphur, citrus products and fatty acid soaps have been used, but these products have provided mixed results (Srinivas et al. 2007).

Another historical difference is that the earlier materials were often broad spectrum and killed more than just the targeted mealybugs. Flaherty et al. (1982) stated that extensive use of DDT and other synthetic insecticides to control leafhoppers, etc. apparently disrupted the natural control of grape mealybugs. Other researchers have since discussed the impact of broad-spectrum insecticides on mealybug natural enemies (e.g., Mani 1986; Walton and Pringle 2001; Mgocheki and Addison 2009). The cosmopolitan goal of managing vineyards with fewer broad-spectrum pesticides along with the development of resistance to common pesticides (Flaherty et al. 1982; Charles et al. 1993) has fuelled the use of more novel materials and research to improve mealybug controls.

For most materials, application timing is critical (Daane et al. 2012). Control measures are to be taken at bud-burst stage, if any mealybugs are found during the previous harvesting. Exposed mealybugs are more easily killed than those under the bark, and the smaller stages are more susceptible than the larger mealybugs. This is especially true for insecticides with a short residual period. Most research, therefore, has been aimed at proper application timing and developing materials with better penetration into the mealybugs' protected habitats. Dormant season or early spring application takes advantage of the leafless vine, but mealybugs are in more protected locations. Applications with systemic materials near bloom are often used as the insecticide moves out quickly to the leaves. After bloom, foliar materials should be applied beneath the leaf canopy and aimed towards the grape clusters and interior canes. In addition to the possibility of berry spotting, fresh market table grapes possess a dull haze or dust on the skin, termed 'bloom' and the use of some insecticides can remove the bloom and lower the crop value. Nevertheless, insecticides are the primary control tool for the mealybug control. Chemicals are to be applied through soil or can be sprayed to check the mealybug populations.

38.5.3.1 Foliar Applications

It is the most common method of applying insecticides to control the mealybugs. Chemicals are effective if the sprays are applied when the mealybugs are in the dispersive crawler stage and when the food plant affords the least shelter. Treatment before the bud-burst stage and again after flowering reduces the mealybug population below the economic threshold. Sprays of methidathion and dimethoate against *Pseudococcus maritimus* (Ehrh.) on grapevines (of the Thompson seedless variety) in California resulted in 100 % control (AliNiazee and Stafford 1972). The best control of *P. citri* on grapevines was obtained with dimethoate, malathion or trichlormetaphos – all at 0.2 % (Kurdyukov and Alan 1973). Three sprays of 0.075 % dichlorvos for controlling mealybugs (*Pseudococcus* sp.) on table grapes were applied. The first was applied seven days before and the second was 7 days after the beginning of harvest; the third spray 2 weeks later enhanced control (Swart and Barnes 1975).

Currently, in North America, insecticide programmes are based on the use of one or more of the following insecticides: imidacloprid (a neonicotinoid applied as a systemic near-bloom time), buprofezin (an insect-growth regulator applied as a foliar in late spring or early summer), acetamiprid (a foliar-applied neonicotinoid applied from late spring to harvest), clothianidin (a third-generation neonicotinoid applied as either a foliar or systemic from late spring to harvest), spirotetramat (a tetramic acid that acts as a lipid biosynthesis inhibitor and is applied from late spring to early summer, or as post harvest) and chlorpyriphos (an organophosphate that is still used as a delayed dormant or post-harvest application) (Bentley et al. 2008). Prothiophos at 30 g/100 L or 1 mL/L afforded very effective control of the mealybugs throughout the season (Prince and Fisher 1982). In the United States, foliar application of buprofezin and chlorpyriphos brought 82.7 and 85.0 % reduction in cluster damage. Buprofezin is less expensive and provides excellent control. It is an insect-growth regulator, most effective against smaller mealybugs undergoing insect moults (Daane et al. 2008b). In India, dichlorvos was the most commonly recommended chemical against mealybugs (FIP 1982). Foliar application of buprofezin at 1125 ml/ha reduced the nymphal and adult populations and bunch infestation of *M. hirsutus* and increased the fruit yield (Muthukrishnan et al. 2005). Buprofezin 25 SC @ 1125 ml/ha along with fish-oil rosin soap @ 3125 g/ha further improved the control of mealybugs on grapes. Application of buprofezin does not affect the locally occurring natural enemies of vine mealybugs in India. Three sprays commencing from the first fortnight of January and subsequent sprays applied at ten days interval with dimethoate 30 EC at 1.7 mL + fish-oil rosin soap at 5 g/L also gave the highest protection from mealybugs (Katke 2008). Application of spirotetramat 6 fl.oz/acre + adjuvant (Vintre 0.25 %v/v) and 44 fl.oz/acre (spray volume 137 gal/ac) were able to reduce the bunch infestation with mealybugs to 3 % and there was little to no honeydew in that treatment. Vintre dissolves mealybug-excreted wax to improve pesticide penetration, knockdown and control, deep within bark crevices. Diafenthiuron @ 800–1600 g/ha recorded the lowest mealybug population with increased cost-to-benefit ratio (Biradar et al. 2006). Methomyl @ 500–800 g a.i/ha was found to be very effective and gave high returns (Raguraman and Premalatha 2006).

38.5.3.2 Dipping of Grape Bunches

Dipping of grape bunches for two minutes in any one of the insecticides, namely phosalone (2 mL/L), monocrotophos (1.25 mL/L) or dichlorvos (mL/L) mixed with 25 g/L of fish-oil soap, was highly effective in controlling mealybugs on bunches. Dipping in insecticide solution mixed with fish-oil rosin soap resulted in the scorching of berries at the blossom end due to the accumulation of the mixture, but spraying was safe. Though efficacy of insecticides was more by dipping than spraying with dichlorvos, both the methods of application were equally effective (Reddy and Narayana 1986).

38.5.3.3 Soil Drenching

Chemigation (application of chemicals through irrigation) is an environmentally safe and the most effective to control mealybugs. Imidacloprid, a systemic transluminar insecticide and also thiomethoxam (applied through the irrigation water and taken by the vine roots), has been used in several countries and excellent control of mealybug has been obtained for a longer time. Imidacloprid provides greatest reduction of 90–93 % in cluster damage when applied through drip irrigation (Daane et al. 2008b). In the drip-irrigated vineyards, a four to six pretreatment irrigation prepares the soil; imidacloprid is then applied through irrigation system, and 6- to 8-h post-treatment irrigation is used to move the insecticide in the root zone. Single application of imidacloprid in spring through drip irrigation systems at rates of 0.75 g a.i. or higher per plant is known to reduce the mealybug abundance by more than 99 % during the entire season and even for two seasons providing population pressures remain low (Patricia Larrain 1999; Lo and Walker 2011; Fu Castillo et al. 2004; Mansour et al. 2010; Mani et al. 2008). Imidacloprid provides 30–60 % reduction in cluster damage when applied through furrow irrigation (Daane et al. 2008a, b, c). In the furrow method, the vineyards are prepared by ploughing a furrow area to expose the surface roots, followed by 1-day pretreatment irrigation. Imidacloprid is applied into the furrows using the herbicide spray rig, and the application is followed by 1-day post-treatment irrigation. In the furrow method, there is a more widespread root zone that makes the delivery of insecticide to the entire root zone difficult and results in a more dilute application and poor uptake of applied imidacloprid. Irrigation of both pre- and post-imidacloprid application is critical and this is very difficult to properly manipulate with furrow irrigation system.

Soil application of granular insecticides, namely phorate, carbofuran, thiodematon, fensulfothion or bendiocarb (6 or 10 kg a.i./ha), once after each pruning, was found to be ineffective in reducing the mealybug infestation. However, one application of granular insecticide aldicarb @ 50 g/vine around the base of the plant at the time of October pruning protected the bunches completely from mealybug infestation for 3–4 months (Anonymous 1984; Mani and Thontadarya 1991). Though it is an excellent chemical for the mealybug control in both April- and October-pruned crops, the time of application (to be applied immediately after pruning) is a critical factor, and the farmers may not adhere strictly to the application time and may apply the chemical to the vines particularly in the fruiting stage (many growers become aware of the damage at that stage, which will result in high residue problem). There are many restrictions in using aldicarb in the vineyard ecosystem in India. A list of insecticides recommended to control mealybugs is given in Table 38.2.

38.5.4 Monitoring of Ants

Ants are known to attack the predators of scales and mealybugs while attending to the pests.

Therefore, it is necessary to check the activity of ants prior to the release of Cryptolaemus. General ant control measures like destruction of ant holes and ant nests, application of sticky

Table 38.2 List of insecticides recommended to control mealybugs

Chemical	Reference
Buprofezin	Muthukrishnan et al. (2005); Mani et al. (2008); Bentley et al. (2008); Daane et al. (2008a, b, c)
Silwet L-77	Tipping et al. (2003)
Imidacloprid	Patricia Larrain (1999); Bentley et al. (2008); Gonzalez et al. (2001); Daane et al. (2008a, b, c); Sunitha et al. (2009)
Azadirachtin	Verghese (1997); Mani et al. (2008)
Nimbecidine	Koli (2003)
Neem-seed kernel extract (NSKE)	Balikai (1999a); Koli (2003)
NSKE + soap powder	Katke (2008)
Neem oil	Beevi et al. (1992)
Neem oil + soap powder	Katke (2008)
Petroleum oil	Michelakis and Hamid (1995)
Fish-oil rosin soap	Reddy and Narayana (1986)
Parathion	Grimes and Cone (1985a); AliNiazee and Stafford (1972)
Methyl parathion	AliNiazee and Stafford (1972)
Permethrin	Grimes and Cone (1985a)
Malathion	Grimes and Cone (1985a); Su and Wang (1988); Baskaran et al. (1999)
Methidathion, supracide	AliNiazee and Stafford (1972)
Dimethoate	AliNiazee and Stafford (1972); Shreedhar Rao et al. (1988); Su and Wang (1988); Baskaran et al. (1999); Sazo et al. (2008)
Dimethoate + Fish-oil rosin soap	Katke (2008)
Methomyl	Mani et al. (2008); Balikai (1999a); Raguraman and Premalatha (2006)
Chlorpyriphos	Mani et al. (2008); Bentley et al. (2008); Hatta and Hara (1992)
Dichlorvos	Mani et al. (2008); Balikai (1999a); Shreedhar Rao et al. (1988); FIP (1982)
Dichlorvos + fish-oil rosin soap	Mani (1990); Beevi et al. (1992)

(continued)

Table 38.2 (continued)

Chemical	Reference
Clothianidin, spirotetromat acetamiprid	Bentley et al. (2008)
Phenthoate	Aida et al. (2010)
Diazinon	Ripa and Rojas (1990)
Aldicarb	Anonymous (1984); Mani (1986)
Monocrotophos	Shreedhar Rao et al. (1988); Beevi et al. (1992); Tejkumar et al. (1977); FIP (1982)
Fenitrothion	Anwar (1991)
Methyl demeton	Beevi et al. (1992)
Triazophos	Persad and Khan (2000)
Pirimiphos-methyl	Persad and Khan (2000); Salazar et al. (2010)
Phosphamidon	Satyanarayana et al. (2003)
Diafenthiuron	Biradar et al. (2006)
Fenvalerate	FIP (1982)
Prothiophos	Lo et als (2009); Swart and Barnes (1976)
Thiamethoxam, acephate	Sunitha et al. (2009)

bands around the tree trunk and chlorpyriphos 0.05 % into the anthills are to be adopted to suppress the activity of the ants. After the patrolling (up and down) of ants on the trunk is stopped, the beetles are to be released. In field trials in a vineyard in San Luis Obispo County, California, between 1989 and 1990, the use of chlorpyriphos as a 6 % solution to control the honeydew-feeding formicid *Iridomyrmex humilis* gave good results. By controlling the formicid, infestation levels of *Pseudococcus affinis*, a pest of grapes, could be significantly reduced (Phillips and Sherk 1991).

38.5.5 Biological Control

Mealybugs are called 'hard-to-kill pests of fruit trees'. There are several reasons that may account for this fact. Chemical control of grape mealybugs was ineffective (Ripa and Rojas 1990). Perhaps the most important factor is the habitat of the mealybug. Mealybugs live in protected areas such as cracks and crevices of bark, at bases of leaf petioles, on the undersides of leaves and inside the fruit bunch. Eggs of the mealybugs, protected by waxy filamentous secretions of ovisac, are almost impossible to reach with insecticides. Late-instar nymphs and adult female mealybugs are not affected by foliar application of insecticides since they are covered with waxy coating. Insecticides are limited in their effectiveness, because vine mealybugs can feed on all sections of the plant and portion of the population remains protected from insecticide sprays under the bark or on the roots resulting in the build-up of mealybug population (Daane et al. 2003). Mealybugs are also known to develop resistance to commonly used insecticides.

Natural enemies of grape mealybugs

A. dactylopii ***L. dactylopii*** ***S. coccivora*** ***C. perigrinus***

A number of natural enemies are known to attack vine mealybugs throughout the world. Many of the parasitoids are mealybug species specific, while most of the predators are generalists. Few fungal pathogens are also known to infect mealybugs in nature. However, mealybugs, being sessile insects, are more amenable to biological control.

38.6 *Maconellicoccus hirsutus*

Natural enemy complex is very rich on vine mealybugs in absence of insecticide sprays. Six parasitoids and seven predators have been associated with *M. hirsutus* in India. The parasitoids are *Anagyrus dactylopii* (Howard), *Allotropa* sp. nr. *japonica* (Ashmead), *Gyranusoidea mirzai* (Agarwal), *Alamella flava* (Agarwal), *Leptopilina* sp. and *Chartocerus* sp. nr. *walkeri* (Hayat). The predators are *Scymnus gratiosus* (Wiese), *Scymnus coccivora* (Ayyar), *C. montrouzieri*, *Chrysopa* sp., *Spalgis epius* (Westwood), *Cacoxenus perspicax* (Knab) and *Triommata coccidivora* (Felt). Among these, *A. dactylopii* and *S. coccivora* were of considerable importance. *A. dactylopii* caused up to 70 % parasitism in nature (Mani et al. 1987). *C. montrouzieri*, though occurring in large numbers in other ecosystems, is not commonly found attacking the mealybugs in vineyard ecosystem. Biological studies were made in the natural enemies by Mani (1986). The major parasitoid *A. dactylopii* is able to complete the life cycle in 15 days' time (Mani and Thontadarya 1988c) and can be reared on 15–20-day-old mealybugs (Mani and Thontadarya 1989). *Allotropa japonica* can be reared on 15–20-day-old *M. hirsutus* (Mani and Krishnamoorthy 1989), and the larva of *S. coccivora* was known to consume 308 eggs or 62 nymphs or 6.55 adult mealybugs (Mani and Thontadarya 1987a, b). Green lacewing adults are frequently abundant on grapevines harbouring mealybugs and other sucking insects. Lacewing adults are attracted to the mealybug honeydew, but it is not known to what degree their egg laying and subsequent control of mealybug is influenced by the presence of mealybug. A positive and significant relationship between the dominant parasites *Anagyrus dactylopii* (Howard) and *M. hirsutus* was observed.

Cryptolaemus montrouzieri (Mulsant) was used to control mealybugs in many countries. *C. montrouzieri* has been ranked second in importance only to *Rodolia cardinalis* (Mulsant). It is popularly known as 'Australian mealybug destroyer', 'Australian ladybird beetle', 'Crypts' and 'Cryptolaemus'. It has often provided spectacular control of heavy infestations of mealybugs on various horticultural crops. Though several local predators are known to attack the vineyard mealybugs, culturing and releasing them did not provide adequate control of mealybugs. Biological control using the Australian ladybird beetle *Cryptolaemus montrouzieri* is found practicable and successful to control almost all the grape mealybug species in India. Field release of laboratory-reared *Cryptolaemus montrouzieri* beetles are found to be effective in suppressing the population of the pink mealybug *M. hirsutus* in vineyards (Reddy and Narayana 1986; Manjunath 1986; Mani and Thontadarya 1988a; Srinivasan and Sundara Babu (1989).

Adults and larvae can be released in the field for the suppression of pests. Adults upon release soon produce sufficient offspring to clear the mealybugs. However, the release of larvae is preferred to adults when the mealybug infestation is confined to few plants. Usually, the releases are made from 8.00 AM to 10.00 AM and from 3 to 5 PM. The best time for the release of predatory beetles is the evening as the predators settle down immediately. It is advised to release *Cryptolaemus* during June–August to clear the residual mealybug population so that the grape plants will be free from the mealybug damage in the main fruiting season (January–April) (Mani et al. 2008).

However, many grape growers did not get the desired level of control with the release of *C. montrouzieri* mainly due to the lack of proper planning of the time of releasing the predator. Considering the interference of pesticides, predator, production time, availability of *C. montrouzieri* from commercial insectaries and mild weather factors in both the laboratory and the field, releasing of the predator *C. montrouzieri* in July is highly preferable for the suppression of mealybugs. During July– September, weather factors prevailing in both the laboratory and field conditions favour the activity of the predator ensuring its production and efficiency. There is less/no application of insecticides during this part of the year (off season) facilitating the non-interference with the predator. Almost 3 months are available for the predator (July–September) to clear the residual population of mealybugs present on the vines. A mean of 97.67 % reduction in the bunch infestation was obtained with the release of *C. montrouzieri* in July (Fig. 38.3). Depending upon the severity of infestation, the beetles have to be released. A release rate of 5,000 beetles/ha is recommended to suppress the pest population. Two to three releases are to be made annually depending upon the severity of pest infestation. The releases have to be made early in the season. The first generation develops from the released beetles. The second generation definitely brings down the pest population. As a prerequisite for release, spraying of insecticides has to be discontinued for 2–3 weeks prior to the release of the predator. It is better to release less number of beetles at many places in unit area of the vineyard rather than more number of beetles at few places.

Anagyrus dactylopii is the naturally occurring parasitoid on *Maconellicoccus hirsutus* in India. Inundative augmentation by flooding the chosen area with large numbers of particular natural enemy is intended to exert rapid control of the pest in the present generation and prevent or bring down the possible damage to host. Conservation of the native *A. dactylopii* through parasite-friendly insecticides like dichlorvos or buprofezin is to be done. Inundative release of *A. dactylopii* may not be useful in controlling the pink mealybug since it is present already in nature and has attained biotic balance. *Anagyrus kamali* (Moursi), an encyrtid parasitoid, caused 80–90 % reduction in population density of pink hibiscus mealybug at release sites in Egypt, Caribbean Islands and the United States. This parasitoid is to be tried against *M. hirsutus* in vineyards in India.

Lecanicillium (*Verticillium*) *lecanii* (Zimmerman) and *Metarhizium anisopliae* (Metch) are known to cause mortality of mealybugs (Katke 2008; Humber and Soper 1981). The pathogen *V. lecanii* (Zimmerman) was isolated from whiteflies and developed as a biopesticide named as Phule bugicide at Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra, India, for the control of mealybugs. A dosage of 20 g formulated material/10 L of water is recommended to control the mealybugs. Two to three sprays at 15-day intervals in rainy season are needed. Addition of milk powder 5 g/10 L water helps to improve the control of mealybugs. Foliar sprays of fungal pathogens, namely *Beauveria bassiana* (Bals.) Vuill and *Metarhizium anisopliae*, in the rainy season under humid conditions were also found to infect the mealybugs. *Verticillium lecanii* WP (Wettable Powder) @ 0.3 % was found to be best against nymphs and adults of grape mealybug in Maharashtra (Koli 2003). The fungus was known to cause 80 % mortality of some sucking pests at 2×10^5 cfu/mL

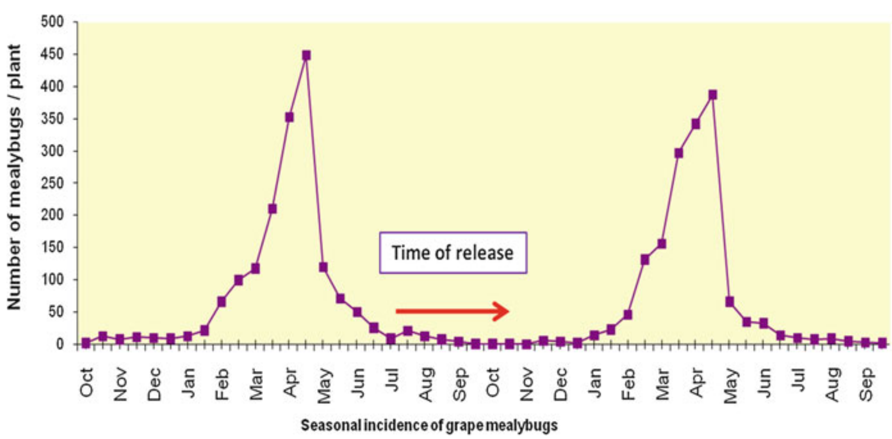


Fig. 38.3 Seasonal incidence of grape mealybug in Bijapur

dose in Maharashtra state within two weeks (Jayachakravarthy 2002). Fish-oil rosin soap (0.5 %) with *V. lecanii* (0.4 %) was the safest and most suitable treatment against grapevine mealybug, *M. hirsutus* (Shelke 2001).

38.7 *Planococcus citri* (Risso)

Besides Spain and Brazil, *Planococcus citri* (Risso) is injurious to grapevine in the Soviet Union. The main parasite of *P. citri* is *Anagyrus pseudococci* (Girault), which occurs in the south of European Russia and in Soviet Central Asia and which destroys up to 75 % of the mealybug population in areas not treated with insecticides. *Allotropa mecrida* (Walker), the second most important parasite, was reared from the mealybug in Turkmenia, and in Georgia it is responsible for up to 20 % parasitism. In 1960, *Leptomastidea abnormis* (Girault) and *Leptomastix dactylopii* (Howard) were introduced into Georgia and subsequently into Turkmenia from the United States. In Transcaucasia and Soviet Central Asia, *Thysanus* (*Chartocerus*) *subaeneus* (Forster) is responsible for up to 18–20 % parasitism of *Allotropa mecrida*. Others are *Coccinella septempunctata* (Linnaeus), *Hyperaspis polita* (Weise), *Scymnus apetzi* (Mulsant), *S. subvileosus* (Goeze), *S. bipunctatus* (Kug.) and *S. biguttatus* (Mulsant), which were noted in Turkmenia. The larvae of *Leucopis* (*Leucopomya) alticeps* (Czerny) and *Chrysoperla carnea* (Stephen) destroy virtually all stages of the mealybug (Niyazov 1969).

Cryptolaemus montrouzieri has given excellent control of *P. citri* in several ecosystems in many countries. Extensive field trials were conducted in Karnataka and Maharashtra in India on the use of *Cryptolaemus* for the control of *P. citri* mealybug on grapevine. *Cryptolaemus montrouzieri* proved to be very useful in suppressing the mealybug in the grape gardens (Mani and Krishnamoorthy 2008). In USSR, *C. montrouzieri* was one of the most effective predators introduced into Black Sea Coastal area for the control of *P. citri* in the vineyards (Niyazov 1969). In the vineyards of Tokat Province and Georgia, *P. citri* was effectively controlled by the release of *C. montrouzieri* (Aykac and Erguder 1972) (Dzhiviladze 1979).

The main parasite of *P. citri* infesting grapes is *Anagyrus pseudococci* (Girault), which occurs in the south of European Russia and in Soviet Central Asia and which destroys up to 75 % of the coccid population in areas not treated with insecticides (Niyazov 1969). *Leptomastix dactylopii* (Howard) is an effective encyrtid parasitoid of citrus mealybug *Planococcus citri* (Risso). The parasitoid can be multiplied on the laboratory-bred *P. citri, P. lilacinus* (Cockerell) and *P. minor (P. pacificus)* (Cox). *L. dactylopii* was recovered in large numbers from *P. citri* infesting wine grapes in Maharashtra. It gives scope of utilizing *L.dactylopii* to control *P.citri* in vineyards in Maharashtra and Karnataka. It has given excellent control of *P. citri* in citrus in India (Krishnamoorthy and Singh 1987) and guava ecosystems in India (Mani 1994). Alternatively, inundative releases of the local *Coccidoxenoides perminutus* can be done to suppress *P. citri* since it can be multiplied easily in large numbers and it is a major parasitoid of *P. citri* in citrus ecosystem in India (Mani 1994).

38.8 *Pseudococcus longispinus*

Currently, *Ps. longispinus* infests a small number of vineyards in California's coastal region. Recent surveys found *Trachelomonas sydneyensis* (Playfair), *Tetracnemus peregrina* (Compere), *Acerophagus angelicus* (Howard), *Anagyrus pseudococci*, *Leptomastidea abnormis* (Girault), *Leptomastix dactylopii* (Howard) and *Coccidoxenoides perminutus* (Girault) attacking this mealybug (Daane et al. 2008a).

38.9 *Planococcus ficus*

As many as 20 natural enemies were recorded on *P. ficus* infesting grapes. Natural enemy complex consists of the parasitoids, namely *Angyrus* sp., *Coccidoxenoides perminutus* (Girault), *Leptomastix dactylopii* (Howard) and the predators (Mulsant), *N. angustus* (Casey) and *N. quadrivittatus* (Mulsant). Biological control was severely hampered by the presence of a variety of ant species. Ant control has been achieved using chemical-stem-barrier treatments. Control of *P. ficus* with the mass releases of *Coccidoxenoides perminutus* was at least as effective as the currently used chemical control programme in South Africa (Walton and Pringle 2004).

38.10 Other Mealybugs

C. montrouzieri can also take care of other mealybug species infesting grapes in India, which are *Nipaecoccus viridis, Pseudococcus citriculus* and *Ferrisia virgata*.

38.11 Integration with Chemicals

The pesticides often interfere with the activity of the predatory beetle. To ensure the best effectiveness of predator's beetles in controlling grape mealybug, it is absolutely essential to release the beetles only in spots having adequate mealybug population and avoid spraying insecticides that are lethal to the predatory beetles. Indiscriminate and frequent sprays of different pesticides proved detrimental to the establishment of the predatory beetles in vineyards.

Commonly used fungicides and acaricides, namely copper oxychloride, mancozeb, sulphur, captafol, carbendazim, bordeaux mixture, dicofol, abamectin, etc., are found to be very safe to *C. montrouzieri*. Dichlorvos, chlorpyriphos and buprofezin are found harmless to the ladybird beetle. These pesticides can be applied safely without affecting the activity of the beetle. Fish-oil rosin soap and most of the botanical origin pesticides are also found to be very safe to the ladybird beetle (Mani et al. 2008; Mani and Thontadarya 1988b).

38.12 Calendar-Based Practices for Grape Mealybug Management in India

- Collection and destruction of the mealybug – infested bunches at the time of harvesting in March–April.
- Removal of loose bark and destruction of the debarked material in April/May.
- Collection and destruction of all the pruned material from mealybug-infested gardens in April/May and again in October.
- Removal of weeds and alternate host plants harbouring mealybugs in and around the vineyards throughout the year.
- Early pruning in August–September usually results in escape of the crop from the mealybug attack as compared to late pruning in December–January.
- Monitoring and destroying the mealybug colonies as and when seen on the trunk, stem, etc. from November to February.
- Locating the ant colonies and destroying them with drenching of chlorpyriphos 20 EC @ 2.5 mL/L or dusting with malathion, since the ants are associated with the build-up of mealybug population.
- Swabbing/washing of trunk and cordons with 2 mL of chlorpyriphos 20 EC + 2 g of fish-oil rosin soap in a litre of water in April–May and again in October.
- Soil drenching with imidacloprid 200 SL at the basins around the trunk through drip irrigation @ 400 mL/ ac in April–May and again in the first week of December.
- Foliar spray with buprofezin @ 1.25 mL/L after 30 days of soil drenching depending on the incidence of the mealybugs.
- Releasing the Australian ladybird beetle (*Cryptolaemus montrouzieri*) @ 5000/ha in August–September to clear the mealybug population present on the plants and again by mid-December, if necessary.
- Alternatively, two to three foliar sprays of *Verticillium lecanii/Beauveria bassiana* (2×10^8 cfu/mL/g) @ 5 g/L at 15 days interval

in the rainy season (July–August) can also be given.

- One or two applications of dichlorvos 76 % EC (2 mL/L) from mid-February to the first week of March, if necessary, depending upon the incidence of mealybugs and time of harvesting or one jet spray of water can also be given on the bunches if the mealybugs are still present just prior to harvest to dislodge the mealybugs.

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39 Fruit Crops: Citrus

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39.1 Mealybug Species

Mealybugs have become an increasing threat to the cultivation of citrus, causing serious losses throughout the world (Table 39.1). Among them, the citrus mealybug (CM), *Planococcus citri*, the pink hibiscus mealybug, *Maconellicoccus hirsutus*, the spherical mealybug, *Nipaecoccus viridis*, the striped mealybug, *Ferrisia virgata* and the oriental mealybug, *Planococcus lilacinus* are important in India. *Planococcus citri* is universally present on citrus.

Life stages of *Planococcus citri*

Adult male | Adult female | Egg mass | Nymphs

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Table 39.1 List of mealybug species recorded on citrus in different regions of the world

Species	Region/Country	References
Crisicoccus matsumotoi (Siraiwa)	India	Williams (2004)
	Philippines	Williams (2004)
Dysmicoccus brevipes (Cockerell)	India	Williams and Watson (1988)
	Australia	Ben-Dov (1994)
	Middle East	Ben-Dov (1994)
	Columbia	Kondo et al. (2008)
	USA	Ben-Dov (1994)
	Japan	Borchsenius (1956); Ben-Dov (1994)
	Russia	Borchsenius (1949); Borchsenius (1956)
	Argentina	Granara de Willink (1991)
Crisicoccus chiponensis (Takahashi)	Taiwan	Williams (2004)
Crisicoccus matsumotoi	India	Williams (2004)
(Siraiwa)		
Dysmicoccus lepelleyi (Betrem)	–	Ben-Dov (1994)
Dysmicoccus debregeasiae (Green)	India, Bangladesh, Nepal, Sri Lanka	Williams (2004)
Dysmicoccus neobrevipes Beardsley	India	Williams and Watson (1988), Williams and Granara de Willink (1992), Williams (2004)
	Australia	Ben-Dov (1994), Williams and Watson (1988)
	Brazil	Williams and Granara de Willink (1992), Ben-Dov (1994)
	Pakistan	Williams (2004)
	Philippines, Sicily	Ben-Dov (1994)
Ferrisia consobrina Williams and Watson	Australia, Ethiopia, Neotropical and Pacific region	Ben-Dov (1994)
Ferrisia terani Williams and Granara de Willink	Argentina	Ben-Dov (1994)
Ferrisia malvastra (McDaniel)	India	Williams and Watson (1988), Williams and Granara de Willink (1992), Williams (2004)
	Australia	Williams and Watson (1988)
	South Africa	Ben-Dov (1991), Ben-Dov (1994)
	Argentina	Williams and Granara de Willink (1992); Ben-Dov (1994)
Ferrisia virgata (Cockerell)	India	Ali (1968), Williams and Watson (1988), Williams and Granara de Willink (1992), Williams (2004), Mani and Krishnamoorthy (2008)
	Australia	Williams (1985), Ben-Dov (1994)
	South Africa	Ben-Dov (1994)
	Columbia	Kondo et al. (2008)
	Bangladesh	Williams (2004)
	USA	Ben-Dov (1994)
	Argentina	Granara de Willink (1979/1991)

(continued)

Table 39.1 (continued)

Species	Region/Country	References
Formicococcus latens sp. n.	India	Williams (2004)
Formicococcus robustus (Ezzat and McConnell)	India	Williams (2004)
	Bangladesh	Williams (2004), Ben-Dov (1994)
Geococcus citrinus Kuwana	China, Japan	Ben-Dov (1994)
Geococcus coffeae Green	India	Green (1922)
Maconellicoccus hirsutus (Green)	India	Williams (1996), Williams (2004), Williams and Watson (1988), Williams (1985), Mani and Krishnamoorthy (1999)
	Australia	Brookes (1964), Williams and Watson (1988), Ben-Dov (1994)
	Kenya	Williams (1986a), Ben-Dov (1994)
	Central Africa	Williams (1986a)
	Saudi Arabia	Matile-Ferrero (1984)
	USA	Chang and Miller (1996)
	Bangladesh	Williams (2004), Ben-Dov (1994)
	Columbia	Kondo et al. (2008)
Nipaecoccus brasilicus Williams and Granara de Willink	Brazil	Ben-Dov (1994)
Nipaecoccus filamentosus (Cockerell)	Iran	Khalaf and Aberoomand (1989)
Nipaecoccus nipae (Maskell)	India	Williams and Granara de Willink (1992)
	Mexico	Williams and Granara de Willink (1992), Ben-Dov (1994)
	USA	Ben-Dov (1994)
	China	Ben-Dov (1994)
	Argentina	Williams and Granara de Willink (1992), Ben-Dov (1994)
	Portugal	Carvalho and Aguiar (1997)
Nipaecoccus viridis (Newstead)	India	Ali (1957), Williams and Watson (1988), Mani and Krishnamoorthy (2002)
	Australia	Ben-Dov (1994)
	Iraq	Abdul Rassoul (1970)
	USA	Sharaf and Meyerdirk (1987)
	Middle East	Ben-Dov (1985)
	Bangladesh, China, Japan	Ben-Dov (1994)
	Taiwan	Lo and Tao (1966)
	Israel	Bar Zaki et al. (1988)
	Jordan	Sharaf (1997)
	Bhutan	Williams (2004)
Paracoccus burnerae (Brain)	India	Ben-Dov (1994)
	South Africa	Ben-Dov (1994)
	Yemen	Marotta et al. (2001)
Paracoccus glaucus (Maskell)	New Zealand	Ben-Dov (1994)
Paracoccus interceptus Lit	India	Williams (2004)
	Malaysia, Thailand	Williams (2004)
	Philippines	Lit (1997)

(continued)

Table 39.1 (continued)

Species	Region/Country	References
Paracoccus marginatus (Williams and Granara de Willink)	Mexico	Miller and Miller (2002)
	USA	Ben-Dov (1994), Miller and Miller (2002)
	Ghana	Cham et al. (2011)
	Palau	Muniappan et al. (2006)
	Florida	Walker et al. (2003)
	Sri Lanka	Galanihe et al. (2010)
Paracoccus tripurae Williams	India	Williams (2004)
Phenacoccus madeirensis Green	Many countries	Ben-Dov (1994)
Phenacoccus manihoti Matile-Ferrero	Ethiopia and Neotropical region	Ben-Dov (1994)
Phenacoccus solenopsis Tinsley	India	Suresh and Chandra Kavitha (2008)
	Pakistan	Arif et al. (2009)
	USA	McKenzie (1967)
Phenacoccus solani Ferris	–	Ben-Dov (1994)
Phenacoccus tucumanus Granera de Willink	Neotropical	Ben-Dov (1994)
Planococcus citri (Risso)	India	Williams (2004), Ben-Dov (1994); Krishnamoorthy and Singh (1987)
	Australia	Williams (1985); Ben-Dov (1994)
	South Africa	Ben-Dov (1994)
	USA	Ben-Dov (1994)
	Argentina	Granara de Willink (1991); Ben-Dov (1994)
	Morocco	Abdelkhalek et al. (1998)
	Hawaii	Bartlett (1977)
	Queensland	Murray (1978)
	Black Sea coast	Rubtsov (1954)
	France	Pussard (1938); Panis (1979)
	Spain	Martinez-Ferrer et al. (2003)
	Italy	Ortu and Pruta (1985)
	Israel	Bartlett (1977)
	Portugal	Ferriera (1939)
	Peru	Bartlett (1977)
	Chile	Gonzalez and Rojas (1966)
	Palestine	Bodenheimer (1951)
	Cyprus	Krambias and Kontzonis (1980)
	Greece	Argyriou (1974)
	Brazil	Gravena (2003)
	Sudan	Tag Elsir and Osman (2011)
	Turkey	Ozkan et al. (2001)
	Bermuda	Bartlett (1977)
	Portugal	Franco and Marotta (1999)
	Yemen	Marotta et al. (2001)
	European Russia, Soviet Central Asia, Turkmenia, Georgia	Niyazov (1969)
Pl. kraunhiae (Kuwana)	California	Smith and Armitage (1931)

(continued)

Table 39.1 (continued)

Species	Region/Country	References
Planococcus minor (Maskell)	India	Williams (2004); Ben-Dov (1994)
	Australia	Ben-Dov (1994)
	Fiji	Williams and Watson (1988); Ben-Dov (1994)
	Madagascar	Ben-Dov (1994)
	Mexico	Williams and Granara de Willink (1992); Ben-Dov (1994)
	Uruguay	Granara de Willink et al. (1997)
	New Zealand	Williams and Butcher (1987); Cox (1987)
	Argentina	Granara de Willink (1991)
Planococcus lilacinus (Ckll.)	India	Mani (1995a, b)
	Philippines	Williams (2004)
Planococcus minor (Maskell)	–	Ben-Dov (1994)
Planococcoides robustus (Ezzat and McConnell)	Bangladesh, India, Pakistan	Williams (2004)
Plotococcus minutus (Hempel)	Brazil	Ben-Dov (1994)
Plotococcus neotropicus Williams de Granara	Neotropical region	Ben-Dov (1994)
Pseudococcus baliteus Lit and Calilung	India, Thailand, Indonesia, Vietnam	Williams (2004)
Pseudococcus cryptus Hempel (*Pseudococcus citriculus* Green)	India	Williams (2004)
	Sri Lanka	Green (1922)
Pseudococcus citriculus Green	USA	Williams and Granara de Willink (1992)
	Micronesia	Beardsley (1966)
	Israel	Blumberg et al. (1999a, b))
	Bhutan, Bangladesh, Indonesia, Nepal, Philippines, Malaysia, Sri Lanka	Williams (2004)
	Israel	Ragusa and Swirski (1977)
	Japan	Itioka and Inoue (1996)
	Israel	Rosen (1967)
Pseudococcus calceolariae (Mask.)	California	Luck and Forster (2003)
	New Zealand	Cox (1977)
	Italy	Rotundo et al. (1980)
	Portugal	Franco and Marotta (1999)
Pseudococcus comstocki (Kuwana)	–	Ben-Dov (1994)
Pseudococcus cryptus Hempel	India, Thailand	Williams (2004)
Pseudococcus fragilis Brain	Italy	Viggiani (1970)
	California	Smith and Armitage (1931)
	Abkhazia	Stephanov (1935)
	Italy	Viggiani (1970)

(continued)

Table 39.1 (continued)

Species	Region/Country	References
Pseudococcus longispinus (Targioni Tozzetti)	India	Williams (2004)
	Australia	Williams (1985); Ben-Dov (1994)
	Philippines	Lit and Calilung (1994)
	USA	Ben-Dov (1994)
	Java	Betrem (1937)
	China	Ben-Dov (1994)
	Italy	Marotta (1987)
	Israel	Wysoki et al. (1977)
	Morocco	De Lepiney and Mineur (1932)
	Portugal	Franco and Marotta (1999)
Ps. comstocki (Kuw.)	California	–
Pseudococcus kikuyuensis James	Sudan,Kenya	Ben-Dov (1994)
Pseudococcus maritimus Ehrh.	USSR	Timofeeva (1979)
Pseudococcus odermatti Miller and Williams	India	Williams (2004)
	Hawaii, USA, China, Japan, Bahamas	Miller and Williams (1997)
Pseudococcus pseudofilamentosus Betrem	Java	Williams (2004)
Pseudococcus trukensis Beardsley	Caroline Islands	Ben-Dov (1994)
Pseudococcus viburni (Signoret) *(Ps. obscurus* (Maskell))	Portugal	Franco and Marotta (1999)
	California	Bartlett (1977)
Puto yuccae (Coquillet)	Texas	Ben-Dov (1994)
Rastrococcus iceryoides (Green)	India	Ali (1968), Sinha et al. (1985), Williams (1989); Williams (2004), Ben-Dov (1994)
	Kenya	Williams (1989)
	Bangladesh	Williams (2004), Williams (1989), Ben-Dov (1994)
	Sri Lanka	Green (1922), Williams (2004), Ben-Dov (1994)
	China	Ben-Dov (1994)
Rastrococcus invadens Williams	India	Williams (1989), Ben-Dov (1994)
	Ghana	Williams (1989), Ben-Dov (1994)
	Bangladesh	Ben-Dov (1994)
	Sri Lanka	Williams (1989), Williams (2004), Ben-Dov (1994)
	Africa	Williams (1986b)
Rastrococcus mangiferae (Green)	India	Ali (1968), Ben-Dov (1994), Williams (2004)
	Sri Lanka	Green (1896), Ben-Dov (1994), Williams (2004)
	Malaysia, China	Ben-Dov (1994)
Rastrococcus rubellus Williams	Malaysia, Indonesia	Williams (2004)
Rastrococcus spinosus (Robinson)	India	Williams (1989), Williams (2004)
	Bangladesh	Williams (1989), Williams (2004)
	Indonesia, Malaysia, Vietnam	Williams (2004)
Rastrococcus vicorum Williams and Watson	Malaysia	Williams (2004)
Rhizoecus kondonis Kuw.	Japan, China	Kawai and Takagi (1971) Huang et al. (1983)

39.2 Damage

Nymphs and adult mealybugs suck the sap from shoot, leaf, bark, stem, flowers and fruits. Fruit production is often adversely affected due to the mealybug damage in citrus. There is an upward trend in the build-up of mealybugs adversely affecting the growth of citrus plants of all ages from young seedlings to grown-up trees, which occasionally attain epidemic forms in citrus. In addition, the sticky honeydew excreted by the mealybugs serves as a substrate for the growth of sooty mould interfering with photosynthesis (Butani and Srivastava 1999). The mealybug infestation on citrus plants ranged from 38 to 65 % in India. Fruits covered with mealybugs and sooty mould lose the market value (Bindra 1970; Rao et al. 2001). In recent years, the incidence of mealybugs causing losses to citrus has been reported from peninsular India (Krishnamoorthy and Singh 1987), the north-east region (Pathak et al. 1999; Shylesha and Pathak 1999) and Punjab (Arora et al. 1999) on different citrus cultivars. *Maconellicoccus hirsutus* is known to inject toxic saliva into the plant while feeding, which results in malformation of leaf and shoot growth, stunting and occasional death. Leaves show a characteristic curling, while heavily infested plants have shortened internodes leading to resetting or a 'bunchy top' appearance (Mani and Krishnamoorthy 1999).

N. viridis on lime

P. citri on lime

F. virgata on pomelo

M. hirsutus on *lime*

39.3 Seasonal Incidence

Mealybugs are most common during the spring and early summer. Several overlapping generations occur in a year. Mealybugs prefer humid conditions and are most often found in groves planted on heavier soils or closely planted trees where a great deal of tree shading occurs. Damage is most severe during summer months. In central India, the pest incidence was heavy during February–May (74.89–100 %) and low during monsoon, which is during August–October (57 %). Heavy infestation during April–May causes more than 50 % fruit drop of *Ambia* (Kalidas and Shivankar 1994). In North Eastern Hilly region of India, 2.9–74.3 % infestation was recorded on various citrus species (Pathak et al. 1999). For sampling underneath, the calyx is the best place to search when there are extremely low population densities (Meyerdirk et al. 1981). In grapefruit groves, mealybugs persist in high numbers throughout the summer and into the fall. Reproduction in the greenhouse can occur year-round, leading to continuous populations of mealybugs. In India, *F. virgata* was found throughout the year though it prefers dry weather, and a prolonged period of drought may result in heavy outbreak of pest, when the insects move even more below and inhabit the roots (Butani and Srivastava 1999).

39.4 Natural Enemies

Several natural enemies have been identified that are effective in controlling the citrus mealybug. *Leptomastidea abnormis* (Girault), *Leptomastix dactylopii* Howard, *Chrysoplatycerus splendens*

Howard and *Anagyrus pseudococci* (Girault) are common wasps of *P. citri*. Some mealybugs are susceptible to infections by the entomopathogenic fungus, *Entomophthora fumosa.* Common predators include the brown lacewing, *Sympherobius barberi* (Banks), and the green lacewing, *Chrysopa lateralis* Guérin, trash bugs, syrphid fly larvae, and the scale-eating caterpillar, *Laetitia coccidivora*, the Australian ladybird beetle, *Cryptolaemus montrouzieri* Mulsant, the little mealybug-eating lady beetle, *Decadiomus bahamicus* (Casey) and the pictured ladybeetle, *Scymnus flavifrons* Melsheimer, which feed primarily on mealybugs. Two other lady beetles, *Chilocorus stigma* (Say) and *Olla abdominalis* var. *plagiata* (Say), occasionally feed on mealybugs (Muma 1954).

In India, *Anagyrus* sp., *Blepyrus insularis* (Cam.), *Diversinervus* sp., *Tetrastichus* sp., *Microterys* sp., *Cryptochaetum* sp., *Scymnus coccivora* Ayyar, *Pullus pallidicollis* Mst., *Nephus* sp., *Chrysopa* sp., *Micraspis cardoni* (Wse.), *Pseudaspidimerus uttami* Kap., *Cryptolaemus montrouzieri* Muls. and *Spalgis epeus* Westwood were recorded on mealybugs in Kodagu, Karnataka (Singh 1990). *Coccidoxenoides perminutus* (Timberlake), *Mallada boninensis* (Okamoto), *Plesiachrysa lacciperda* (Kimmins), *Anisochrysa basalis* Walker and *Chrysoperla carnea* (Steph.) (Krishnamoorthy and Mani 1988a,1989a, b; Krishnamoorthy and Mani 1988b) were recorded in Karnataka. In Assam, *C. montrouzieri* and *Entomophthora fumosa* Speare were observed on *P. citri* (Chowdhury and Majid 1954). In central India, *Cacoxenus perspicax* and *Promuscidea unfasciativentris* were observed on *P. citri. C. montrouzieri* is known to consume about 3,300 eggs of *P. citri*. The eggs as well as other stages of mealybug are essential in the diet for successful development of the predator (Oncuer and Bayhan 1982).

Cryptolaemus on *P. citri*

Adult *Cacoxenus perspicax*

Maggot *C. perspicax*

Scymnus larva on *P. citri*

Mallada larva on *P. citri*

Cryptolaemus on *P. citri*

39.5 Varietal Tolerance/ Susceptibilty

In Meghalaya, three micropropagated varieties, namely Assam lemon (*Citrus limon* (L.) Burm. f.), Satkara (*C. macroptera* Montrouz) and pumelo (*C. grandis* Osbeck), were found to be highly resistant to *P. citri* (2.95–17.72 % leaf infestation), which can be used as rootstock. Soh bitara (*C. sinensis* L.) and sweet lime (Sour mutant) (*C. limmettioides* Tanaka) were found to be moderately resistant (20.65–30 % leaf infestation) and Indian wild orange (*C. indica* Tanaka) was found to be moderately susceptible. The varieties Jaintia lemon, *C. limon,* Khasi papeda, *C. latipes* (Swingle) Tanaka, Adajamir, *C. assamensis* R.M.Dutta and Bhattacharya, Volkamer lemon, *C. volkameriana* Tan. and Pasq., Khasi mandarin, *C. reticulata* Blanco and Sohmyndong and *C. jambhiri* Lush were found to be highly susceptible to *P. citri* and suffered 61.2–74.3 % foliage infestation (Pathak et al. 1999).

39.6 Management

An integrated approach is needed to manage the mealybugs in citrus orchards (Franco et al. 2004).

39.6.1 Monitoring

Sampling of the mealybugs prior to fruit colonization is difficult during the spring and it is an obstacle to mealybug management. Monitoring population densities is based on the male capture using traps baited with female sex pheromones. At the orchard level, the diverse population density between the plots allowed significant linear relationship in certain trapping periods between male capture and fruit infestation. Information on the level of male capture in spring or early summer by application of pheromone traps may be used to predict the mealybug density or the percentage of fruit infestation and consequently to assist in the decision-making for the purpose of citrus mealybug (CM) management (Franco et al. 2001).

39.6.2 Cultural Control

Processes such as pruning of affected shoots during winter, opening up of the canopy from the centre to allow sufficient sunlight interception below the canopy, destruction of ant colonies in the orchards as they act as the carriers of mealybugs to their feeding sites and raking of the soil around the trunk during summer months help in the desiccation of eggs and exposure of the mealy bugs to natural enemies. The smearing of sticky band of 7–8 cm around the trunk at about 0.5 m height from the ground during the second week of December helps to trap the ascending nymphs, and the debarking and destruction of the harbouring population help in checking the pest (Shivankar and Shyam Singh 2000; Michelakis and Hamid 1995). Thorough cleaning of equipment and harvest materials helps in preventing the spread of mealybugs from an infested grove to other plant parts (Kerns et al. 2004). In California, banding the trees with sticky tree-tangle foot or baiting for ants is recommended to protect citrus plants from the Argentine ants that interfere with the activity of natural enemies

39.6.3 Chemical Control

Chemical control of citrus mealybugs is often an inefficient management strategy due to their habit of hiding in crevices between foliage and fruit. Horticultural soaps and oils can be effective in controlling mealybugs; they are most effective if applied before an infestation. Applying soaps and oils kills mealybugs that are exposed, but may not reach those that are hidden in well-concealed areas. High-pressure water sprays are moderately effective in achieving control. A powerful force pump and penetrating insecticide can be used to control mature insect populations. Repeated application of horticultural soaps for young insects has also been recommended. Pre- and post-bloom spray applications are recommended for management of mealybugs. Applications made before spring flush have been found to be the most effective strategy for citrus mealybug management. After the spring flush, sprays should be applied immediately after most of the eggs have hatched to prevent the crawlers from hiding themselves in crevices

The intervention threshold for *P. citri* on Nagpur mandarin was reported to be 5–10 % infested fruits in summer and 15 % infested fruits in autumn (Shivankar and Shyam Singh 2000). Spraying of 1.5 ml dimethoate + 2.5 ml kerosene oil in 1 l water or 1 ml carbaryl + 1 ml kerosene oil or 2 ml malathion in 1 l water checks mealy bugs effectively. Spraying with chlorpyriphos 0.05 %, carbaryl 0.1 % or fenitrothion 0.05 % (Jadhav et al. 1997; Jadhav and Pujari 1999) and also with 2 ml dichlorvos + 25 g fish oil rosin soap in 1 l water resulted in 75 % of reduction in mealybug population. Since the pest harbours under the loose bark, debarking by treating with chlorpyriphos and methyl parathion (both at 4 ml/l) helps in minimizing the pest population (Mani and Krishnamoorthy 1996). The settling of crawlers on the plant was reduced by swabbing it with carbaryl (1 %), used for trunk borer management (Shylesha and Pathak 1999). Chlorpyriphos performs very well against the citrus mealybug; but, since this product is especially harmful to parasitoids, it is not considered to have a good fit in the integrated pest management (IPM) programmes, where parasitoid conservation is emphasized.

Citrus oil mixed with chlorobenzilate is effective against first-instar nymphs of the mealybugs in an integrated control programme (Meyerdirk et al. 1981). On grapefruit in the Spanish Province of Castellon against *Planococcus citri,* spot treatments on the trunks and main branches of the trees provided complete control. The products tested contained 50 % fenitrothion, a mixture of 50 % fenitrothion + 40 % dimethoate, 50 % omethoate, 40 % methidathion, 40 % dimethoate or 50 % dichlorvos (Limon de la Oliva et al. 1972). In California, dimethoate remained effective for 3 months against *Planococcus citri* (Risso), a serious pest attacking the greenhouse crops.

Soil injection of imidacloprid (Admire) at 16 and 32 oz/ac appeared to have a very good activity against *P. citri* (Kerns et al. 2004).

Chemical control of *Pseudococcus longispinus* was most effective if sprays were applied when the mealybugs were in the dispersive crawler stage and when the food-plant afforded the least shelter. A two-spray programme with applications in August and late November effectively controlled a dense infestation on citrus. An overall pest management programme has been developed for citrus, in which all the insect pests are controlled by combinations of natural enemies and insecticides as required. Outbreaks of *Ps. longispinus* and other secondary pests are controlled by sprays of aminocarb and methomyl. These two insecticides prevented the resurgence of the mealybug in the subsequent generation that occurred when malathion was used (Furness 1977). *N. viridis* is susceptible to treatments of methidathion and chlorpyriphos. On heavy infestations, repeated treatments are essential (Bar Zaki et al. 1988). Effective control was achieved by Mospilan (acetamiprid 20 soluble powder (SP)) 0.05 % and 0.075 % sprayed on small fruits or by 0.3 % chlorpyrifos at both stages of the development of *N. viridis* (Gross et al. 2000).

39.6.4 Insect Growth Regulators

Buprofezin, an insect growth regulator, showed strong ovicidal activity resulting in more than 80 % inhibition of egg hatch and 91–99 % nymphal mortality of *P. citri* (Mendel et al. 1991). It was an effective treatment and should be considered for the citrus mealybug control to avoid destruction of parasitoids.

The addition of narrow-range crop oil, NR-415 at 1.0 gal/ac, appeared to be beneficial for initial mealybug knock-down, especially for the slower-acting insecticides such as buprofezin. ZR-777 (prop-2-ynyl 3,7,11-trimethyl-(2E,4E)-dodecadienoate), which exhibits high morphogenetic activity against the species of Homoptera, gave good control of nymphs in all instars receiving 0.01 % sprays (Staal et al. 1973). In grapefruit orchards, 0.025–0.10 % kinoprene, 0.025 %

CGA-13353 [ethyl3-methyl-4-[4-(phenylmethyl) phenoxy]-2-butenoate] and 0.025–0.10 % epofenonane (Ro 10–3108) gave good control of citrus mealybugs compared to the control that was obtained with 0.06 % dimethoate. In tests on the efficacy against specific life stages, both insect growth regulators and conventional insecticides were most effective against first-instar nymphs and least effective against adults (French and Reeve 1979). In Egypt, the insect growth regulator methoprene (Altosid) applied by spraying on the infested citrus leaves at 0.01 and 0.05 % gave satisfactory suppression of populations of the citrus pest *Planococcus citri*. Concentrations of 0.1 and 0.5 % gave 100 % suppression of mealybugs (Hamdy 1984).

Leptomastix dactylopii

39.6.5 Biological Control

Pesticides were frequently used, often unsuccessfully to control the citrus mealybugs (Shrewsbury et al. 2004). On the other hand, natural enemies proved to be effective against several mealybug species attacking citrus.

39.6.5.1 Citrus Mealybug – *Planococcus citri*

The encyrtids, *Leptomastidea abnormis* and *Leptomastix dactylopii*, and the coccinellid, *Cryptolaemus montrouzieri*, are the three natural enemies frequently used for biological control of the citrus mealybug *Planococcus citri* (Cadee et al. 1997). These three encyrtids are used in several countries including Austria, Belgium, Czechia, Denmark, Finland, France, Germany, Greece, Guernsey, Ireland, Italy, Jersey, Netherlands, Norway, Poland, Portugal, Russia, Slovakia, Spain, Sweden, Switzerland, Tunisia, UK indoors/outdoors and Mediterranean area.

The Brazilian encyrtid parasitoid, *Leptomastix dactylopii* How., is a highly specialized parasitoid of the citrus mealybug *Planococcus citri.* It is a very efficient parasitoid and particularly good at seeking out mealybugs in their natural hiding places. Because of this trait, *Leptomastix* is able to control mealybugs in low-density infestations. This parasitoid multiplied in 15–20-day-old *P. citri* (Krishnamoorthy 1988) and *P. lilacinus* (Mani 1995a). The mummies of *L. dactylopii* could be stored for about 20 days at 15 °C and 70–80 % RH. It is to be released at 7,500 wasps/ha as three releases of 2,500 wasps/ha at intervals of 2 weeks.

California

Biological control efforts against the citrus mealybugs, chiefly *P. citri*, in California started with the introduction of *C. montrouzieri* in 1891–1892. It readily cleaned up the infestations but subsequently proved to be generally slow in response and unable to survive in winter eventually persisting only along the coast (Clausen 1915). Complete control of *P. citri* in some orchards in California was obtained with the continued liberations of large numbers of *C. montrouzieri* (Smith 1919). After being colonized in citrus mealybug-infested orchards in California, these ladybird beetles sometimes showed remarkable ability to destroy many kinds of mealybugs (Hoyt 1912). Later, great interest was stimulated in this method of periodic colonization. Subsequently, many insectaries were established and periodic colonization of *Cryptolaemus* reached a peak in the 1920s against citrus mealybugs. Ten beetles per tree during summer were adequate for the control of most of the infestations of the mealy bugs. More than 40 million beetles were released over some 50,000 acres of citrus during 1926–1927 (Essig 1931). In 1928, over 42 million beetles were released in citrus in California. An average of 23 adults were released per tree and over one million trees received liberations (Beckley 1956). In addition, the number of outbreaks of *P. citri* was reduced due to the presence of *Cryptolaemus* (Clausen 1956). The outstanding reduction in citrus mealybug was related to the peak period of *Cryptolaemus* activity. The predator was more active in late April and the activity started decreasing in June as the mealybug population declined (Bartlett 1957). It was, however, rated as partial control (Debach and Hagen 1964). In the later years, the citrus mealybug was kept under check by the periodic colonization of *C. montrouzieri* along with the encyrtid *Leptomastix dactylopii* Howard (Beckley 1960). The Brazilian encyrtid parasitoid, *Leptomastix dactylopii* How., was utilized in the suppression of the mealy bug *Planococcus citri* in USA (Fisher 1963).

Florida

C. montrouzieri was introduced into Florida in 1930 for the control of *P. citri* on citrus and bulbs. Despite permanent establishment, it failed to survive in sufficient numbers from year to year for adequate control (Bishop 1931; Watson 1932; Muma 1954).

Hawaii

P. citri was partially controlled by *C. montrouzieri* that was accidentally introduced in Hawaii (Bartlett 1977).

USSR

C. montrouzieri was used to control *P. citri* in Black Sea coast (Rubtsov 1954). In the Soviet Union, *Planococcus citri* (Risso) is injurious to over 20 species of plants, including *Citrus*. The main parasite of *P. citri* is *Anagyrus pseudococci* (Gir.), which occurs in the south of European Russia and in Soviet Central Asia and which destroys up to 75 % of the coccid population in areas not treated with insecticides. *Allotropa mecrida* (Wlk.), the second most important parasite, was reared from the coccid in Turkmenia in 1967 and is responsible for up to 20 % parasitism in Georgia. In 1960, *Leptomastidea abnormis* (Gir.) and *Leptomastix dactylopii.* How were introduced into Georgia and subsequently into Turkmenia from the United States (Niyazov 1969).

France

C. montrouzieri was introduced in France from California in July 1918 against *P. citri* (Turinetti 1921). The predator became established and produced a marked reduction in the numbers of *P. citri*. But its overwinter survival was low (Marchal 1921; Anonymous 1922; Poutiers 1922; Marchal and Pussard 1938). An outbreak of *P. citri* at Cap d'Antibes was checked by *C. montrouzieri* without any liberation of the predator at that time. It might be due to the development of adapted strain from the beetles released earlier in the 1920s (Pussard 1938).

Spain

Planococcus citri is a major pest of citrus in Spain (Martinez-Ferrer *et al*. 2003). *C. montrouzieri* became established some time before 1928 and good results were obtained. Periodic colonization was also successful in controlling the mealybug (Gomez 1932). Repeated releases of *C. montrouzieri*, when the mealybug resumes activity after winter, were suggested (Limon de la Oliva and Blasco Pasaral 1973). *P. citri* was also controlled by *C. montrouzieri* in citrus orchards of Valencia except in winter (Carrero 1981). In Malaga (Spain), the biological control of *P. citri* was successful when the infestation with citrus mealybug on the fruit became lower than 5 % for at least 2 months after the *C. montrouzieri* release. With the data collected, a probability model was designed based on the logistic regression method, which allowed to define the release doses suitable for every initial-incidence level of *P. citri* (Olivero et al. 2003). In Spain, there were decreasing populations of *P. citri* due to the presence of natural enemies, chiefly *C. montrouzieri* (Villalba et al. 2006).

Italy

The permanent establishment of *C. montrouzieri* was achieved in certain warm areas, through a number of importations beginning from 1908 (Constantino 1935). In Nervi, the predator although got established and spread, it was not found in abundance (Capra 1927; Paoli 1927). In Sicily, *C. montrouzieri* was released in more than 1,000 citrus orchards and satisfactory control was achieved (Liotta and Mineo 1963). Good control was also achieved in 1964 when the predator was liberated in August. After a month, it has spread to 220 yards, and after 2 months to 550 yards providing complete control (Liotta and Mineo 1965). Thus, the control was achieved by periodic colonization, which helped to overcome winter mortality (Mineo 1967). In Sardinia, the introduction and release of *Cryptolaemus* with *Leptomastix dactylopii* have resulted in the reduction of the number of sprays from three to one in 1981 (Ortu 1982). The predator has adapted satisfactorily to the climate of Sardinia (Ortu and Pruta 1985). Introduction of *C. montrouzieri* from Sicily into Campania region of mainland Italy was made. Since 1973, the predator survived at released sites and spread subsequently to a large citrus area of Angri-Corbera. In 1977, *Cryptolaemus* was found to be abundant in this area and some localities around Portici (Mazzone 1977). In Sardinia, 12,000 individuals of the coccinellid were liberated in five releases. The use of *C. montrouzieri* and other biocontrol agents led to a drastic reduction in the use of synthetic insecticides against *P. citri* on citrus (Fronteddu et al. 1996). In Sicily, *C. montrouzieri* was mass-reared and released against *P. citri* on citrus (Raciti et al. 1995). New introductions of *Leptomastix dactylopii* How. to the Campania region of Italy and Sicily were made in 1974, and the encyrtid became established in some *Citrus*-growing areas (Mineo and Viggiani 1976). The Brazilian encyrtid parasitoid, *Leptomastix dactylopii* How., has been utilized in the suppression of the mealy bug *Planococcus citri* in the Island of Procida and Italy (Luppino 1979).

Israel

Attempts were made to establish *C. montrouzieri* by importing it from Egypt in 1924 (Bodenheimer and Guttfeld 1929) and later in 1941 and 1958 but without success in permanent establishment (Bartlett 1977).

Portugal

C. montrouzieri was introduced from Spain in 1929. The released beetles had survived in the field and spread but the predator did not give complete control of *P. citri* (Ferriera 1939).

Peru

The predator, *Leptomastix dactylopii*, introduced from USA did not establish on *P. citri* on infesting citrus (Wille 1936). *Leptomastix dactylopii* has also been used to control *P. citri* in Peru (Bartlett 1977).

Chile

C. montrouzieri was colonized in 1931, 1933 and 1939. It proved effective when released in large numbers, but it was to be liberated each year since it did not establish permanently (Duran 1944; Gonzalez and Rojas 1966).

Australia

The predator was brought from New South Wales in 1902 to Eastern Australia for the control of the citrus mealybugs. It was readily established and effective control was obtained. Its introduction is regarded as the outstanding biological control success (Wilson 1960).

South Africa

The liberations of *C. montrouzieri* were made in the citrus mealybug-infested orchards from early January, and good control was obtained in every instance (Bishop 1931). The biological control of the citrus mealybug by *C. montrouzieri* was rated as complete control in South Africa (Greathead 1971). *Allotropa kamburovi* sp. n., recovered from *Planococcus citri* (Risso), is derived from citrus in Western Transvaal, South Africa (Annecke and Prinsloo 1977). *Cryptolaemus montrouzieri* is used in augmentation programme in the control of *P. citri* on citrus in South Africa (Moore and Hattingh 2004).

Palestine

No practical success in the control of *P. citri* was observed with *C. montrouzieri* (Bodenheimer 1928, 1951).

India

During 1963–1965, the release of the coccinelllid, *C. montrouzieri*, did not result in establishment in the citrus orchards, located 20 miles away from Gauhati, India. It might be due to the activity of the ant *Oecophylla smaragidina* (Narayanan 1957). A release rate of ten beetles per Coorg mandarin orange tree was suggested for the control of citrus mealybug in Karnataka (Singh 1978). Following the release of *C. montrouzieri* at 2000/acre (ac) on acid lime plants, the population of mealybug (*P. citri*) was declined from 126.64 in August 2003 to 0.4/plant in November 2003. A mean of 99.68 % reduction in the mealybug population on acid lime was achieved by the predator within 3 months of its release (Mani and Krishnamoorthy 2007). In the pummelo orchard, the population of *P. citri* declined from 313.84/plant in August 2005 to 2.63/plant in October 2005 following the release of *C. montrouzieri* at 30 larvae/plant in August 2005 (Mani and Krishnamoorthy 2008). Several green lace wings preying on mealybugs have been reported from India (Krishnamoorthy and Mani 1988a).

The encyrtid parasitoid *Coccidoxenoides peminutus* played a dominant role in the suppression of *P. citri* on acid lime and lemon in India (Mani 1994). The parasitoid was multiplied on 5–10-day-old laboratory-bred *P. citri*. Several plant products and deltamethrin were found to be safer to *C. perminutus.* The exotic parasitoid *Leptomastix dactylopii* was imported from West Indies to India during 1983 for trials against *P. citri* (Nagarkatti et al. 1992). Releases of *L. dactylopii* gave excellent control of *P. citri* causing up to 100 % parasitism in citrus orchards in Karnataka (Manjunath 1985; Krishnamoorthy and Singh 1987; Nagarkatti et al. 1992; Krishnamoorthy 1990). *L. dactylopii* released in April 1984 was recovered in large numbers from *P. citri* infesting acid lime and lemon in 1991–1992 (Mani 1994). Later *L. dactylopii* was recovered from *P. citri* infesting several horticultural crops (Krishnamoorthy and Mani 1989c). Dichlorvos, dicofol, several fungicides and plant products are safer to *L. dactylopii* (Mani et al. 1993). When *L. dactylopii* and C. *perminutus* were found together, with the latter one playing a dominant role in suppressing *P. citri.* However, *L. dactylopii* is known to prefer the late-nymphal instars of *P. citri* (Krishnamoorthy 1988), while C. *perminutus* is known to attack preferentially the early-nymphal instars (Krishnamoorthy and Mani 1988b). *L. dactylopii* had not displaced the local *C. peminutus* in Bangalore. Under this situation, C. *perminutus* was largely responsible for the control of *P. citri* in both the orchards. Similar control of *P. citri* on grapefruit was achieved in April when C. *perminutus* was abundant in October in Texas (Dean et al. 1971). The same parasitoid has also been used to control *P. citri* in Peru and Bermuda (Bartlett 1977). In India, the mealybug infestation was first noticed in the second week of February on lemon in India. The mean number of mealybugs per five shoots was 1342.4, and initial samples, collected on 16

February 1991, yielded both *L. dactylopii* and C. *perminutus*. Both the parasitoids were active up to the second week of May. C. *perminutus* was always found to emerge in larger numbers than *L. dactylopii* from all the samples collected from February to May. It was particularly abundant in March/April, and a mean maximum of 318.5 parasitoids emerged from the samples collected on 1 April 1991. In the case of *L. dactylopii,* a mean maximum of 49.2 adults were recovered from the samples collected on 2 March 1991. There was a marked reduction in the mealybug population, which was negligible in the second week of May.

Cyprus

C. montrouzieri was imported from California and releases were carried out in 1954 and 1960 resulting in temporary establishment, but the beetles did not survive the winter (Greathead 1976). The Brazilian encyrtid parasitoid, *Leptomastix dactylopii* How., has been utilized in the suppression of the mealy bug *Pl. citri* (Krambias and Kontzonis 1980).

Greece

P. citri disappeared in 1933 as a pest after the introduction of the predator from Spain (DeBach and Argyriou 1967; Pelakasis 1974). Recoveries were also made following the introductions in 1965 and 1969 (Argyriou 1974).

Brazil

C. montrouzieri was used as a biological control agent against *P. citri* in Brazilian citriculture (Gravena 2003). The Brazilian encyrtid parasitoid, *Leptomastix dactylopii*, has been utilized in the suppression of the mealy bug *Planococcus citri* in several countries.

Turkey

C. montrouzieri was introduced into Turkey and compared with native races in the control of *P. citri* in citrus orchards. There were no significant variations in the cold hardiness, prey consumption capacity and other biological characteristics of native and introduced races of *C. montrouzieri* (Yigit and Canhilal 1998). In Turkey, *P. citri,* the main pest of citrus, was controlled by the natural enemies including *C. montrouzieri* (Ozkan et al. 2001).

Morocco

In Morocco, *P. citri* is a major pest of citrus orchards. The predator *C. montrouzieri* was used to control the mealybug pest (Abdelkhalek et al. 1998).

Bermuda

The encyrtid parasitoid *L. dactylopii* has also been used to control *P. citri* in Bermuda (Bartlett 1977).

39.6.5.2 Japanese Mealybug – *Planoccoccus kraunhiae*

An isolated infestation of *P. kraunhiae* on citrus disappeared following the release of *C. montrouzieri* in Southern California (Smith and Armitage 1931).

39.6.5.3 Oriental Mealybug – *Planococcus lilacinus*

The oriental mealybug appeared on 3-year-old acid lime plants at Indian Institute of Horticultural Research (IIHR) farm, Bangalore in September 1998. The initial sampling done on 19th September did not yield any natural enemy. Since *C. montrouzieri* is known to feed on *P. lilacinus*, releases of *C. montrouzieri* were made on 20th September and 10th October at 20/plant. Prior to the release of the predator, ants attending the mealybugs were checked. A mean of 160.50 mealybugs/shoot was observed when the study was initiated. The mealybug population had started declining following the release of *C. montrouzieri*. It was found in negligible numbers by mid-November 1998 and ceased to be a problem from January 1999. The cecidomyiid *T. coccidivora* was also observed but in negligible numbers in India.

The mealybug (*P. lilacinus)* population was first observed in April 1991. More than 35 % of fruits were found infested with *P. lilacinus*. The population of *L. dactylopii* ranged from 2.46 to 6.00, but *T. indica* was observed in large numbers ranging from 14.45 to 96.00. Due to the action of both the parasitoids, especially *T. indica*, the mealybug population was reduced by the end of July. The mealybug did not appear up to December 1991 (Mani 1995b). The 5-day-old *P. lilacinus* was found suitable for the breeding of *T. indica* (Mani and Krishnamoorthy 1995).

39.6.5.4 Citriculus Mealybug – *Pseudocccoccus cryptus* (*Ps. citriculus*)

In Israel, the imported *C. montrouzieri* released in 1924 did not successfully establish (Bodenhiemer 1928). It was again released in 1941 (Mason 1941) and 1958 (Rosen 1967), but there were no reports of permanent establishment. Four parasitoid species, *Allotropa burrelli*, *A. convexifrons*, *Pseudaphycus malinus* (from central Asia) and *Anagyrus sawadai* (from Japan), were introduced into Israel during 1996–1997 against *P. cryptus*. Only *Allotropa convexifron*s and *Anagyrus sawadai* successfully parasitized *P. cryptus* and therefore were released in the field. So far, only *A. sawadai* has been recovered. A considerable reduction in population densities of the pest has been recorded since May 1998 in the major release site (Blumberg et al. 1999a, 1999b).

39.6.5.5 Citrophilus Mealybug

Pseudococcus fragilis
(= *P. citrophilus; P. gahani*)

Release of *C. montrouzieri* was made in 1916 in Southern California and it provided some control of *P. fragilis*. At Los Angles County, 4,000,000 adults were released over an area of 4,775 acres at ten per tree. Although prolonged cool damp weather at first delayed the activities, the control for the season later became entirely satisfactory. Over 350,000 adults were released in 3-weeks' time against *P. fragilis* in California. Infestation appears to be less severe than the previous years (Anonymous 1929). The first release was suggested between 1st and 15th April when the field temperature was 70 °F and rainfall was low. Liberations were continued up to September (Armitage 1929). The beetles released at first increased to controlling numbers in the progeny of first generation of adults. Banding citrus trees benefited *C. montrouzieri* (Smith and Armitage 1931). The application of burlap bands around the trunks of infested trees attracted the mealybugs to congregate beneath the bands to oviposit. The bands also attracted the coccinellids, thereby increasing the intensity of predation. In San Francisco, serious infestations of *P. fragilis* were invariably controlled by *C. montrouzieri* (Smith 1928). In Abkhazia of USSR, complete control of *P. fragilis* was secured in 1933 by releasing 15–20 adults on severely infested tree or ten adults on slightly infested tree. The coccinellid thrived throughout the summer and autumn without being affected by high humidity and torrential rain or the maximum temperature of 35 °C (Stephanov 1935). Also in Chile, *C. montrouzieri* was utilized against *P. fragilis*. *Pseudococcus fragilis* is recorded for the first time in Italy on *Citrus* in the Province of Salerno in 1969. The heaviest infestation was on the fruits of orange, lemon and mandarin. *P. fragilis* appeared to be controlled effectively by natural enemies, especially the encyrtid *Hungariella pretiosa* (Timb.); *Dendrocerus laevis* (Ratz.) and an aphelinid of the genus *Coccophagus* were also recovered from the mealybug (Viggiani 1970).

Pseudococcus calceolariae

Cryptolaemus montrouzieri, initially introduced as a classical biological control agent for *Pseudococcus calceolariae*, in southern California, was unable to survive in sufficient numbers to provide control without augmentation. *C. montrouzieri* is still commercially available and being used in citrus to suppress the mealybug pests (Luck and Forster 2003).

39.6.5.6 Obscure Mealybug – *Pseudocccoccus obscures* (*Ps. viburni*)

The mealybug responded well to periodic releases of *C. montrouzieri* in citrus orchards of California (Bartlett 1977).

39.6.5.7 Grape Mealybug

Pseudococcus maritimus

C. montrouzieri did not give sufficient results in the control of *P. maritimus* on citrus (Timofeeva 1979).

Nipaecoccus filamentosus

Nipaecoccus filamentosus (Syn: *Pseudococcus filamentosus)* has been recorded on limes in Iran. There were four generations annually in the Fars region. *Cryptolaemus montrouzieri* has been imported from northern Iran and has proved to be effective as a biological control agent of *P. filamentosus* (Khalaf and Aberoomand 1989).

39.6.5.8 Long-Tailed Mealybug – *Pseudococcus longispimus* (= *P. adonidum*)

Sporadic outbreaks of the mealybug were often reduced by the imported parasitoids and predators including *Cryptolaemus* (Debach and Fleschner 1947). *C. montrouzieri* was used during 1959–1965 against *P. longispinus*, but the information was not available regarding the establishment (Bartlett 1977). In Italy, *C. montrouzieri* got established against *P. longispinus* on oranges (Paoli 1927). But the predator was not effective against the mealybug in Morocco (De Lepiney and Mineur 1932).

39.6.5.9 Spherical Mealybug – *Nipaecoccus viridis*

Nipaecoccus viridis (Newstead) was a severe pest on acid lime in India. Over a dozen parasitoids were recorded on *N. viridis* in India. *Anagyrus dactylopii* How. was found parasitizing up to 90 % in the field (Ali 1957; Subba Rao et al. 1965). A severe infestation of *N. viridis* (= *Pseudococcus corymbatus*) in Andhra Pradesh (India) on citrus was wiped out with the liberation of ten beetles per tree (Tirumala Rao and David 1958). Breeding and release of *C. montrouzieri* were suggested for obtaining control in early summer when *N. viridus* (= *Pseudococcus filamentosus*) were high (Lo and Tao 1966). The predator became well established against the mealybug in Hongkong (Simmonds 1971). The population of *N. viridis* declined from 221.3 on 16th March to 1.40/plant on 10th June 1994 due to the action of *C. montrouzieri* and *Anagyrus* spp. in acid lime orchard in Karnataka, India (Mani and Krishnamoorthy 2002) (Table 39.1). In the pummelo orchard, the population of *N. viridis* declined from 165.48 in August to 6.85/plant in October with the release of *C. montrouzieri* at 30 larvae/plant in August (Mani and Krishnamoorthy 2008). *Nipaecoccus viridis* (*N. vastator*) (Mask.) is considered to be one of the most serious pests in Iraq, where it attacks various economic plants especially citrus, mulberry and *Ziziphus* spp. Peaks of activity by predators and parasites of the mealybug occurred between 15 May and 15 June for *Exochomus nigripennis* (Erichs.), *Dicrodiplosis* sp., *Anagyrus pseudococci* (Gir.) and *Marietta picta* (Andre), and in September–October for *Nephus bipunctatus* (Kug.), *Chrysopa* sp., *Dicrodiplosis* sp., *A. pseudococci* and *M. picta* (El-Haidari et al. 1978). *N. viridis* invaded Israel during 1984. *Anagyrus indicus* was introduced in Israel and Jordan. The parasitoid has established well on *N. viridis* in citrus plantations in both the countries (Bar Zaki et al. 1988).

39.6.5.10 Striped Mealybug – *Ferrisia virgata*

Following the release of *C. montrouzieri* at 30 larvae/plant in August in the pummelo orchard, the population of *F. virgata* declined from 248.85 in August to 7.57/plant in October (Mani and Krishnamoorthy 2008) (Table 39.1).

39.6.5.11 Pink Hibiscus Mealybug – *Maconellicoccus hirsutus*

Release of *C. montrouzieri* reduced the mealybug population from 39.4 in January to 1.3 in mid-March on acid lime in Karnataka, India (Mani and Krishnamoorthy 1999).

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40 Fruit Crops: Guava

M. Mani

40.1 Species

Mealybugs are reported to be injurious to guava in India, Bangladesh, Taiwan, South Africa, Egypt, Pakistan, Sri Lanka, Hawaii etc (Table 40.1).

40.2 Damage

Nymphs and adults suck the sap from leaves, stem and fruits. In addition, the sticky honeydew excreted by the mealybugs serves as a substrate for the growth of sooty mould interfering photosynthesis. Severe mealybug infestation causes heavy economic losses (Mani and Krishnamoorthy 1993). In the case of *Maconellicoccus hirsutus*, the mealybug injects toxic saliva into the plant while feeding which results in malformation of leaf and shoot growth, stunting, and occasional death. Leaves show a characteristic curling, while heavily infested plants have shortened internodes leading to rosetting or a "bunchy top" appearance (Mani and Krishnamoorthy 2001). Infestations of *Ferrisia virgata* remain clustered around the terminal shoots, leaves and fruit, sucking the sap which results in yellowing, withering and drying of plants and shedding of leaves and fruit. The foliage and fruit also become covered with large quantities of sticky honeydew which serves as a medium for the growth of black sooty moulds. The sooty moulds and waxy deposits result in the reduction of photosynthetic area. Ornamental plants and produce lose their market value.

40.3 Seasonal Development

In Taichung, Taiwan, populations of both nymphs and adults of *Planococcus citri* on guava were large in the cool dry months from November to April and small in the warm wet months from July to September. Nymphal populations had 4 or 5 marked peaks between November and April, considered ideal times for insecticide applications. There was a negative relationship between mealybug populations and temperature. Incessant rainfall and heavy pruning of trees also had adverse effects on populations (Liu and Chang 1984). In India, the mealybugs are found throughout the year on guava plants but the population was found in greater numbers in summer months (February-June).

40.4 Management

Most of the insecticides do not provide adequate control of the guava mealybugs due to their concealed habitat and waxy coating over the body.

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Table 40.1 List of mealybugs recorded on guava in different countries

Mealybug species	Country/region	Reference
Chlorozococcus alami Khalid & Shafee	India	Khalid and Shafee (1998)
Crisicoccus hirsutus (Newstead)	India	Williams (2004)
Deltococcus aberiae (Delotto)	Kenya, South Africa	Ben-Dov (1994)
Dysmicoccus bispinosus Beardsley	Neotropical region	Ben-Dov (1994)
Dysmicoccus brevipes (Cockerell)	Indonesia	Williams (2004)
	Bangladesh	Ullah et al. (1993)
Dysmicoccus bispinosus (Beardsley)	Spain	Angeles Martinez et al. (2006)
Dysmicoccus debregeasiae (Green)	India	Williams (2004)
Dysmicoccus lepelleyi (Betrem)	Indonesia, Philippines, Vietnam	Williams (2004)
Exallomochlus camur sp.n.	Philippines	Williams (2004)
Exallomochlus hispidus (Morrison)	Malaysia	Williams (2004)
Ferrisia neovirgata Khalid & Shafee	India	Williams (2004)
Ferrisia virgata (Ckll)	India	Mani and Krishnamoorthy (1993)
	Bangladesh	Boucek and Bhuiya (1990)
	Italian Somaliland	Chairomonte (1933)
	South Africa	Villiers and de Stander (1978)
	Yemen	Marotta et al. (2001)
	Pakistan	Williams (2004)
Ferrisicoccus psidii Mukhopadhyay & Ghose	India	Mukhopadhyay (2005)
Maconellicoccus hirsutus (Green)	India	Baskaran et al. (2007), Jalaluddin and Sadakathulla (1998)
	Egypt	Hall (1926)
	George Town, Grand Cayman.	–
	Italian Somaliland	Chairomonte (1933)
	Philippines, Malaysia	Williams (2004)
Nipaecoccus nipae (Maskell)	Hawaii	Ben-Dov (1994)
Nipaecoccus viridis (Newstead)	India	Hayat (1981), Williams (2004)
Paracoccus marginatus Williams and Granara de Willink	India	Tanwar and Jeyakumar (2010)
	Sri Lanka	Galanihe et al.(2010)
	Australia	www.planthealthaustralia.com.au
Paracoccus interceptus Lit.	Philippines	Williams (2004)
Phenacoccus pseudopumilis Hadzibejli	Mexico	Ben-Dov (1994)
Phenacoccus sp.	Bangladesh	Boucek and Bhuiya (1990)

(continued)

Table 40.1 (continued)

Mealybug species	Country/region	Reference
Phenacoccus parvus Morrison	Ethiopian, neotropical & Pacific region	Ben-Dov (1994)
Phenacoccus peruvianus Granara de Willink	Los Angeles County	http://ucanr.edu/blogs/pestnews/index.cfm?tagname=Bougainvillea% 20mealybug
Planococcus citri (Risso)	India	Mani and Krishnamoorthy (1989)
	Bangladesh	Ullah and Parveen (1993)
	Taiwan	Liu and Chang (1984)
	South Africa	Joubert (1964)
	Egypt	El-Sebae and El-akkari (1977)
	UK	Tingle and Copland (1988)
Planococcus lilacinus Ckll.	India	Mani (1995a)
	Malaysia	Williams (2004)
Planococcus minor (Maskell) = *Planococcus pacificus* Cox	Bangladesh	Boucek and Bhuiya (1990)
	Malaysia, Sri Lanka, Vietnam, Thailand	Williams (2004)
Planococcus psidii Cox	Malaysia	Williams (2004)
Planococcus psidii sp. nov.	UK	Cox (1989)
Pseudococcus baleiteus Lit.	Thailand	Williams (2004)
Pseudococcus cryptus Hempel	Bangladesh, Bhutan, Indonesia, Malaysia, Sri Lanka, Vietnam	Williams (2004)
Pseudococcus jackbeardsley Gimpel and MilleR	Thailand, Sudan, Kenya	Williams (2004), Ben-Dov (1994)
Pseudococcus sp.	Pakistan	Muhammad Sarwar (2006)
Pseudococcus longispinus (Targioni Tozzetti)	–	Ben-Dov (1994)
Rastrococcus sp.	Bangladesh	Boucek and Bhuiya (1990)
Rastrococcus monachus sp. nov.	Malaysia	Williams (1989)
Rastrococcus iceryoides Green	India	Mani and Krishnamoorthy (1998)
Rastrococcus invadens Williams	Nigeria	Ivbijaro et al. (1992)
	Bangladesh, India, Philippines	Williams (2004)
Rasrococcus monachus Williams	Malaysia	Williams (2004)
Rasrococcus spinosus (Robinson)	Cambodia, Malaysia, Philippines	Williams (2004)
Rastrococcus vicorum Williams & Watson	Malaysia	Williams (2004)

Application of insecticides also eliminates the important naturally occurring bioagents resulting in the outbreak of mealybugs. On the other hand, the parasitoids and predators are able to suppress the mealybugs on guava (Mani and Krishnamoorthy 1990a, 2007; Manjunath 1986).

Leaf damage

P. lilacinus on guava

Pa. marginatus on Guava

Fruit damage

40.4.1 *Maconellicoccus hirsutus*

Atso, an inorganic oil emulsion spray at 3 %, gave good control of *M. hirsutus* on guava in India (Jalaluddin and Sadakathulla 1998). *C. montrouzieri* undoubtedly reduced the infestation of *M. hirsutus* on certain trees including guava in Egypt (Hall 1926). Due to release of *C. montrouzieri* against *M. hirsutus*, on guava at 20/plant, there was a reduction in the mealybug population from 918.50/plant to 4.60/plant within a month of release of the predator (Mani and Krishnamoorthy 2001). Releases of *S. coccivora* at 15 grubs per infested shoot took 42 and 56 days from the release to bring down the population of *M. hirsutus* by 38.2 (158.2/infested shoot) and 68.6 (80.6/infested shoot) percent, respectively, while at 15 adults per infested shoot, the reduction in the population of *M. hirsutus* was 44.1 (180.0/infested shoot) and 68.4 (120.8/infested shoot) percent for the same period in Periyakulam, Tamil Nadu, India (Baskaran et al. 2007).

40.4.2 *Planococcus citri*

It is a polyphagus pest causing severe damage to guava at times. In nature, *C. montrouzieri* appeared along with other natural enemies in the mealybug infested orchards and brought down the mealybug population in India (Manjunath 1986; Mani and Krishnamoorthy 1990a, b). In some guava orchards, *P. citri* was found suppressed by *S. epeus, C. lacciperda* and *C. montrouzieri* in nature (Mani and Krishnamoorthy 1990a).

Natural enemies of guava mealybugs

Cryptolaemus clearing the mealybugs

Aenasius advena

Scymnus coccivora

Releases of the exotic parasitoid *Leptomastix dactylopii* were found to be highly effective against *P. citri* in guava orchards (Mani 1994). In a guava orchard in Bangalore North, initial samples collected on June 14, 1990 revealed the presence of exotic parasitoid *L. dactylopii* but at a very low level. At the same time, the mean mealybug population was 1,084. This was due to indiscriminate application of insecticides like methyl parathion, monocrotophos and BHC against *P. citri.* However, after the suspension of insecticidal sprays, the population of *L. dactylopii* started increasing. It was found in large numbers between 23rd July and 4th August, 1990. Natural enemy complex of *P. citri* consisted of the encyrtid parasitoid, *Coccidoxenoides perminutus* (Timberlake) and the gregarious platygasterid *Allotropa* sp. besides *L. dactylopii.* C. *perminutus* was observed in small numbers, but, *Allotropa* sp. emerged in large numbers in the late samples collected in August-September. Indigenous predators like the lycaenid *Spalgis epeus* Westwood and *Chrysopa* sp. were noticed in very low numbers. Due to build-up of the population of the parasitoids especially *L. dactylopii*, the population of *P. citri* gradually declined from 1,084 in May to 1.42 in September, 1990. The mealybug population was negligible after September, 1990 to December, 1991 (Mani 1994).

In another guava orchard also in Bangalore North, a mean mealybug population of 1954 was observed in February 1991. A total of 2,000 *L dactylopii* was released in February, 1991. The parasitoid was recovered only after the releases made in March. The samples collected between 23rd March and 10th May, 1991 yielded a large number of adult *L dactylopii* (Table). However, the local natural enemies like C. Natural enemy complex of *P. citri* consisted of the encyrtid parasitoid, *Coccidoxenoides perminutus* (Timberlake), the gregarious platygasterid *Allotropa* sp. besides *L. dactylopii.* In general, C. *perminutus* was observed in small numbers in the present study. But, *Allotropa* sp. emerged in large numbers in the late samples collected in August-September, *Chrysopa* sp. and *C. montrouzieri* Muls. remained at a very low level throughout the study. *P. citri* once found in very high numbers in February, 1991 almost completely disappeared by the end of May 1991, and the mealybug was kept under check up to December, 1991 (Mani 1994).

Allotropa sp.

Coccidoxenoides perminutus

Neem oil and pongamia oil (both at 4 %) are recommended for the control of *P. citri* on guava; they caused 93.23 and 89.39 % mortality of the pest, resp., 10 days after the second spray (applied 10 days after the first) (Hussain and Puttaswamy 1996).

At Taichung, Taiwan, insecticide treatments were generally more effective against nymphs than adults. Spray applications made two or three times at intervals of 7–10 days prior to population build-up gave the best control. Application of omethoate, methidathion, formothion and dimethoate at various rates gave effective control of *P. citri*. However, treatment with mixtures of malathion with methidathion or formothion, each applied at half the rate when used alone, gave effective and economic control, without being phytotoxic (Liu and Chang 1984).

Introduction of parasitoids gave improved biological control of *P. citri* in a large glasshouse stocked with guava plants in the UK, supplementing that achieved by the coccinellid predator *Cryptolaemus montrouzieri*. Following parasitoid release, there was evidence of pest population regulation on guava with reduced and stabilized mealybug numbers and stable percentage parasitism. The mean temperature during one sampling period was significantly correlated with percentage parasitism 2 months later, indicating that temperature has a major impact on parasitism efficiency. The encyrtid *Leptomastidea abnormis* was responsible for about 90 % of the parasitism observed; the remainder was by another encyrtid, *Leptomastix dactylopii* (Tingle and Copland 1988).

40.4.3 *Ferrisia virgata*

Prothiophos, either alone or with mineral oil (0.5 %), gave better control of *F. virgata* than did malathion (the standard insecticide), the difference being evident from 8 days after application. Harvest residues were negligible. Mineral oil (1 %) alone was also more effective than malathion but it caused leaf scorch followed by defoliation. An ant barrier was ineffective (Villiers and de Stander 1978).

Aenasius advena Comp. and *Blepyrus insularis* (Cam.), *S. coccivora*, *Mallada boninensis* (Okamoto), *Brumus suturalis* (F.) and *Spalgis epeus* (Westwood), *C. sexmaculata* were recorded on *F. virgata* (Mani et al. 1990). *Chrysopa lacciperda* (Kimmis) and *Chrysoperla carnea* were observed on *F. virgata* and *P. citri* in guava orchards (Krishnamoorthy and Mani 1988). A single larva of *M. boninensis* was able to prey about 345, 490 and 560 nymphs of *F. virgata, P. lilacinus* and *P. citri* respectively (Mani and Krishnamoorthy 1990b). *Blepyrus insularis* bred very well on 5–10 old nymphs of *F. virgata* (Mani and Krishnamoorthy 1991). The key parasitoid *A. advena* could be conserved by the applications of diazinon, phosalone and dichlorvos (Mani and Krishnamoorthy 1992).

Cryptolaemus montrouzieri was released against *F. virgata* on guavas in the guava orchards in India in 1987. *C. montrouzieri* along with the local natural enemies *Aenasius advena* Compere and *Scymnus coccivora* Ayyar effectively controlled the mealybugs within 50 days of release. The control of the striped mealybug was rated as outstanding (Mani et al. 1990). *F. virgata* appeared in severe form on guava in the polyhouse in 2006 in Bangalore North. A mean of 146.38 mealybugs/plant was observed on 5th March 2006 which declined to 0.96/plant on 7th May 2006 following the release of *C. montrouzieri*. *Cryptolaemus montrouzieri* was the only natural enemy recorded on *F. virgata* during the study period. No other natural enemy was recorded on *F. virgata* infesting the potted guava plants in the polyhouse (Mani 2008).

According to Zimmerman (1948), *F. virgata* was first recorded in the Hawaiian Islands in 1898 but was a widespread and common pest in the Islands long before this. It is no longer common in the Hawaiian Islands as it has been controlled by the coccinellids *Cryptolaemus montrouzieri, Olla v-nigrum* and *Azya luteipes*, together with the syrphid, *Alloagrapta obliqua*. At the beginning of a local outbreak, severely infested branches should be cut and burnt immediately (Schmutterer 1969).

40.4.4 *Planococcus lilacinus*

Cryptolaemus montrouzieri supplements the local natural enemies *Brumoides suturalis* (Fabricius), *Scymnus coccivora*, *Spalgis epeus* Westwood in clearing the population of *P. lilaci-*

nus in guava orchards (Mani 1995). *P. lilacinus* was first observed in January, 1990, on guava. Malathion (5 %) dust was applied around the trees and ant holes to check the activity of ants. The mealybug population remained very high from January to July. About 200 adult beetles were released on guava variety selection 113 infested with *P. lilacinus* since only about ten trees Predators per ten shoots were affected. Both the predators, *viz., S. epeus* and *C. montrouzieri* were also found throughout the study. However, S. *epeus* appeared in considerable number from June onwards and cleared mealybugs. The mealybug population declined rapidly, and by the end of September several infested fruits were cleared from mealybugs by *S. epeus* (Table). At the same time, *P. lilacinus* was found in abundance in Block No. 9 where the natural enemies were absent due to hectic activity of black ant, *Camponotis compressus* (F.).

40.4.5 *Nipaecoccus viridis*

Alamella flava Agar was found parasitizing *N. viridis* infesting guava plants in India (Hayat 1981).

40.4.6 *Rastrococcus iceryoides* (Green)

The encyrtid *Praleurocerus viridis* (Agarwal) and *S. coccivora* were found very effective in reducing the population of *R. iceryoides* in Tamil Nadu (Mani and Krishnamoorthy 1998).

Praleurocerus viridis

40.5 Mixed Mealybug Populations

*C. montrouzier*i is recommended to control the mixed mealybug population on guava.

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41 Fruit Crops: Mango

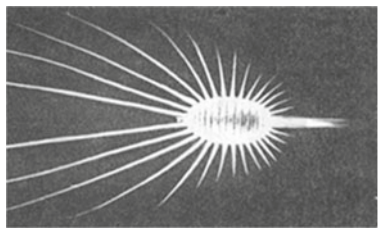
M. Mani

41.1 Species

Mealybugs are reported to be injurious to mango India, West Africa, Central America, Ghana, Florida, India, Indonesia, Hawaii, Sri Lanka, Pakistan etc (Table 41.1). So-called mango mealybugs in India belonging to family margarodidae are discussed under chapter mealybugs alike in Section 1.

R. iceyroides

R. mangiferae



R. invadens

41.2 Damage

41.2.1 *R. iceyroides*

It is serious pest of mango in India and Africa. Mealybugs are known to cause serious damage to the mango leaves, flowers and fruits. Fruits covered with mealybugs are unfit for marketing (Mani et al. 1995; Pramanik and Ghose 1991). In the northern part of Malawi, on the border with Tanzania, infestation of mangoes by *R. iceyroides* was reported to cause severe damage to mango trees. Later the infestation by the mealybug extended up to 18 km into Malawi from the Songwe River border (Luhanga and Gwinner 1993).

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R. iceryoides on mango fruit

Ra. rubellus on fruit

Table 41.1 List of mealybugs recorded on mango in different countries

Species	Region/country	Reference
Crisicoccus hirsutus (Newstead)	India	Williams (2004)
Dysmicoccus bispinosus Beardsley	Neotropical region	Ben-Dov (1994)
Dysmicoccus brevipes (Cockrell)	Bangladesh	Williams (2004)
Dysmicoccus grassii (Leonardi)	Neotropical	Ben-Dov (1994)
Dysmicoccus neobrevipes Beardsley	Philippines	Williams (2004)
Dysmicoccus nesophilus Williams & Watson	Austroriental and Pacific region	Ben-Dov (1994)
Ferrisia virgata (Cockerell)	India	Godse and Bhole (2003)
	Pakistan	Williams (2004)
	Benin	Germain et al. (2010)
Formicoccus mangoferacola sp.n	India	Williams (2004)
Formicoccus corbetti Takahashi	Malaysia	Williams (2004)
Formicoccus (Planococcoides) robustus Ezzat & McConnell comb	Bangladesh, India	Williams (2004)
Maconellicoccus hirsutus (Green)	Yemen	Marotta et al. (2001)
	Egypt	Bodkin (1931)
	India	–
	Mexico	Rosas-Garcia and Parra-Bracamonte (2011)
Nipaecoccus viridis (Newstead)	India	Anonymous (1987)
	Pakistan	Williams (2004)
Nipaecoccus nipae (Makell)	–	Ben-Dov (1994)
Paracoccus interceptus Lit.	Benin	Germain et al.(2010)
Paracoccus marginatus Williams and Granara de Willin	Ghana	Cham et al. (2011)
	Florida	Walker et al. (2003)
	Palau	Muniappan et al. (2008)
	India	Jacob Mathew (2011); Shylesha et al. (2011)
	Indonesia	Muniappan et al. (2008)
	Hawaii	Ronald et al. (2007)
	Sri Lanka	Galanihe et al. (2010)
	Australia	www.planthealthaustralia.com.au
Paraputo corbetti (Takahashi)	Malaysia, Indonesia	Williams (2004)
Paraputo leveri (Green)	Thailand	Williams (2004)

(continued)

Table 41.1 (continued)

Species	Region/country	Reference
Paraputo mangiferae (Betrem) comb n.	Indonesia	Williams (2004)
Paraputo latebrae sp.n	Malaysia	Williams (2004)
Phenacoccus madeirensis Green	–	Ben-Dov (1994)
Phenacoccus parvus Morrison	Queensland	Swarbrick and Donaldson (1991)
Phenacoccus solenopsis Tinsley	Benin	Germain et al. (2010)
Planococcoides robustus Ezzat & McConnell	India	Puttarudriah and Eswaramurthy (1976); Godse and Bhole (2003)
Planococcus citri (Risso)	India	Godse and Bhole (2003)
	Florida	Ben-Dov (1994)
Planococcus ficus (Signoret)	–	Ben-Dov (1994)
Planococcus lilacinus (Cockrell)	–	Ben-Dov (1994)
Planococcus minor (Maskell)	–	Ben-Dov (1994)
Pseudococcus cryptus Hempel	Philippines, Thailand, Nepal	Williams (2004)
Pseudococcus elisae Borkhsenius	Central America, Hawaii	Beardsley (1986)
Pseudococcus longispinus (Targioni Tozzetti)	–	Ben-Dov (1994)
Pseudococcus viburni (Signoret)	Philippines	Williams (2004)
Rastrococcus invadens Williams	India	Narasimham and Chacko (1988); Godse and Bhole (2003)
	Togo in Africa	Agricola et al. (1990)
	Malaysia, Philippines	Williams (2004)
	West Africa	Vogele et al. (1991)
	Nigeria	Ivbijaro et al. (1992)
	Malawi	Luhanga and Gwinner (1993)
	Benin, Gabon, Ghana, Nigeria, Sierra Leone and Zaire	Neuenschwander et al. (1994)
Rastrococcus iceryoides (Green)	India	Ghose (1961); Ali (1970); Varshney (1985); Tandon and Lal (1978); Rawat and Jackmola (1970); Narasimham and Chacko (1988); Mani et al. (1995)
	Malawi	Luhanga and Gwinner (1993)
	Bangladesh, Malaysia, Nepal	Williams (2004)
Rastrococcus mangiferae Green	India	Ali (1970); Varshney(1985); Narasimham and Chacko (1988)
	Malaysia, Sri Lanka	Williams (2004)
Rastrococcus spinosus (Rob.)	Pakistan	Ausaf and Ahmed (1973)
	Indonesia, Philippines, Thailand, Malaysia, Bangladesh, Brunei, Cambodia	Williams (2004)
Rasrococcus rubellus Williams	Malaysia	Williams (2004)
	Sri Lanka	Galanihe and Watson (2012)

41.2.2 *Planococcoides robustus*

It was found infesting the roots of mango in the Kolar district of Karnataka, India. The mealybugs were enclosed in a parchment-like covering produced by a symbiotic fungus, but in May the surface of fruits that touched the soil was covered with mealybug in various stages in the life-history. Ants were seen to carry nymphs, which were active in the soil at this time (Puttarudriah and Eswaramurthy 1976).

41.2.3 *Rastrococcus invadens*

It was accidentally introduced into the West African region in the early 1980s, has become a serious pest of mangoes in several African countries (Vogele et al. 1991). The spread of *R. invadens* in Nigeria was limited to Lagos, Ogun and Oyo States of the humid south-west contiguous with the Republic of Benin. The frequency with which infested plants were being felled, burnt or sprayed with synthetic chemicals suggested that the presence of *R. invadens* caused a degree of panic by growers (Ivbijaro et al. 1992). On mangoes in the field in Togo, all instars of *R. invadens* were seen to stretch out the abdomen from the leaf surface at a right angle if the leaves were exposed to bright sunlight. In the laboratory, the degree of lifting was found to be related to temperature. The reaction started at about 34 °C and reached a maximum at 37 °C. Temperatures measured in the field on leaves exposed to bright sunlight were 34.5–41.1 °C, indicating that the reaction of the mealybug to high temperature can be interpreted as a heat-regulating mechanism (Agricola 1993). In Benin cv. 'Quinte' WAS heavily infested with *R. invadens* and the cv. 'Gouverneur' was slightly infested. The pre-reproductive period of *R. invadens* on the heavily infested tree was shorter and total offspring production greater than on the uninfested tree. Plant genotype had the importance on *R. invadens* size and survival (Boavida and Neuenschwander 1995). Protein, fat, carbohydrate, ash, crude fibre and moisture contents were depleted with increase in mealybug population on mango plants (Pitan et al. 2002). After its appearance at the eastern border of Cote d'Ivoire in 1989, the mango mealybug, *R. invadens* rapidly became a nationwide constraint in mango production. On farmlands, 100 % yield losses could be reached so that infested orchards or trees were destroyed by farmers (Hala et al. 2004). The mango mealybug species are serious pests on mangoes in South Africa and result in considerable financial losses due to the downgrading of mango fruits (Lagadec et al. 2009).

41.2.4 *Maconellicoccus hirsutus*

In Mexico, *M. hirsutus* was observed on Tommy Atkins, Haden, Manila, Ataulfo, Keitt, and Kent cultivars. Presence of insects was observed on terminal buds and fruits in trees, as well as surrounding weeds (Rosas-Garcia and Parra-Bracamonte 2011).

41.3 Natural Enemies

41.3.1 *Rastrococcus iceryoides*

Several natural enemies were recorded on *R. iceryoides* in Northern India. *Anagyrus pseudococci* Girault, *Gyranusoidea* sp., *Praleurocerus viridis* Agarwal, *Allotropa* sp., *Microterys flavus* (Howard), *Dinocarsis* sp., *Metastenus concinnus* Walker, *Cybocephalus* sp., *Scymnus coccoivora* Ayyar, *Monomorium floricola* (Jerdon), *Coccophagus* sp. and *Proctolaelaps* sp. were recorded from Malihabad in UP. But *A. pseudococci* was found to be an important parasitoid of *R. iceryoides* (Tandon and Lal 1978; Rawat and Jackmola 1970; Shafee et al. 1975; Sinha et al. 1985). Up to 42 % parasitism was observed in nature in UP (Tandon and Lal 1978). According to Narasimham and Chacko (1988), parasitoids: *Anagyrus* sp. nr. *dactylopii* (How.), *Anagyrus* sp. nr *inopus* Noyes and Hayat., *Coccophagus sexvittatus* Hayat, *Coccophagus* sp. (pseudococci group), *Praleuricerus viridis* (Garwal), *Allotropa* sp., predators: *Nephus* sp., *Leucopis* sp., *Cacoxenus perspicax* (Knab.), *Spalgis epeus*

Westwood, *Scymnus coccivora* Ayyar, *Coccidodplosis* sp., *Didiplosis* sp. and predatory ants: *Camponotus* sp., *Myrmicaria brunnea* Saunders and *Oecophylla smaragdina* (F.) were known to attack *R. iceryoides*. Mani et al. (1995) reported that the parasitoid *Anagyrus pseudococci* (Gir.) and the predator *Cacoxenus perspicax* (Knab.) were important natural enemies on *R. iceryoides* in mango ecosystem. An individual *C. montrouzieri* was known to consume about 350 mealybug eggs or 500 nymphs during its larval development. In West Bengal, *Chartocerus walkeri*, *Aprostocetus* sp., *Promuscidea unfasciativentris*, *Anagyrus pseudococci* and *Anagyrus mirzai* were recorded on *R. iceryoides* (Das and Sahoo 2005).

41.3.2 *Rastrococcus mangiferae*

In India, *Anagyrus* sp., *C. montrouzieri* and *Spalgis epeus* Westwood were recorded on *R. mangiferae* (Narasimham and Chacko 1988).

41.3.3 *Rastrococcus invadens*

Coccophagus sp., *Anagyrus* sp., *Gyronusodea tebygi* Noyes, *C. montrouzieri, Spalgis epeus* Westwood, *Psectra inigua* Hagen were recorded on *R. invadens* in India. *Anagyrus* sp. and *G. tebygi* are worth trying parasitoids for trials against *R. invadens* in Africa (Narasimham and Chacko 1988). In West Bengal, *Chartocerus* sp., *Azotus* sp. [*Ablerus* sp.] and *G. tebygi* were recorded on *R. invadens* (Das and Sahoo 2005).

41.4 Management

41.4.1 *Planococcoides robustus*

Disulfoton as granule was applied to the soil monthly for a year, the plants were watered weekly, and the affected plants which had suffered desiccation and leaf-fall, showed signs of revival in India (Puttarudriah and Eswaramurthy 1976).

41.4.2 *Rastrococcus iceryoides*

Rastrococcus iceryoides on mango was mostly kept under check in India by the predators chiefly *C. montrouzieri* in India (Manjunath 1986). Field releases of *C. montrouzieri* were found very effective in controlling *R. iceryoides*. The percentage of mealybug infested fruits was more than 70 % on varieties like Gola and Kallapady prior to the release of the predator. Field releases of *C. montrouzieri* were made in June–July 1992–1993. Following the release of *C. montrouzieri*, there was significant reduction in the percentage of infested fruits on all 15 varieties. In May 93, the mango varies like Langra, Totapuri, Jehangir, Gola, Black Andrews, Maharajaja, Pasanth and Janardhan Pasand were free from the mealybug infestation (Mani et al. 1995). In the field, adult females were effectively controlled by three species of chalcidoid parasitoids, nymphs by the predatory coccinellid *Scymnus* sp. and the contents of ovisacs by a predatory cecidomyiid in India (Pramanik and Ghose 1991).

41.4.3 *Rastrococcus invadens*

Both physical and chemical control procedures practiced by farmers have been ineffective against *R. invadens*. It was observed that the mealybug is closely related to a complex of natural enemies as parasitoids *Gyranusoidea tebigi* and *Anagyrus mangicola* in African counties (Hala et al. 2004).

The parasitoid *Gyranusoidea tebygi* native of India was introduced into Togo in Africa in November 1987 and released as a biological control agent against the mealybug on mangoes. Establishment, spread and effectiveness of the encyrtid were very good, resulting in satisfactory control (Agricola *et al*. 1990). In Togo and Benin, both *G. tebygi* and *Anagyrus mangicola* were capable of eliminating the mealybug (Moore and Cross 1992). The model predicted that the addition of *Anagyrus* sp. to a system already containing *G. tebygi* would lead to little improvement in the suppression of *R. invadens* (Godfray and Waage 1991). *G. tebygi* was released in Benin, Gabon, Ghana, Nigeria, Sierra Leone and Zaire. In Togo, this parasitoid was established in all areas infested by *R. invadens*. In addition, it established itself without previous release in Congo and Cote d'Ivoire. *A. mangicola* was released in Benin, Gabon and Sierra Leone since 1991 and by mid-1993 was recovered from a few sites. It seemed locally established in southern Benin (Neuenschwander et al. 1994).

The mealybug population's potential rate of increase ranged from 0.066/day to 0.078/day. The potential for increase of the parasitoid was double that of its host. In southern Benin, the population density of *R. invadens* decreased during the rainy seasons and peaked during the dry seasons. Mealybug field sex ratios were extremely variable, and the impact of such variability on the mealybug's potential rate of increase was analysed. The populations of the exotic encyrtid *G. tebygi*, introduced into Benin in 1988 for control of the pest, were synchronized with the mealybug populations. The spatial patterns of parasitism distribution in relation to the host population density were either independent or directly density-dependent, both at the tree level and for larger zones. In the two orchards studied, mealybug populations eventually collapsed and disappeared. It is concluded that the biological control of the mango mealybug by *G. tebygi* was achieved by non-equilibrium local dynamics, and should be evaluated in a metapopulation perspective (Boavida and Neuenschwander 1995).

In Benin, within 3 years, *G. tebygi* had colonized the entire area of infestation, and was found on practically all infested mango trees as well as other infested host plants. The percentage of infested mango trees declined from 31 % in 1989 to 17.5 % in 1991. Average mealybug densities declined steadily from 9.7 females/48 leaves in 1989 to 6.4 females/48 leaves in 1991. In multiple regression analyses, based on 23 meteorological, agronomic and plant variables, the duration of the parasitoid's presence proved to be the major factor. It influenced mealybug population densities and sooty mould incidence, which in turn, affected the production of new leaves. In all analyses, the impact of rainfall, for example, on the sooty mould or the mealybug was less important than the effect of *G. tebygi* (Bokonon-Ganta and Neuenschwander 1995).

In Nigeria, *G. tebygi* was released in 1991. By 1997 and 1998, *G. tebygi* was found to have crossed all agro-ecological barriers to colonize the entire area of infestation nationwide. During this period, the populations of *R. invadens* had greatly decreased from between 11.0 and 98.0 mealybugs per leaf in 1991 to between 0.0 and 18.2 mealybugs per leaf in 1998 (Pitan et al. 2000). The population density of *G. tebygi* was found to be negatively but significantly correlated with mango mealybug population and positively correlated with mango fruit yield. Parasitism was highly correlated with mealybug population and yield, and was considered a major factor in the control of the pest and the subsequent increase in mango fruit yield. Rainfall did not have a significant impact on yield, mealybug population or sooty mould score (Pitan et al. 2002). In Ibadan, Nigeria, significantly higher numbers of infested trees and mealybug population, and significantly lower parasitism levels were found on mango trees in exhaust areas, compared with others. Pollution level was correlated with mealybug population (positively) and parasitism (negatively) in 2000 and 2007. Whereas mealybug population gradually built up on hitherto clean trees where pollution sources were relocated, parasitoid activity seemed to be enhanced by the relocation of smoke sources. The effectiveness and conservation of the parasitoids may therefore depend on the air quality around the infested trees (Pitan 2008).

Mango mealybug *R. invadens* an exotic pest of mango was achieved with the release of parasitoids in African countries. Most producers attributed the observed improvement of mango production to the success of biological control. Based on production estimates by producers, the negative impact of the pest on plant production and the positive impact of the introduced natural enemy were demonstrated. Interviewed mango producers gained on average US$ 328 per year by the biological control programme. Extrapolated to all producers of Benin, a yearly gain of US$ 50 million in mango production was estimated. The value of accrued benefits was estimated at US$

531 million over a period of 20 years. The total cost of the biological control of mango mealybug was estimated at US$ 3.66 million, which included initial costs in other African countries and the introduction of the natural enemy from India, resulting in a benefit–cost ratio of 145:1 for benefits in Benin alone (Bokonon-Ganta et al. 2002).

The mango mealybug species are serious pests on mangoes in South Africa and result in considerable financial losses due to the downgrading of mango fruits. Application of thiamethoxam at the point of drip irrigation was most effective, resulting in approximately 90 % of the crop being of export quality. The untreated control plots yielded significantly less fruit of export quality (Lagadec et al. 2009).

41.5 India

C. montrouzieri was found to be very effective in suppressing *R. invadens* during April 1995 in Karnataka. Due to the release of C. *montrouzieri* on mango plants in February 1995, there was 99.44 % reduction in the meal-bug population *R. invadens* from second week of February to the first week of April on mango cv. Alphonso. The mealybug population showed 102.82 % increase in the same period on the control plants (Mani and Krishnamoorthy 2001).

41.5.1 *Rastrococcus spinosus*

Salithion [2-methoxy-4H-1, 3, 2-benzo ioxaphosphorine 2 sulphide], fenitrothion, carbaryl, dimethoate, methyl-parathion and phosphamidon were 26.6, 1.2, 1.2, 1.1, 0.9 and 0.7 times as toxic to *Rastrococcus spinosus*, respectively, as malathion, for which the LC50 was 0.4458 % (Ausaf and Ahmed 1973).

41.5.2 *Nipaecoccus viridis*

Release of *Cryptolaemus* grubs has cleared mealybug colonies on mango at Hindupur (Anonymous 1987).

41.5.3 *Ferrisia virgata*

At times, fruits were found covered with *F. virgata* in Tamil Nadu and Karnataka. *C. montrouzieri* was suggested for the suppression of the mealybug (Anonymous 1987).

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42 Fruit Crops: Papaya

M. Mani, M. Kalyanasundaram, and C. Shivaraju

42.1 Species

Mealybugs are reported to be injurious to papaya plantation in several countries (Table 42.1). Papaya hardly suffers heavily from insect damage in India until the recent introduction of the mealybug *Paracoccus marginatus* Williams & Granara de Willink which had caused heavy loss to papaya growers (Muniappan et al. 2008).

Planococcus citri on papaya

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42.2 Papaya Mealybug: *Paracoccus marginatus*

Paracoccus marginatus Williams and Granara de Willink popularly known as papaya mealybug (PMB) has invaded several countries and damaged many economically important crop plants (Muniappan et al. 2008; Shylesha et al. 2011a). It is 'hard to kill pest' with conventional insecticides because of protected habitat and waxy coating over the body.

42.2.1 Origin and Distribution

Paracoccus marginatus Williams & Granara de Willink is native to Mexico and/or Central and North America (Miller et al. 1999; Watson and Chandler 1999). Since its first description in 1992 from new tropical region, *P. marginatus* has spread to several Caribbean islands and central and south America (Miller et al. 1999; Matile-Ferrero et al. 2000; Kauffman et al. 2001b; Watson and Chandler 1999; Miller and Miller 2002), Mexico (Williams and Granara de Willink 1992); U.S. Virgin Islands (CABI/EPPO 2000); The Dominican Republic (CABI/EPPO 2000) and Grenada in 1994, Antigua and Barbuda (CABI/EPPO 2000), Saint Martin (Pollard 1999) and The British Virgin Islands in 1996 (CABI/EPPO 2000); USA (Florida) (Pollard 1999; Miller and Miller 2002; Walker et al. 2006), Haiti, St. Kitts and Nevis (CABI/EPPO 2000); St

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Table 42.1 List of mealybugs recorded on papaya in different regions of the world

Species	Country	Reference
Dysmicoccus grassii (Leonardi)	Brazil	Culik et al. (2006)
	Cuba	Angeles Martinez et al. (2001)
Dysmicoccus nesophilus Williams & Watson	Austro-oriental and Pacific region	Ben-Dov (1994)
Ferrisia virgata (Cockerell)	–	Ben-Dov (1994)
Maconellicoccus hirsutus (Green)	Florida	Anonymous (2003)
Niapecoccus nipae (Makell)	–	Ben-Dov (1994)
Planococcus citri (Risso)	–	–
Planococcus minor (Maskell)	Trinidad	Francis et al. (2012)
*Phenacoccus solenopsis*Tinsley	India	–
Pseudococcus jackbeardsleyi Gimpel and Miller	India	Mani et al. (2013a, b)
	Many countries	Ben-Dov et al.(2001)
Paracoccus marginatus Williams and Granara de Willink	Ghana	Cham et al. (2011)
	India	Cham et al. (2011); Shylesha et al. (2011d); Tanwar et al. 2010; Mani Chellappan (2011a); Muniappan et al. (2008); Jacob Mathew (2011)
	Florida	Walker et al. (2003), Miller and Miller (2002)
	Sri Lanka	Galanihe et al. (2010)
	Malaysia	Mastoi et al. (2011)
	Puerto Rico	Pantoja et al. (2007)
	Indonesia	Muniappan et al.(2008)
	Hawaii	Ronald et al. (2007)
	Palau	Muniappan et al.(2006)
Pseudococcus viburni (Signoret)	–	Ben-Dov et al.(2001)
Pseudococcus longispinus (Targioni Tozzetti)	–	Ben-Dov et al.(2001)

Barthélemy (Ben-Dov 2008), Guatemala (Ben-Dov 2008), Haiti (CABI/EPPO 2000), and Guadaloupe (Ben-Dov 2008) in 1998; French Guyana (Ben-Dov 2008), Guiana (Ben-Dov 2008), Guadeloupe (Matile Ferrero and Etienne 1998), Cuba (CABI/EPPO 2000), and Puerto Rico in 1999 (CABI/EPPO 2000); Barbados (CABI/EPPO 2000); Belize (Ben-Dov 2010), the Cayman Islands (CABI/EPPO 2000), Costa Rica (Ben-Dov 2010), Cayman and Montserrat in 2000 (CABI/EPPO 2000), Nether lands Antilles (CABI/EPPO 2000), the Bahamas and Guam in 2002–2003 (Meyerdirk et al. 2004); Palau in 2003 (Anonymous 2003; Muniappan et al. 2006) and neighbouring islands in the Pacific (Meyerdirk et al. 2004); Hawaii-Maui and Oahu in 2004 (Heu and Fukada 2005; Heu et al. 2007), the Northern Marianas (Tinian) in 2005, and the Northern Marianas (Tinian) in 2005.

In Africa, it was reported in Ghana in 2009 (Cham et al. 2011). It was noticed in South and South East Asian region during 2008–2009. In May 2008, it was recorded in Java, Indonesia and spread to Bali and Sulawesi Islands (Muniappan et al. 2008; 2009). It was also reported in July 2008 in Colombo and Gampaha districts in Sri Lanka (Galanihe et al. 2010), Joyedpur in Bangladesh; Phnom Penh in Cambodia in 2010, Manila in Philippines in 2008; Thailand in 2010 (Muniappan et al. 2009). The pest was first reported from Negeri Sembilan and Selangor in Malaysia in February, 2009 (Muniappan et al. 2008; Mastoi et al. 2011) and Taiwan in 2010 (Chen et al. 2011) and Maldives very recently.

In India, it was found at Coimbatore in July 2008 in Tamil Nadu (Muniappan et al. 2008; Regupathy and Ayyasamy 2009; Suresh et al. 2010). Since July 2008 from Coimbatore in Tamil Nadu, it has spread subsequently neighbouring states such as Karnataka, Andhra Pradesh, Maharashtra, Kerala, Tripura, Jorat and Orissa in India (Shylesha et al. 2011c; Rabindra 2010; Krishnamoorthy and Mani 2011; Sajeev 2011; Jacob Mathew 2011; Mani Chellappan 2011a; Chandele et al. 2011; Lyla and Philip 2010; Krishnakumar and Rajan 2009; Mahalingam et al. 2010; Suresh et al. 2010).

Taxonomy *Paracoccus marginatus* Williams & Granara de Willink (Hemiptera: Pseudococcidae) specimens were collected first in 1955 in Mexico, but it was described in 1992 from the specimen collected in neotropical region (Belize, Costa Rica, Guatemala and Mexico) by Williams and Granara de Willink (1992) and re-described by Miller and Miller (2002) and also Angeles Martinez and De Los Suris (2005). Miller and Miller (2002) gave a complete description of all the stages of the papaya mealybug.

Damage Papaya mealybug infestations are typically observed as clusters of cotton-like masses on the above-ground portion of plants. *Paracoccus marginatus* damages various parts of the host plant including the leaves, stems, flowers and fruits. *P. marginatus* may show very similar symptoms to pink hibiscus mealybug *Maconellicoccus hirsutus* (Green) (Pollard 1999). The insect sucks the sap by inserting its stylets into the epidermis of the leaf, fruit and stem. While feeding, it injects a toxic substance into the leaves resulting in curling, crinkling, rosetting, twisting and general leaf distortion (Miller et al. 1999; Walker et al. 2003; Heu and Fukada 2005; Pantoja et al. 2007). Heavy mealybug infestations render fruit inedible. Due to the build-up of thick white waxy coating and sooty mould development on the honeydew excreted by mealybug, infested fruits get reduced market value. Fruits may fail to develop normally and may be unusually small. Such fruits eventually shrivel and drop (Tanwar et al. 2010; Heu et al. 2007). Some economically important crops such as papaya, mulberry, cotton, cassava, citrus, sweet potato, peas and beans, okra, eggplant, guava and ornamentals such as hibiscus, *Jathropha, Allamanda, Acalypha* were severely damaged by P. marginatus (Miller and Miller 2002; Mccomie 2000; Meyerdirk et al. 2004; Shylesha et al. 2011b).

Damage by P. marginatus

Ecology Mealybug occurs throughout the year but is active in warm dry weather. Prolonged drought with scanty rainfall and less number of rainy days favour the faster multiplication (Ayyasamy and Regupathy 2010). During the rainy season, papaya mealybug populations decreased drastically because heavy rain washed the insects off the plants. However, mealybugs sheltered within unopened leaves and other hiding places survived and built up their numbers again during the warm, dry weather. The climatic preferences of *P. marginatus* have been documented well, but its occurrence in countries located 30 °C from the Equator suggest that probably does not tolerate cold conditions (CAB International 2001). Heavy rains caused mortality of PMB especially of the crawler's stage.

42.2.2 Host Plants

It is highly polyphagus insect pest that can damage large number of tropical and subtropical fruits, vegetables and ornamental plants (Miller and Miller 2002). According to Muniappan et al. (2008), it was known to infest plants belonging to 22 families from Asia. Galanihe et al. (2010) recorded more than 40 plant species in Sri Lanka compared to 55 plants species recorded in Florida (Walker et al. 2003). *Paracoccus marginatus* attacks over 60 species of plants including field crops, fruit trees ornamentals, weed and scrub vegetation in India (Shylesha et al. 2011b).

42.2.3 Natural Enemies

It has never gained status as pest in the native home of Mexico, Central and North America probably due to presence of endemic natural enemy complex (Walker et al. 2003). The papaya mealybug became pest when it invaded the Caribbean region mainly due to the absence of natural enemies. *Spalgius epeus* Westwood was the predominant natural enemy on papaya mealybug damaging several host plants in South India (Thangamalar et al. 2010). *Cryptolaemus montrouzieri* Mulsant a general predator of mealybug was also recorded occasionally on papaya mealybug in India and elsewhere. Parasitoids of *P. marginatus* from Mexico and Caribbean are listed by Schauff (2000). Four species of chalcidoid parasitoids and two predators were found attacking PMB in Malaysia (Mastoi et al. 2011).

A total of 22 natural enemies occurring either naturally/introduced were reported on papaya mealybug in different countries (Mani et al. 2012; Table 42.2.

42.2.4 Management

Mealybugs are difficult to control because they live in protected areas such as cracks, crevices and under the bark of their host plants. Most of the stages including eggs of mealybug are covered with waxy secretions that protect them. An integrated pest management (IPM) approach involving cultural practices, legal, chemical and biological control is advisable.

42.2.4.1 Legal

Strict quarantine measures are needed to prevent the entry of mealybug infested planting materials/fruits/flowers from other countries. Domestic quarantine measures are to be strengthened to prevent the movement from one state to other states within the country (Tanwar et al. 2010).

42.2.4.2 Cultural Control

Planting material free from mealybugs is to be used. In the initial stages of appearance of mealybug, collection and destruction of infested plant parts are to be carried out (Ayyasamy and Regupathy 2010; Tanwar et al. 2010).

42.2.4.3 Chemical Control

Chemicals were used desperately when there was outbreak of mealybugs, and other methods were not available immediately. A number of insecticides like monocrotophos, methyl demeton, dimethoate, acephate, methomyl, fenthion, imidacloprid, thiomethoxam, dichlorovos, quinalphos, profenophos, fenitrothion, carbaryl, chlorpyriphos, diazinon, malathion, buprofezin were used against papaya mealybug (Tanwar et al. 2010; Regupathy and Ayyasamy 2009; Mahalingam et al. 2010; Banu et al. 2010; Suresh et al. 2010). They give short-term control but chemical control is difficult and requires repeated application of the insecticides (Tanwar et al. 2010; Ayyasamy and Regupathy 2010; Galanihe et al. 2010). The chemicals were recommended for the control of the mealybug until the biological control agents could be introduced.

42.2.4.4 Biopesticides

Fish oil rosin soap, azadirachtin and white mineral oils were found partially effective against papaya mealybug. The three fungal pathogens *Verticillium lecanii* (Zimm.), *Beauria bessiana* (Bals.) and *Metarhium anisopliae* (Metsch.) were known to cause 40–50 % mortality of *P. marginatus* (Banu et al. 2010).

42.2.4.5 Biological Control

Though several methods were available, excellent control of mealybug was obtained with use of biocontrol agent throughout the World (Meyerdirk 2000). In the case of PMB also, outstanding control was achieved with use of parasitoids in several countries (Mani et al. 2012; Shylesha et al. 2011c).

Parasitoids of *P. marginatus*

A. papayae

P. mexicana

A. loecki

42.2.4.6 Guam

P. marginatus was reported in April 2002; Survey of *P. marginatus* in Guam before the release of the parasitoids showed that there were no local parasitoids recorded on this mealybug. A few coccinellids such as *C. montrouzieri* and *Chilocorus nigrita* (Fabricius) were however found feeding on it. They were not capable of suppressing the populations of *P. marginatus*. The parasitoids, *Acerophagus papaya*e, *Anagyrus loecki* and *Pseudleptomastix mexicana* totalling 46,200 individuals were introduced from Puerto Rico, and released in Guam from June to October, 2002. Establishment of the parasitoids was confirmed within a month of release at the sample sites and releases were continued at other geographical locations across the Island. A reduction of over 99 % of PMB was observed about a year of introduction of these parasitoids. By August 2003, the population of PMB declined to a level which was hard to find in the field. Almost all papaya, *Plumeria* spp. and *Hibiscus* spp. plants recovered and no symptoms of damage were noted at that time (Meyerdirk et al. 2004).

A. papayae* on *P. marginatus

Coccons of *A. papayae*

Table 42.2 List of natural enemies on *Paracoccus marginatus*

Family and species	Country	References
Hymenoptera: Encyrtidae	India	Shylesha et al. (2011d); Tanwar et al. 2010; Jothi et al. (2011); Ayyasamy and Regupathy (2010); Chandele et al. (2011); Qadri (2011); Nakat et al. (2011); Kalyanasundaram et al. (2011); Muniappan et al. (2008); Jacob Mathew (2011)
Acerophagus papayae Noyes and Schauff	Indonesia	Muniappan et al. (2008)
	Sri Lanka	Galanihe et al. (2010)
	Malaysia	Mastoi et al. (2011)
	Puerto Rico	Pantoja et al. (2007)
	Indonesia	Muniappan et al. (2008)
	Hawaii Palau	Ronald et al. (2007)
	Florida	Muniappan et al. (2006)
	Mexico	Kaushalya et al. (2008), Miller and Miller (2002), Meyerdirk and Kauffman (2001)
Anagyrus loecki Noyes	India	Shylesha et al. (2011d); Tanwar et al. 2010; Jothi et al. (2011); Ayyasamy and Regupathy (2010); Chandele et al. (2011); Qadri (2011); Nakat et al. (2011); Kalyanasundaram et al. (2011) Muniappan et al. (2008); Jacob Mathew (2011)
	Indonesia	Muniappan et al. (2008)
	Sri Lanka	Galanihe et al. (2010)
	Malaysia	Mastoi et al. (2011)
	Puerto Rico	Pantoja et al. (2007)
	Indonesia	Muniappan et al. (2008)
	Hawaii Palau	Ronald et al. (2007)
	Florida	Muniappan et al. (2006)
	Mexico	Kaushalya et al. (2008); Miller and Miller (2002)
		Meyerdirk and Kauffman (2001)
Apoanagyrus californicus Compere	Mexico	Meyerdirk and Kauffman (2001)
	Puerto Rico	Pantoja et al. (2007)

(continued)

Table 42.2 (continued)

Family and species	Country	References
Pseudleptomastrix mexicana Noyes and Schauff	India	Shylesha et al. (2011d); Tanwar et al. 2010; Ayyasamy and Regupathy (2010); Chandele et al. (2011); Qadri (2011); Nakat et al. (2011); Muniappan, et al. (2008); Kalyanasundaram et al. (2011)
	Indonesia	Muniappan et al. (2008)
	Sri Lanka	Galanihe et al. (2010)
	Malaysia	Mastoi et al. (2011)
	Puerto Rico	Pantoja et al. (2007)
	Florida	Miller and Miller (2002)
	Indonesia	Muniappan et al. (2008)
	Hawaii Palau	Ronald et al. (2007)
	Florida	Muniappan et al. (2006)
	Mexico	Kaushalya et al. (2008)
	Guam	Meyerdirk and Kauffman (2001)
		Meyerdirk et al. (2004)
Pseudaphycus sp.	Mexico	Meyerdirk and Kauffman (2001)
Lepidoptera: Lycaenidae	India	Shylesha et al. (2011d); Tanwar et al. 2010; Jothi et al. (2011); Jonathan et al. (2011); Thangamalar et al. 2010); Krishnamoorthy and Mani (2011); Chandele et al. (2011); Nakat et al. (2011)
Spalgis epius (Westwood)		
Coleoptera: Coccinellidae	India	Shylesha et al. (2011d); Tanwar et al. 2010; Nakat et al. (2011); Jothi et al. (2011); Ayyasamy and Regupathy (2010); Jonathan et al. (2011)
Cryptolaemus montrouzieri Mulsant	Malaysia	Mastoi et al. (2011)
	Palau	Muniappan et al. (2008)
	Hawaii	Ronald et al. (2007)
	Florida	Anonymous (2010)
	Guam	Meyerdirk et al. (2004)
	British Virgin Island	CAB International (2001)
Nephus bilucernarius (Mulsant)	Hawaii	Ronald et al. (2007)
Scymnus taiwanus (Ohta)	India	Shylesha et al. (2011d); Tanwar et al. 2010; Nakat et al. (2011); Chandele et al. (2011); Jonathan et al. (2011);
	Hawaii	Ronald et al. (2007)
Brumoides suturalis Fabricius	Hawaii	Ronald et al. (2007)
Hyperaspis silvestrii Weise	Hawaii	Ronald et al. (2007)
Curinus coeruleus Mulsant	Hawaii	Ronald et al. (2007)
Cheilomenus sexmaculata (F.)	India	Jonathan et al. (2011)
Coccinella transversalis Fabricius	India	Jonathan et al. (2011)
Neuroptera: Chrysopidae	India	Shylesha et al. (2011d); Tanwar et al. 2010; Ayyasamy and Regupathy (2010)
***Chrysoperla carnea* (Stephens)**		
Apertochrysa sp.	Malaysia	Mastoi et al. (2011)

(continued)

Table 42.2 (continued)

Family and species	Country	References
Diptera: Syrphidae	India	Shylesha et al. (2011d); Tanwar et al. (2010); Jonathan et al. (2011)
Ischiodon scutellaris F.		
Entomopathogenic fungi	India	Shylesha et al. (2011d); Ayyasamy and Regupathy (2010)
Metarrhizium anisopliae (Metsch.)		
Verticillium lecanii (Zimm.)	India	Shylesha et al. (2011d); Ayyasamy and Regupathy (2010); Jonathan et al. (2011); Mani Chellappan (2011b)
Paecilomyces pictus	India	Ayyasamy and Regupathy (2010)
Beauveria bassiana (Bals.)	India	Shylesha et al. (2011d)
Neozygytes	India	Shylesha et al. (2011d)
Chilocorus nigrita Fab	Guam	Meyerdirk et al. (2004)
	Mexico	Gonzalez et al. (1999)

42.2.4.7 Palau

The pest was reported in March 2003, and was causing serious damage to papaya plumeria, Hibiscus and many other plants. Very few *C. montrouzieri* larvae and adults were encountered on *P. marginatus* in the survey. The parasitoids *A. loecki*, *P. mexicana* and *A. papayae* totalling 24,586 were imported from Puerto Rico, and released in Palau from August 2003 to June 2004. Establishment of parasitoids was confirmed within a month. *A. loecki* and *A. papayae* appeared to be promising biological control agents of PMB in Palau. No field recovery of *P. mexicana* was made in spite of several field releases. The reduction of the papaya mealybug population density levels below detectable levels was observed in a 6-month period following the introduction of these exotic parasitoids. Following the successful implementation of a classical biological control program, the risk of this mealybug spreading to other islands in the Republic of Palau and to neighbouring Micronesian Islands has been considerably reduced (Muniappan et al. 2006).

42.2.4.8 Sri Lanka

The PMB was reported on a large number of plant species in Columbo and Gampha district in Sri Lanka for the first time in 2008. It has caused worst damage in papaya growing districts of Sri Lanka. A classical biological control work was initiated in 2009. Three parasitoids *A. loecki* (2,000), *P. mexicana* (3,200) and *Acerophagus papayae* (4,800) were released in October, 2009. After 3 months, *A. papayae* established in all the sites and subsequently PMB was controlled to level of 90–100 % by December, 2009 (Wahundenya et al. 2009).

42.2.4.9 Mexico

Biological control appears to be the main factor keeping the mealybug species under control in Mexico. The most important natural enemies were the encyrtids, *Anagyrus* spp., *Acerophagus* spp. and *Apoanagyrus* spp. The general predators such as *Chrysopa* spp. and *Chilocorus* spp. were also encountered in low densities on PMB (Gonzalez et al. 1999; Walker et al. 2006).

42.2.4.10 Puerto Rico and Dominican Republic

Paracoccus marginatus was first intercepted from Puerto Rico in 1995, and by 1998 it was found to be distributed throughout Puerto Rico with a higher density on the west side of the Island (Sáez 2000). During 2001–2002, severe infestation of papaya mealybug required several insecticides applications to control pest (Pantoja et al. 2007). USDA-APHIS found that the five parasitoid species, *Anagyrus loecki, Apoanagyrus californicus, Acerophagus* sp. and *Pseudophycus* sp and *Pseudleptomasix mexicana* brought about a 99.7 % reduction in papaya mealybug populations in the Dominican Republic, and a 97 % reduction in Puerto Rico, with parasitism levels of 35.5–58.3 % (Kauffman et al. 2001a;

Meyerdirk and Kauffman 2001). However, *Acerophagus* sp. emerged as the dominant parasitoid species in both Puerto Rico and the Dominican Republic (Meyerdirk and Kauffman 2001; Ramirez and Sáez 2002; Walker et al. 2003; Arnold 2001; Kauffman et al. 2001b).

42.2.4.11 Florida

Paracoccus marginatus was discovered in Florida 1998. The USDA Animal and Plant Health Inspection Service (APHIS) and USDA Agricultural Research Service (ARS) initiated a classical biological control programme for the papaya mealybug. Four genera of encyrtid endoparasitoid wasps specific to the mealybug were collected in Mexico by USDA and ARS researchers and Mexican cooperators as potential biological control agents: *Acerophagus papayae*, *Anagyrus loecki*, *Anagyrus californicus* and *Pseudaphycus* sp. (USDA 1999, 2000; Meyerdirk and Kauffman 2001). A fifth collected species was later reared and identified as *Pseudleptomastix mexicana* (Noyes and Schauff 2003). The first releases of these four parasitoids were made in Florida in October 2000 (Walker et al. 2003) and again released in 2003 (Meyerdirk 2003). Although it is believed that these parasitoids are established in the released areas, *Acerophagus papayae* had higher per cent parasitism than *A. loecki* and there is no recovery of *P. mexicana* (Kaushalya et al. 2008).

42.2.4.12 India

Paracoccus marginatus invaded India in 2008 and has become severe on several agricultural and horticultural crops. The potential economic loss due to this pest ranges from 60 to 80 % in papaya. The parasitoids *Acerophagus papayae, Pseudleptomastix mexicana* and *Anagyrus loecki* from USDA-APHIS Puerto Rico were shipped to India. A total of 3,429 of *A. papayae*, 1,485 of *P. mexicana* and 516 of *A. loecki* were received by National Bureau of Agriculturally Important Insects, Bangalore during July–October, 2010. After ascertaining the safety in quarantine, these three parasitoids were distributed to different states in India. *Acerophagus papaya* has done exceedingly well in Karnataka & Andhra Pradesh (Shylesha et al. 2011c; Krishanamoorthy et al. 2011; Qadri et al. 2011), Maharashtra (Pokharkar et al. 2011; Mundale and Nakat 2011; Chandele et al. 2011; Nakat et al. 2011), Tamil Nadu (Kalyanasundaram et al. 2011; Jonathan et al. 2011), Kerala (Mani challappan 2011b; Jacob Methew 2011; Sajeev 2011), Orissa (Shylesha et al. 2011a) and Tripura state (Agarwala 2011) state in India.

C. montrouzieri was found colonizing on *P. marginatus* in India (Shylesha *et al.* (2011b), Malaysia (Mastoi et al. 2011), Palau (Muniappan et al. 2008), Hawaii (Ronald et al. 2007), Florida (Walker et al. 2003), Guam (Meyerdirk et al. 2004) and British Virgin Island (CAB International 2001) but proved ineffective in checking the mealybug populations.

42.2.4.13 Caribbean Islands

As an exotic introduction to the Caribbean islands, there were good prospects for control of *P. marginatus* by hymenopteran parasitoids originating from its area of origin in Central America (Pollard 1999).

42.2.4.14 Malaysia

Paracoccus marginatus was reported for the first time in Malaysia on papaya, cassava, eggplant, jatropha and hibiscus plants. Four species of chalcidoid parasitoids were observed parasitizing the PMB. *Acerophagus papayae* was the major parasitoid of PMB. Two common predators namely *Apertochrysa* sp. and *Cryptolaemus montouzieri* were also found feeding on PMB (Mastoi et al. 2011).

42.2.4.15 Taiwan

P. marginatus was found damaging papaya in Taiwan for the first time in 2011. *A. papayae* was useful in controlling the papaya mealybug in Taiwan. Bio-control is to be initiated for the control of PMB (Chen et al. 2011).

42.2.4.16 Indonesia

The papaya mealybug, *Paracoccus marginatus* was recorded in Indonesia (Java) in 2008. Introduction of parasitoid, *A. papayae* is to be carried out in controlling the papaya mealybug in Indonesia (Herlina 2011).

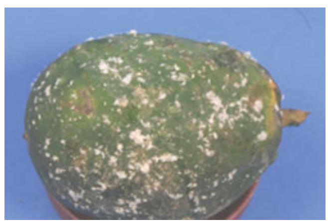
42.2.4.17 Ghana

Real Metarhizium is a biopesticide that contains the active ingredient *Metarhizium anisopliae* ICIPE 69 (3%w/v) at 3.0 ml real metarhizium/l of water is known to cause about 75 % mortality of *P. marginatus*. Application of Real metarhizium at 3 ml/l is recommended for farmers for use in the management of the papaya mealybug in Southern parts of Ghana.

42.3 Jack Beardsley Mealybug, *Pseudococcus jackbeardsleyi* Gimpel and Miller

Pseudococcus jackbeardsleyi was found colonized on papaya in Tamil Nadu and Karnataka in India (Mani et al. 2013b), *Pseudococcus jackbeardsleyi* is distributed throughout the neotropical region and a few countries in southern Asia (Williams and Watson 1988). It was originally described as *Pseudococcus elisae* collected on banana in Hawaiii by Beardsley (1986). It has been re-described as the Jack Beardsley mealybug- *Pseudococcus jackbeardsleyi* in 1996 by Gimpel and Miller (1996). Thus *Pseudococcus jackbeardsleyi* Gimpel & Miller is the valid name but *Pseudococcus elisae* Borchsenius, cited by Beardsley (1986) is a misidentification of *Pseudococcus jackbeardsleyi*, discovered by Gimpel and Miller (1996).


Jack beardsley mealybug


Fruit damage by JMB


Leaf infestation by JMB

42.3.1 Damage

Jack Beardsley mealybugs were found scattered on the leaves, flowers, fruits and trunk of papaya plant. Heavy colonization was not found on papaya plants in the field. However, in the laboratory, it was found in colonies. Like any other mealybug JMB is also phloem feeder. They suck the sap from various parts of the host plant including the leaves, stems, and fruits (Mani et al. 2012).

42.3.2 Natural Enemies

A total of three predators were recorded on JMB. Larvae of green lacewings, lycaenids and coccinellids were found actively feeding on the Jack Beardsley mealybug on many papaya gardens. They were identified as *Cryptolaemus montrouzieri* (Coccinellidae), *Mallada boninensis* (Okamoto) (Chrysopidae) and *Spalgis epeus* Westwood (Lycaenidae). Among the predators the Australian ladybird beetle was found in large numbers. All stages of *C. montrouzieri* were found amongst the mealybug colonies indicating natural colonization on JMB. Number of larvae ranged from 18 to 30 per papaya leaf. Similarly they were found feeding on the mealybugs infesting fruits, trunk and flower panicles. As many as 300 larvae of *C. montrouzieri* were also found per plant (Mani et al. 2013a).

Colonization of *C. montrouzieri* on Jackbeardsley Mealybug

Both adults and larvae of *C. montrouzieri* were found feeding on all the stages of JMB both in the field and laboratory. A single predatory larva had consumed 3.83 (2–4), 13.75 (12–14), 68.88 (61–73) and 172.50 (164–179) mealybug nymphs of 10 days old during the development of first, second, third and fourth instar, respectively. The larva of *C. montrouzieri* took 13.85 days to complete its development on JMB. The predator took 29.30 days on JMB (Mani et al. 2013a).

42.3.3 Biological Control

Among the natural enemies *C. montrouzieri* was found in large numbers followed by *S. epeus* and *M. boninensis*. The results on impact of natural enemies on the population of JMB on papaya are presented in table 3. A mean of 16.6 mealybugs/plant was observed in mid May 2012. Following the appearance of the mealybugs, the natural enemies have also started appearing on JMB. The mealybug population steadily increased to 179 in the mid August, and thereafter steadily declined to 1.72 in the first week of December. The natural enemies were observed throughout the study period. The population of *C. montrouzieri* reached peak of 65.62/plant in August. During the same period, the mean of 10.00 *Spalgis epeus* and 4.10 *M. bonensis*/plant were recorded. All these three predators particularly *C. montrouzieri* played a major role in the suppression of JMB on papaya. Statistical analysis revealed that there was no significant influence of weather factors on the population of mealybugs. Hence the reduction of the mealybugs was attributed mainly to the action of/by all the three predators particularly *C. montrouzieri* (Mani et al. 2013a). Williams and Watson (1988) state "There are no records of actual damage but the species is polyphagous and, in the absence of suitable natural enemies, it could be injurious". No classical biological control attempt has been made for the Jack Beardsley mealybug, and possibly it is kept under control by the local natural enemies in the invaded countries (Muniappan et al. 2011). Hence there is no need for any panic for the new invasive *P. jackbeardsleyi* in India (Mani et al. 2013a).

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Fruit Crops: Pineapple

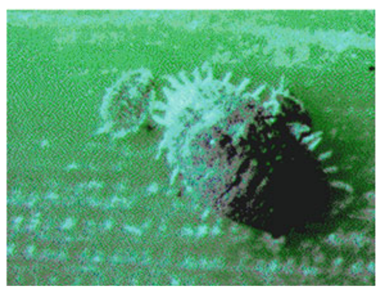
43

M. Mani

43.1 Species

Pineapple plants worldwide are infested with mealybugs feeding on the plant sap. Pink pineapple mealybug (PPM) *Dysmicoccus brevipes* (Cockerell), and grey pineapple mealybug (GPM) *Dysmicoccus neobrevipes* Beardsley are the mealybugs associated with pine apple plant (Beardsley 1964). PPM is the most widely distributed mealybug on pineapple worldwide (Williams and Watson 1988). It was thought by Ferris (1950) to be of North American origin, whereas, Carter (1935) considered it native to South America. *Dysmicoccus brevipes* is known to attack pine apple in several countries including India. This mealy bug generally occurs in moist tropical areas where pineapples are grown. It has been a prominent pest in Mauritius, tropical Africa, the South Pacific Islands, Hawaii, and the Philippines, Taiwan, and in common in the West Indies, South and Central America, with its distribution extending into Florida and Louisiana in the United States (Table 43.1). *Dysmicoccus brevipes* has become an increasing threat to pineapple cultivation in Kerala, West Bengal and Assam in India.

Dysmicoccus brevipes



D. neobrevipes

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Table 43.1 List of mealybugs recorded in pine apple in different countries

Mealybug species	Region	Reference
Dysmicoccus brevipes (Cockrell)	Several countries	Ben-Dov (1994)
	India, Indonesia, Philippines	Williams(2004)
Dysmicoccus mackenziei Beardsley	Neotropical region	Ben-Dov (1994)
Dysmicoccus neobreipes Beardsley	Several countries	Ben-Dov (1994)
	Malaysia	Williams (2004)
Ferrisia virgata (Cockerell)	–	Ben-Dov (1994)
Maconellicoccus hirsutus (Green)	India, Malaysia	Williams (2004)
Phenacoccus hargreavesi (Laing)	Ethiopian	Ben-Dov (1994)
Phenacoccus madeirensis Green	–	Ben-Dov (1994)
Planococcoides nijalensis (Laing)	–	Ben-Dov (1994)
Planococcus citri (Risso)	Florida	Ben-Dov (1994)
Planococcus minor Maskell	–	Ben-Dov (1994)
Pseudococcus viburni (Signoret)	–	Ben-Dov (1994)
Pseudococcus cryptus Hempel	Singapore	Williams (2004)
Pseudococcus longispinus (Targioni Tozzetti)	–	Ben-Dov (1994)
Trionymus internodii (Hall)	Israel	Ben-Dov (1994)

43.2 Damage

D. brevipes is common on the roots of pineapple and large colonies develop on the stems just above ground level. The mealybugs may spread upwards to feed in the floral cavities, on both small and mature fruit, and on the crown leaves. The leaves turn bright pink with some degree of flaccidity. The leaf tips turn brown, curl downward and the leaf margins show a light inward curving. Later, these symptoms become more pronounced. Ultimately, the plant wilts and dries with downward browning due to necrosis on leaf tips. Finally, the leaf tips dry up completely, and the bright pink turns completely dull. Correspondingly, the roots cease to elongate and collapse. Often, new roots appear above the old ones, and, concurrently, the renewed aerial growth associated. Sometimes, infected plants recover from the ailment, and normal new leaves come out at the centre. Mealybugs attack in basal portion and in fruit as well (Mandal 2009). The plants exhibit stunted appearance and size of fruits are reduced. Mealybugs may cause pineapple growers problems because they may impact the size of pineapple fruit due to withdrawal of plant nutrients; they produce large volumes of the sweet liquid called “honeydew” that makes the pineapple fruit sticky and black coloured from an associated fungus called sooty mould.

In Hawaii, *D. brevipes* is known to occur in two forms with distinctive body colours and biologies, and with different capacities to produce disorders or disease in pineapple plants (Carter 1936). Pink pineapple mealybug (PPM) *D. brevipes* and grey pineapple mealybug *D. neobrevipes* are the primary vectors of Pineapple Mealybug Wilt Associated Virus (PMWaV). On the Cook Islands of Atui and Mangaia, *D. brevipes* (whose dissemination is assured by ants, mainly *Pheidole megacephala)* could seriously affect the developing pineapple industry. And honeydew secretion by the mealybugs causes a decay of the maturing fruits. In conclusion, four types of damage are possible on pineapple: (1) the transmission of pineapple wilt (also called mealybug wilt and edge-wilt); (2) the production of chlorotic areas where there has been prolonged feeding and the underlying tissues have been exhausted; (3) damage to the bottom of the pineapple by the feeding of large mealybug populations which makes the bottom slices unmarketable and may cause the rotting and leaking of the fruits; and (4) “mealybug stripe” which results from the feeding of a short section of each of 3 or 4 inner whorl leaves. It is characterized by streaks of pale green to yellow and by the collapsing of the water storage tissues within these streaks.

Mealybug damage on pineapple

43.3 Behaviour

Pineapple mealybugs are secretive in habit and usually inhabit the base of their host plants such as the lower portions of stems and the butts of pineapple plants, These sites of attack differ from that of grey pineapple mealybugs which are normally found on the aerial parts of its hosts such as leaves, stems, aerial roots, and flower and fruit clusters.

43.4 Natural Enemies

There are many natural enemies known to attack *D. brevipes*. Parasites include *Aenasius cariocus* Compere, *Aenasius colombiensis* Compere, *Anagyrus ananatis* Gahan, *Euryhopauus propinquus* Kerrich, *Hambletonia pseudococcina* Compere and *Ptomastidae abnormis* (Girault). Predators include *Cryptolaemus montrouzieri* Mulsant, *Lobodiplosis pseudococci* Felt, *Nephus bilucernarius* Mulsant, *Scymnus* (*Pullus*) *unicatus* Sicard and *Scymnus pictus* Gorham. Although many natural enemies to the pineapple mealybug are present, they exhibit minimal control if protective ants are tending the mealybug colony. The encyrtid *Anagyrus ananatis* preferred to parasitize adult females of *Dysmicoccus brevipes*. It is capable of parasitizing up to 27 mealybugs (González et al. 2005). It can be found attacking mealybugs in the presence of ants, although its impact on mealybug mortality is low. When ants are absent, the parasitoid is highly effective in lowering the mealybug populations in pineapple plantings (Hill 1983).

43.5 Management

Mealybug control often focuses on the control of caretaking ants that are essential for the proper development of pineapple mealybugs. They provide the mealybugs for shelter, protection from predators and parasites, and keep them clean from detritus that may accumulate in the secreted honeydew and be deleterious to the colony. Because of the essential role of the ants, management practices often include the control of tending ant species. Without the ants, mealybug populations are small and slow to invade new areas and the field would be free of a serious mealybug infestation. Three ant species are responsible for maintaining mealybug populations on pineapple.

Carter (1967) asserted that it is essential to first control ants in the pineapple fields prior to control of pine apple wilt. Ant control relies heavily on bait preparations since insecticides are used most efficiently and selectively in this form (McEwen et al. 1979). Insecticidal baits are a common and effective method of controlling ants. Amdro (hydramethylnon) and insect growth regulators are the most promising chemicals for ant control in pineapple (Reimer et al. 1990). When ants encounter a fence or wall they are likely to travel the course of the fence rather than up and over the fence to forage on the other side.

Physical barriers such as ant fences running parallel to the field periphery are partially successful in keeping ants out of the field, and subsequently controlling mealybug populations.

43.6 Cultural Control

Previously infested fields should be turned over and all crop residues removed and burnt. Crop residues and grass roots left in the field may harbour mealybug populations until the new crop has developed enough to support a mealybug population. Field borders should be kept clean of weeds and debris that may support mealybugs between plantings. Weeds also provide alternative food sources that maintain ant populations between periods where mealybug infestations are small. A common cultural practice is to allow a field to lie fallow for 6–12 months after post-ratoon knockdown. This period is referred to as the inter cycle. Shortly before replanting, the field is burnt to remove pineapple trash.

43.7 Chemical Control

Granular formulations of commercial products 30 kg aldicarb/ha, 60 kg thiofanox/ha or 60 kg carbofuran/ha, gave the best results against *Dysmicoccus brevipes* (Ckll.) (Menezes et al. 1977). Malathion or diazinon is still used for direct mealybug control in pineapple, when ant control does not result in a sufficient reduction in mealybug populations. The chemical control of mealybugs is not easy. Complete coverage of a pineapple plant with insecticides not possible. Mealybugs tend to be deep in leaf axils, under the sepals of blossoms, or inside of closed blossom cups where they are protected from insecticidal sprays (Jahn 1995). According to Hu et al., spraying of quinalphos @ 0.025 %, fenitrothion @ 0.05 %, fenthion @ 0.05 %, chlorpyriphos @ 0.05 %, dimethoate @ 0.05 % or monocrotophos @ 0.05 % is done carefully so that the chemicals should reach the base and also the sides of the plant. Among non-systemic organophosphates, diazinon provided a minimum of 30 days of residual effects. The thick, waxy coating on mealybugs makes insecticide penetration difficult. Even the use of systemic insecticides is frequently impractical for mealybug control. Pineapple industry, however, still needs an alternative for diazinon that can be used on mature fruit prior to fruit harvest.

Dipping the basal portion of the planting material in methyl parathion @ 0.02 to 0.05 % or monocrotophos @ 0.02 % as a prophylactic measure and application of carbofuran 3G @ 15 to 17 kgha-1 in affected fields or phorate 10G @ 1.75 kgaiha-1 at 100 DAP can effectively control pineapple mealybug (Anonymous 2007). It indicated that the basal portion of the planting material needed double prophylactic measures (phorate 10 G and neem cake ground application at 100 DAP and 180 DAP respectively), and three times manual weeding helps to protect from mealybug infestation (Mandal 2007). According to the Pineapple Technical, PNB Krishi Samachar, Punjab National Bank expressed their views that BCR in pineapple cultivation may be 1.92 and invest rupee return (IRR) may be more than 50 % (Anonymous 2007).

43.8 Biological Control

Elimination of tending ants from pineapple fields with the ant bait has led to improved mealybug suppression by their natural enemies. In a sense, the pineapple industry already uses biological control to manage wilt disease transmitted by mealybugs. When ants are controlled through chemical means, mealybug populations are regulated by the myriad of natural enemies found in pineapple fields. However, parasites became established but did not provide adequate control of mealybugs particularly in the presence of ants.

43.9 Hawaii

Attempts to establish effective natural enemies of the pineapple mealybug were conducted over a long period but with little success in the early years. A number of the species imported specifically against this mealybug did not propagate readily on the Hawaiian form, nor was establishment secured with a long list of general predators, among which were about 12 species of *Hyperaspis* and 6 species of *Scymnus,* presumably well adapted to attack on this mealy bug. Some minor degree of control was attributable to the establishment of the cecidomyiid predator, *Vincentodiplosis pseudococci* (Felt), imported from Mexico in 1930, and to a few of the numerous coccinellids that had been imported as general mealybug feeders (Fullaway 1924, 1933; Swezey 1925; Carter 1935; Zimmerman 1948). Mealybug species *Pseudococcus bromelias* on pineapple was kept down by *C. montrouzieri* in Hawaii (Fullaway 1922). The encyrtid *Euryrhopalus schwarzi* (How.) *(=pretiosa* Timb.) and the cecidomyiid *Dicrodiplosis guatemalensis* Felt, both imported in 1935 from Guatemala, have been reported as established.

Two encyrtid parasites, *Anagyrus coccidivorus* Dozier to *A. ananatis* Gahan and *Hambletonia pseudococcina* Comp., were imported from Brazil in 1935–1936 and further stocks of the latter species from Venezuela and Colombia. It was found that the *H. pseudococcina* from Brazil, which is a bisexual race, would not propagate on the Hawaiian *D. brevipes,* but the stock from Venezuela, which reproduces parthenogenetically, was well adapted to it. Both of the above species became established (Carter 1937).

Anagyrus ananatis Gahan (Hymenoptera: Encyrtidae) is the most common solitary, endoparasitoid of PPM in Hawaii. The parasitoid has provided partial control of PPM in association with other natural enemies. Field parasitization of PPM by *A. ananatis* in the presence of ants can be as high as 9.9 %. It was present in all pineapple fields surveyed and parasitized ant-tended mealybugs (Gonzalez et al. 1999). Because of its host specificity, abundance, and persistence, *A. ananatis* was chosen as a candidate for an augmentative biological control project targeted against PPM (González-Hernández et al. 1999).

Anagyrus ananatis

Hambletonia pseudococcina

Mass production of a desired biological agent is crucial to the implementation of any augmentative biological control program. The ability to store reared biological control agents provides an opportunity to manufacture them during low demand periods and utilize them during high demand periods. It also permits synchronized field releases of natural enemies during the critical stages of pest outbreaks. *Anagyrus ananatis* prepupal and pupal stages could be stored for over 6 weeks at 15 °C without affecting their eclosion rate. When immatures were stored at 14.8 °C, they had emergence rates comparable to the control after 8 weeks, which indicated high survival rates at that temperature.

43.10 Florida

Although *D. brevipes* was only of very minor significance on a few small pineapple plantings in Florida, stocks of *Hambletonia pseudococcina* Comp. were imported from Puerto Rico in 1943–1944. The 1943 releases of very small numbers were unsuccessful, but 374 adults released at three sites in 1944 resulted in establishment at Sebring, Florida.

43.11 Puerto Rico

Anagyrus coccidivorus Doz. and *Hambletonia pseudococcina* Comp. were received from Brazil, via Hawaii in 1937–1938. The first was propagated in the insectary and over 7,000 adults released in the field. Despite releases continuing into 1940, there have been no recoveries. Although only two females of the unisexual race of *Hambletonia pseudococcina* were received alive, about 7,000 adults were reared and released. Establishment of *H. pseudococcina* occurred readily and field populations built up rapidly (Bartlett 1939).

43.12 Jamaica

There have been no reports of establishment of *Hambletonia pseudococcina, Hyperaspis* sp., and *Diomus* sp., imported from Hawaii in 1939.

43.13 Philippine Islands

The predators *Cleodiplosis koebelei* (Felt), *Scymnus margipaliens* Muls., and *Hyperaspis silvestrii* Weise were all established from Hawaiian importations in 1931, but reports as to their effectiveness are not available. In Philippines, *C. montrouzieri* was introduced against pineapple mealybug from USA in 1928 but establishment was reported only at one locality (Rao et al. 1971).

43.14 Mauritius

In Mauritius, biological control efforts against *D. brevipes* centred on *C. montrouzieri* which was imported from South Africa during 1936–1939. A total of 1,949 individuals were released in 19 sites in 1939–1940. No field recoveries were made (Mamet 1949).

43.15 Taiwan and Bonnin Islands

C. montrouzieri was imported for the control of *D. brevipes* but was only partially successful in Taiwan and Bonnin Islands (Sakimura 1935).

43.16 Africa

The ladybird beetle was introduced into South Africa in 1900. Later it became established on other crops but it was not effective against *D. brevipes* on pineapple (Greathead 1971). The predator was colonized on *D. brevipes* in pineapple plantations in West Africa (Mallamaire 1954).

43.17 Virginia

Mass releases of *C. montrouzieri* were made to control the heavy infestations of *Pseudococcus comstocki* on pineapple in Virginia but the predator proved ineffective against the mealybug (Haeussler and Clancy 1944).

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Fruit Crops: Avocado

44

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44.1 Species

The long-tailed mealybug *Psudococcus longispinus* (Targioni Tozzetti) had been reported to be injurious to avocado in South California (Flanders 1940; 1944), Israel (Wysoki et al. 1976), Chile (Sazo et al. 2006), New Zealand (Blumberg and van Driesche 2001; Zulhendria et al. 2012) and also in Los Angeles. The vine mealybug *Planococcus ficus*, is also a serious new exotic pest in California known to attack avocados. *Planococcus citri* (Risso) was recorded on avocado in Israel (Dunkelblum et al. 2002). *Planococcus citri*, *Maconellicoccus hirsutus* (Green) and *Paracoccus marginatus* were known to infest avocado Florida. *F. virgata* is also known to attack *Persea americana* (http://www.plantwise.org/KnowledgeBank/Datasheet.aspx?dsid=23981). *Parcoccus marginatus* is known to infest avocado, and so also *Nipaecoccus viridis* (http://www.plantwise.org/KnowledgeBank/Datasheet.aspx?dsid=36335). The mealybugs known to infest includes *Dysmicoccus impararlis* sp.n. in India (Williams 2004), *Ferrisia consobrina* Williams & Watson, *Planococcus citri*, *Niapecoccus nipae* (Makell) in Hawaii, *Phenacoccus graminicola* Leonardi and *Puto barberi* (Cockrell) (Ben-Dov 1994).

Pseudoccocus longispinus on Avocado

44.2 Damage

Mealybugs suck phloem sap from avocado. When abundant, they can reduce tree vigour. The infested plants are found with sticky honeydew and blackish sooty mould that fouls fruit. New scion grafts on old (top-worked) trees have sometimes been damaged by long-tailed mealybugs abundant during late winter to early spring. In Israel, no damage by *Ps. longispinus* to avocado was recorded before the 1950s, but since then, the biological equilibrium appears to have been upset in plantations near cotton fields, by the adverse effect on the natural enemies of the mealybug of chemical treatments applied to cotton. In avocado plantations heavily attacked by the mealybug, the variety Hass was the most heavily infested, followed in order of decreasing

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susceptibility by Nabal, Fuerte and Ettinge (Wysoki et al 1977). On grafted avocado trees, long-tailed mealybugs are an important problem at Los Angeles. In recent years, much grafting has been done in the coastal areas on varieties. The scions are covered with paper bags to keep the direct sunlight off the tender, new foliage. Long-tailed mealybugs were found to establish on the scions. The shade afforded by these bags makes it possible for the mealybugs to attack this foliage, and unless they are controlled, the mealybugs usually kill the scion. The mealybugs were found to be just as abundant on the scions of trees which were shaded by parasols as they were on those scions covered by bags. Every spring, tender terminal sprouts, in shady portions of avocado trees, are attacked by long-tailed mealybugs, but these infestations have not been considered to be of practical importance. A similar infestation on the scion of a grafted tree, however, results in its death.

44.3 Management

Mealybugs are widely distributed in tropical and subtropical regions. They are usually found in cracks and crevices and other sheltered locations on the fruit surface, and can be difficult to control using topical chemical treatments. Conserving the natural enemies is advised to control most mealybug populations. Selectively controlling ants causes long-tailed mealybug populations to decline and can prevent outbreaks. Dust on the plants is to be reduced since the dust interferes with natural enemies of the mealybug. Pesticide application is not advised for mealybugs on avocado.

44.4 Biological Control

Mealybug predators include green lacewing (*Chrysoperla* spp.) larvae, pirate bugs, predaceous fly larvae, and lady beetles, such as the mealybug destroyer (*Cryptolaemus montrouzieri)*. Parasitic wasps are especially important in controlling outbreaks because the wasps specialize on mealybugs and reproduce rapidly. The encyrtids *Acerophagus notativentris* (Girault), *Arhopoideus peregrinus* (Compere) and *Anarhopus sydneyensis* Timberlake are known to parasitize long-tailed mealybug.

Long-tailed mealybugs were at one time serious pests of avocado trees in San Diego County, California but they have generally been adequately controlled by the parasitoids introduced to combat them. The parasitoids however, are not giving adequate protection for the scions on newly grafted trees. Although the parasitoids will eventually wipe out an infestation of mealybugs, on grafted trees they do not work sufficiently rapidly to prevent the destruction of the scions once they are attacked. Therefore insecticides must be relied upon for control. Insecticidal dusts by a small hand duster sometime before the foliage appears on the scions. The dust may be applied immediately after grafting and before the graft is covered with the usual paper bag. It should be applied not only to the top of the stump, but also 5 or 6 inches down the sides, especially in the section where the scion is inserted. The sealing material which is applied for this purpose forms a "bridge" over which the mealybugs and attending ants may gain access to the scion. The stumps of trees which have been resealed should again be treated with insecticides (Walter Ebeling and Pence 1948).

Regular liberations of *C. montrouzieri* were made to reduce the mealybug infestation (Flanders 1940, 1944). The peak populations of *P. longispinus* occurred in late spring and early summer; numbers declined in autumn and winter and were usually lowest in April. The integrated programme includes the release of *Hungariella peregrina* (Comp.) (first introduced into Israel in 1954 and the main parasite of *Ps. longispinus*); the introduction (from Australia) and establishment of *Anagyrus fusciventris* (Gir.), another parasite of the mealybug; and limitating the sprayings from aircraft near avocado plantations. As a result of limiting aerial sprays of cotton near avocado, and the release of natural enemies, the long-tailed mealybug population and its damage were greatly reduced (Swirski et al. 1979, 1980).

In Los Angeles, Cryptolaemus beetles are liberated under the paper bags, and immediately try to leave the bag without attacking the mealybugs.

For some reason they will not stay under the bags. The parasites, if they should find the mealybugs, would not be able to result in their death rapidly enough to prevent the destruction of the initial growth of foliage which is so vital to the development of the scion. The prevention by the parasites of the spread of incipient infestations of mealybugs is sufficient for control as far as the avocado tree as a whole is concerned, but on the newly foliaged scions of grafted trees, prevention or immediate control is desirable. It is necessary, therefore, to turn to insecticides for the answer to this problem. The long-tailed mealybugs appear to the most abundant in late winter and early spring, their numbers decreasing as summer approaches. This period happens to coincide with the period of greatest activity in the grafting of avocado trees.

44.5 Insecticide Needed

Since prevention of attacks by the mealybug during the entire late winter early spring period is the desired goal, an insecticide with a prolonged residual effect against the young mealybug crawlers, likely to become established on the grafted trees, might logically be, expected to be the solution to the problem. The insecticide mixtures were applied with a paint brush to the top of the avocado stumps and for 3 or 4 inches down the side. It is especially important to apply the insecticides thoroughly to the area around each scion, both on top of the stump and down the side. Imidacloprid (Confidor Forte 200 SL) applied to the foliage was efficient in controlling *P. longispinus* in both locations during the 2004 season in Chile. Applications to the trunk were not efficient against long-tailed mealybugs, apparently due to the reduced absorption and translocation in the trees at both locations (Sazo et al. 2006).

44.6 Quarantine Treatment

Metabolic stress disinfection and disinfestations (MSDD) is a potential quarantine treatment in which a combination of cycles of rapid decompression and compression are followed by exposure to ethanol vapour under decompression. The response of 'Hass' avocado (cv. Hass) to MSDD treatment for control of long-tailed mealybug (*Pseudococcus longispinus*) was investigated. The best treatment for the most resistant life stage (2nd/3rd instars) was 90-min MSDD treatment with 371 mg L^{-1} ethanol. Early and late season 'Hass' avocados were subjected to MSDD treatments (with 371 mg L^{-1} ethanol), or in air (control). Following the treatments, early season fruit were ripened at 20 and 25 °C. Half of the late season fruit were ripened at either 20 or 25 °C, and the remainder were stored at 5.5 °C for 6 weeks, then ripened at 20 °C. There were no significant difference in quality and rot incidence between non-treated controls and MSDD-treated fruit. The main disorders found were stem-end and body rots, vascular browning and flesh greying for the stored fruit. There were also no significant differences in fruit respiration rate or ethylene production. Thus, MSDD was shown to be a potentially 'soft' disinfestation treatment for surface pests of avocado (Blumberg and van Driesche 2001).

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45 Fruit Crops: Banana

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45.1 Species

Mealybugs are injurious to banana in India, Africa, Florida, West Indies, Hawaii and Canary Islands etc (Table 45.1).

45.2 Damage

Arboreal mealybugs are found infesting leaf sheath and bunches. The mealybugs infest developing bunches and affects the growth very badly. *Plannococcus citri* and *Phenacoccus solenopsis* were found to damage banana cultivars in Tamil Nadu, India. *Geococcus coffeae* and *Geococcus citrinus* are also known to damage to the roots of banana cv. Nendran (AAB) and also Rasthali (AAB) in Kerala, India. Root mealybug infestation leads to symptoms like creamy white discolouration of the last unfurled leaf and the leaf remaining unopened for longer duration, with a burnt-like appearance at the tip. The feeder roots are found to be severely damaged with dead root hairs. Mealybugs infest on the root portion and affect the absorption of nutrients from the soil. In India, the banana streak virus is transmitted mostly through planting materials, but also in a semi-persistent manner by the mealybug, *Planococcus citri*. There was severe crop and yield loss due to viral disease transmitted by the mealybugs (Jones 1994; Lockhart 1994). *Planococcus ficus* was able to transmit Banana streak OL (badna) virus (BSLOV) (Meyer et al. 2008).

45.3 Varietal Susceptibility

Highest percent incidence of root mealybugs was recorded in Wynad District Kerala, India. Among the cultivars, Nendran (AAB) was the most susceptible but Palayankodan (AAB) and Kodappanillakunnan (AB) were completely devoid of root mealybug infestation (Smitha and Maicykutty 2007).

45.4 Natural Enemies

Anagraphus sp. has been reported as a common parasitoid of *Plannococcus citri* infesting banana in India.

45.5 Management

The waxy coating of the mealybug creates problem in getting desired results on mealy bug mortality with to insecticides. Therefore, use of

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Table 45.1 List of mealybugs recorded on banana in different countries

Species	Region/country	Reference
Cataenococcus ensete Williams & Matile-Ferreo	Africa	Watson and Kubiriba (2005); Matile-Ferreo and Williams (1995)
Cataencoccus larai Williams	Columbia, Mexico	Ben-Dov (1994)
Dysmicoccus brevipes (Cockerell)	Taiwan	Huang and Chien (1969)
	Nigeria	Matile-Ferreo and Williams (1995)
	Africa	Watson and Kubiriba (2005); Matile-Ferreo and Williams (1995)
Dysmicoccus grassii (Leonardi)	Southern Asia and Canary Islands	Williams (2004)
	Nigeria	Matile-Ferreo and Williams (1995)
	Africa	Watson and Kubiriba (2005); Matile-Ferreo and Williams (1995)
Dysmicoccus lepelleyi (Betrem)	Indonesia and Vietnam	Williams (2004)
Dysmicoccus neobreipes Beardsley	Vietnam	Williams (2004)
Exallomochlus liti sp.n.	Philippines	Williams (2004)
Ferrisia virgata (Cockerell)	India	Williams (2004)
	Africa	Watson and Kubiriba (2005); Matile-Ferreo and Williams (1995)
Geococcus coffeae Green	Africa	Watson and Kubiriba (2005); Matile-Ferreo and Williams (1995)
	India	Ben-Dov (1994)
Geococcus citrinus Kuwana	India	Ben-Dov (1994)
Maconellicoccus hirsutus (Green)	India	–
	Africa	Watson and Kubiriba (2005); Matile-Ferreo and Williams (1995)
Neochavesia caldasiae (Balachowsky)	Columbia and Trinidad	Ben-Dov (1994)
Neochavesia eversi (Beardsley)	Columbia	Ben-Dov (1994)
Nipaecoccus nipae (Maskell)	Africa	Watson and Kubiriba (2005); Matile-Ferreo and Williams (1995)
Niapecoccus viridis (Newstead)	Vietnam	Williams (2004)
Parputo anomalus (Newstead)	Tanzania	Ben-Dov (1994)
	Africa	Watson and Kubiriba (2005); Matile-Ferreo and Williams (1995)
Paracoccus burnerae (Brain)	Africa	Watson and Kubiriba (2005); Matile-Ferreo and Williams (1995)
Paracoccus marginatus Williams & Granara de Willink	Sri Lanka	Galanihe et al. (2010)
Phenacoccus parvus Morrison	Africa	Watson and Kubiriba (2005); Matile-Ferreo and Williams (1995)
Phenacoccus solenopsis (Tinsley)	India	–
Planococcus citri (Risso)	India & Florida	Ben-Dov (1994)
	Africa	Watson and Kubiriba (2005); Matile-Ferreo and Williams (1995)
Planococcus ficus (Signoret)	Africa	Watson and Kubiriba (2005); Matile-Ferreo and Williams (1995)

(continued)

Table 45.1 (continued)

Species	Region/country	Reference
Planococcus kraunhiae (Kuwana)	California, Taiwan, China & Japan	Ben-Dov (1994)
Planococcus lilacinus (Cockrell)	India	Williams (2004)
Planococcus minor (Maskell)	West Indies	Francis et al. (2012)
	Philippines	Williams (2004)
Planococcus musae sp. nr.	Nigeria	Matile-Ferreo and Williams (1995)
Planococcus musae Matile-Ferreo & Williams	Africa	Watson and Kubiriba (2005); Matile-Ferreo and Williams (1995)
Pseudococcus columbianus Borchsenius	Columbia	Ben-Dov (1994)
Pseudococcus comstocki (Kuwana)	Africa	Watson and Kubiriba (2005); Matile-Ferreo and Williams (1995)
Pseudococcus cryptus Hempel	Malaysia	Williams (2004)
	Africa	Watson and Kubiriba (2005); Matile-Ferreo and Williams (1995)
Pseudococcus elisae Borchsenius	Caribbean region of Costa Rica	Vargas Calvo and Cubillo Sanchez (2010)
	Hawaii	Beardsley (1986)
	Pacific region & Southern Asia	Williams (1988)
Pseudococcus longispinus (Targioni Tozzetti)	Africa	Watson and Kubiriba (2005); Matile-Ferreo and Williams (1995)
Pseudococcus microadonidum Beardsley	Seychlles & Caroline islands	Ben-Dov (1994)
Pseudococcus pergrinabundunus Brchaenius	Columbia	Ben-Dov (1994)
Pseudococcus solomonensis Williams	Solomon Islands	Ben-Dov (1994)
Pseudirhizoecus proximus Green	Columbia	Ben-Dov (1994)
Rasrococcus iceryoides (Green)	India	Williams (2004)
	Africa	Watson and Kubiriba (2005); Matile-Ferreo and Williams (1995)
Rasrococcus invadens Williams	Africa	Watson and Kubiriba (2005); Matile-Ferreo and Williams (1995)
Saccharicoccus sachari (Cockerell)	India	–
	Africa	Watson and Kubiriba (2005); Matile-Ferreo and Williams (1995)

biocontrol control agents will be of great use. The ant population present near mealybug colony has to be cleared.

Arboreal Mealybugs Spray infested areas with dichlorovas 76 EC @ 2 ml+2 g of fish oil rosin soap in a litre of water is to be done for the control of arboreal mealybugs. Treatment against *D. brevipes* in banana should begin 30 days before harvesting, that two applications should be made (the second one 15 days before harvest), and that the whole tree should be treated. If it is necessary to reduce costs, the second application can be made to the fruits only (Huang and Chien 1969). The crop residues infested with mealybugs has to be destroyed. Australian lady bird beetle, *Cryptolaemus montrouzieri* Mulsant for the arboreal mealybugs in general, and the hymenopteran parasitoid *Leptomasitx dactylopii* How. specific to *P. citri* are recommended for their control in India.

P. citri damage

Ferrisia infestation

45.6 Root Mealybugs

Since suckers are suspected to be the possible source of infestation, spread of this serious pest (*Geococcus* spp.) is to be checked by prevention of use of suckers from infested areas within and outside the state. Dipping of suckers in boiled water for 10 s helps to destroy the live stages of mealybug adhered to the sucker. Soil drenching with chlorpyriphos 20 EC @ 2.5 ml per litre of water in the root zone helps to reduce the root mealybug population. Sodium silicate was the best in reducing mealybug population on the roots. Drenching of 3 % neem seed kernel extract (NSKE) and *Verticillium lecanii* (Zimmerman) (Econil 7 g/l) were also effective against root mealybugs (Smitha and Maicykutty 2007). *In vitro* application of *Verticillium lecanii*, *Beauveria bassiana* (Bals.-Criv.) Vuill. and *B. brongniartii* (Saccardo) Petch and *Metarhizium anisopliae* (Metchnikoff) Sorokin at single dose (1×10^7 conidiospores/ml) against *P. citri* inflicted mortality of 91.1, 75.5, 66.6 and 45.3 % respectively. *Verticillium lecanii* at five doses (ranging from 1×10^5 to 1×10^9 conidiospores/ml) caused a mortality of 45, 65, 80, 90 and 95 % mortality respectively (Saranya 2008). Entomopathogenic nematode, *Steinernema glaseri* is also known to cause mealybug mortality under laboratory conditions.

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Fruit Crops: Sapota

46

M. Mani

46.1 Species

Mealybugs are found injurious to sapota (Manilkara zapota (Forberg)/Acharas zapota) in India, Florida, Indonesia, Philippines, Malaysia, Cambodia, Singapore, Vietnam and some West African countries (Table 46.1).

46.2 Damage

Sapota leaves are found infested with *Rastrococcus invadens*. Fruits were found covered with *P. lilacinus*. Shoots with leaves are malformed due to *M hirsutus*. Both leaves and fruits are found damaged by *P. citri*.

46.3 Management

46.3.1 *Maconellicoccus hirsutus*

Cryptolaemus montrouzieri is found useful to control *M. hirsutus* on sapota when released @ 20/plant on sapota plants infested with mealybugs. The mealybug population declined from 54.20/plant on April 23 to 1.50/plant on June 15 in 2003. The decline in the mealybug population on sapota was attributed to the predatory activity of *C. montrouzieri* (Mani and Krishnamoorthy 2008).

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46.3.2 *Rastrococcus invadens*

The mealybug *R. invadens* was recorded in serious form on sapota in May 2002 in Bangalore North, India. The coccinellid predator *Cryptolaemus montrouzieri* Mulsant was released against *R. invadens* on sapota. The population of the mealybug declined from 507.6/shoot to 0.0 in 2 months' time. The decline in the mealybug population on sapota was due to the predatory activity of *C. montrouzieri* (Mani et al. 2004).

46.3.3 *Planococcus citri*

The two encyrtid parasitoids *Coccidoxenoides perminutus* (Timberlake) and *Leptomastix dactylopii* How. are useful in the suppression of *P. citri* on sapota in India. In a sapota orchard located in Bangalore North, the mealybug infestation was noticed in the first week of January on 3-year-old sapota at the Indian Institute of Horticultural Research Farm, Bangalore North. The mean number of mealybugs per shoot was 82.50, and the activity of the encyrtid parasitoids was observed from 9th January to 20th February. A mean maximum of 36.41 parasitoids emerged

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Table 46.1 List of mealybugs recorded on sapota in different countries

Mealybug species	Region/country	Reference
Dysmicoccus brevipes (Cockrell)	India	Williams (2004)
Dysmicoccus lepelleyi (Betrem)	Indonesia	Williams (2004)
Dysmicoccus neobreipes Beardsley	Philippines	Williams (2004)
Exallomochlus hispidus (Morrison)	Malaysia	Williams (2004)
Exallomochlus philippinensis sp.n.	Philippines	Williams (2004)
Ferrisia virgata (Cockerell)	India	Williams (2004)
Formicoccus matileae sp.n.	Cambodia	Williams (2004)
Maconellicoccus hirsutus (Green)	Philippines	Williams (2004)
	Florida	Hodges et al. (2005)
	India	Mani and Krishnamoorthy (2008)
Paracoccus marginatus Williams and Granara de Willink	India	–
Planococcus citri (Risso)	India	Mani and Krishnamoorthy (1997)
Planococcus lilacinus (Cockrell)	India	Williams (2004); Dhara Jothi and Tandon (1991)
Planococcus minor Maskell	Indonesia & Vietnam	Williams (2004)
Rasrococcus iceryoides (Green)	India & Singapore	Williams (2004)
Rastrococcus invadens Williams	India	Mani et al. (2004)
	West African countries	Agounke et al. (1988)

from samples collected on 15th January. The correlation and regression analysis indicated a highly significant relationship ($r = 0.958$) between *P. Citri* (Y) and the parasitoid *C. perminutus*. The regression equation fitted with the mealybug population (Y) and the parasitoid (X_1) was: $Y = 20.5092 + 0.3912\ X_1$. Abiotic factors (except the minimum temperature) did not have any significant relationship with *P. citri*. The decline in the mealybug population from 156.4 in January to 2.05 in February 1996 attributed due to the activity of the parasitoid *C. perminutus* (Mani and Krishnamoorthy 1997).

In yet another orchard at lIHR Farm, Bangalore North, *Planococcus citri* was observed in the first week of March, 96 on sapota. A mean of 94.37 mealy bugs per shoot was observed. The samples collected on 3rd March revealed the presence of the exotic encyrtid parasitoid, *Leptomastix dactylopii* How. The parasitoid was found to be active up to the first week of April, 1996. The mealybug population of 112.41 observed on 11th March had declined to 2.16 on 4th April. Statistical analysis revealed that the parasitoid, *L. dactylopii* had a highly significant relationship with the population of *P. citri* ($r = 0.969$) during March-April. The regression equation fitted with the mealybug population (Y) and the parasitoid (X_I) was: $Y = 7.56555 + 0.7644\ X_I$. The relationship of the mealybug population with any of the weather parameters was not significant. Hence, the reduction in the mealybug population during March–April may be due to the activity of *L. dactylopii* (Mani and Krishnamoorthy 1997).

R. invadens damage on sapota

P. lilacinus on sapota

46.3.4 *Planococcus lilacinus*

Cryptolaemus montrouzieri is highly effective in reducing the populations of *P. lilacinus* and also the above other mealybug species on sapota.

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Fruit Crops: Pomegranate

47

M. Mani

47.1 Species

Mealybugs are injurious to pomegranate in India, Sri Lanka, South Africa, Florida, Iran, Palestine, Israel, and USSR, etc (Table 47.1).

47.2 Damage

Both nymphs and adult female mealybugs caused considerable damage to the pomegranate by sucking the sap from the leaves, flowers and fruits, resulting in yellowing of leaves and shedding of flowers and tender fruits. Fruits covered with the mealybugs lose their market value. Fruit infestation with the mealybugs ranged from 25 to 100 % with a mean of 56.55 % in South India (PDBC-ICAR 1994; Karuppuchamy 1994). Bagging of pomegranate fruits for the control of fruit borers had increased mealybug infestation (*N. viridis*) (Shevale and Kulgud 1998).

Flower damage by *M.hirsutus*

Fruit damage by *P.lilacinus*

Cryptolaemus feeding on *M. hirsutus*

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Table 47.1 List of mealybugs recorded on pomegranate in different regions of the world

Mealybug species	Region/Country	Reference
Crisicoccus theobromae Williams & Watson	Malaysia	Williams (2004)
Dysmicoccus grassii (Leonardi)	Neotropical region	Ben-Dov (1994)
Dysmicoccus neobreipes Beardsley	Thailand	Williams (2004)
Ferrisia consobrina (Ckll.)	India	Williams (2004); Mani and Krishnamoorthy (1996)
Ferrisia virgata (Ckll.)	India	Nayar et al. (1976); Karuppuchamy (1994)
	Pakistan	Williams (2004)
Heliococcus destructor Borchsenius	Palaearctic region	Ben-Dov (1994)
Maconellicoccus hirsutus (Green)	India	Mani and Krishnamoorthy (1991)
	Maldives	Williams (2004)
Nipaecoccus viridis (Newstead)	India	Mani and Krishnamoorthy (1990)
Paracoccus ferrisi Ezzat & McConnel	Mexico	Ben-Dov (1994)
Paracoccus marginatus Williams and Granara de Willink	Sri Lanka	Galanihe et al. (2010)
	Florida	Walker et al. (2003)
Peliococcus trsipinosus (James)	Kenya	Ben-Dov (1994)
Phenacoccus solenopsis Tinsley	–	–
Planococcus citri (Risso)	Soviet Union	Niyazov (1969)
	Iran	Bodenheimer (1944)
	Palestine	Rivnay (1945)
	Israel	Rivnay (1960)
	USSR	Niyazov (1969)
	Egypt	EL-Rahn et al. (1974)
	India	Mani and Krishnamoorthy (1991, 2000)
	Florida	Hodges et al. (2005)
Planococcus dorsopinosus Ezzat & Mc Connel	Philippines, India, Thailand	Williams (2004)
Planococcus lilacinus (Ckll.)	India	Mani and Krishnamoorthy (1990); Ananda (2007); Balikai (2000)
	India	Tanwar et al. (2010)
Pseudococcus comsocki (Kuwana)	–	Ben-Dov (1994)
Pseudococcus cryptus Hempel	India	Williams (2004)
Pseudococcus filamentosus Ckll.	France	Frappa (1931)
Pseudococcus longispinus (Targioni Tozzetti), *Ps. maritimus & Pl. citri*	Africa	Moawad et al. (2011); Wohlfarter et al. (2010)
Pseudococcus comstocki (Kuw.)	Uzbekistan	Sheffer (1974)
Pseudococcus maritimus (Ehrhorn)	–	http://ucce.ucdavis.edu/files/datastore/391-534.pdf

47.3 Seasonal Development

The incidence of mealybugs was more from March onwards and gradually reached to a peak with 11.33 per 30 cm shoot per plant during second fortnight of April in North Karnataka. From June onwards, there was gradual decline in mealybug population (Ananda 2007). Morning relative humidity recorded significant and positive (r=0.5956) relationship, while evening relative humidity recorded negative and significant relationship (r = −0.57499) with incidence of mealybug *Pl. lilacinus* infesting on pomegranate in Karnataka, India. Both maximum and minimum temperatures had positive and non-significant (r=0.3750, r = 0.1872), relationship with mealy bugs, but rainfall and number of rainy days had negative and non-significant relationship. Among all regression factors listed, only morning and evening relative humidity were found to exert significant influence on incidence of mealy bug; their influence differed significantly when considered individually. Among the above factors morning and evening relative humidity influenced to the tune of 35 and 33 %, respectively (Ananda 2007). Mani and Krishnamoorthy (1990), Karuppuchamy (1994) and Shevale and Kulgud (1998) also reported incidence of mealybug *Ferrisia* spp. more abundant during March to June which is also a fruiting period.

47.4 Management

Cultural Collection and destruction of the infested twigs and leaves and burying them; Removal of the plants which serve as alternate hosts for the mealy bugs.

Chemical Phosphamidon (0.03 %), monocrotophos (0.1 %), malathion (0.04 %) and dimethoate (0.03 %) gave effective control of *F. virgata* (Butani, 1976). According to Ananda (2007), 3 and 7 days after treatment imidacloprid, thiamethoxam, dimethoate, dichlorvos+Fish Oil Rosin Soap (FORS), dimethoate+FORS recorded significantly higher per cent reduction of mealybug population and finally afforded 71.97, 69.24, 72.74, 70.76 and 73.37 % reduction over untreated control. But at the end of 14 days after treatment (DAT), all insecticides were inferior to the treatment which received 10 grubs of Australian ladybird beetle *Cryptolaemus montrouzieri* Mulsant recorded significantly higher per cent reduction (94.09) of mealybugs. Among all treatments, dimethoate+FORS recorded higher (73.37) per cent reduction of mealybugs over untreated control. Dimethoate was next best treatment which recorded 72.48 % reduction of mealybugs over untreated control (Ananda 2007).

Bufrofezin can be recommended for use against *Pseudococcus maritimus* on pomegranates. Lannate is effective, but a single spray will only control the part of the population moving between the bark and the fruit, which is never more than half. The mealybugs hidden between fruit or inside the flower end are protected from the spray. Materials with better residual action are to be registered in pomegranates (Carroll et al. 2006).

Biological Control Biological control is effective unless disrupted by ants and insecticidal application. *Cryptolaemus montrouzieri* supplements other local natural enemies in clearing the mealybug species on pomegranate in India (Mani and Krishnamoorthy 1990; Ananda et al. 2009).

47.4.1 *Planococcus lilacinus* (Ckll.)

Spalgis epeus Westwood, *Hyperaspis maindronii* Sic., *Scymnus severini* Weise. *Eublemma* sp., *Leucopis lutecornis* Malloch and *Anagyrus* sp., *Triommata coccidivora* (Felt.), *Spalgis epeus* Westwood, *Cryptolaemus montrouzieri* Muls. *Scymnus coccivora* Ayyar and *Cacoxenus perspicaux* (Knab) were reared from *P. lilacinus*.

Only *S. epeus* and *Cryptolaemus montrouzieri* were found very efficient in clearing the mealybug populations (Nair 1975; Mani and Krishnamoorthy 1990; Mani 1995).

The encyrtid parasitoid *Tetracnemoidea indica* (Ayyar) played a significant role in reducing the mealybug population on pomegranate in India (Mani and Krishnamoorthy 2000). The mealybug *P. lilacinus* was observed in the last week of June and the number of mealybugs per plant (four shoots) was 180.30 at that time. The initial sampling had yielded large number of the encyrtid *T. indica*. A mean maximum of 90.20 adults of *T. indica* was recovered from the samples collected on 25th June, 1997. The parasitoid was found to be active up to the last week of Aug. The population of *P. lilacinus* had gradually declined from 180.30 on 25th June to 4.50 on 22nd August 1997.

In yet another pomegranate orchard at Bangalore North, *P. lilacinus* was first noticed in August, 1991. The mealybug population persisted for about four months. The decrease in mealybug population was attributed mainly to the action of *Spalgis epeus* Westwood and *C. montrouzieri* to certain extent. *Triommata coccidivora* (Felt) was also observed in smaller numbers throughout the study (Mani 1995).

According to Ananda (2007), the treatment which received 10 grubs of *C. montrouzieri* recorded significantly higher per cent reduction (94.09) of mealybug *P. lilacinus* in India.

47.4.2 *Planococcus citri*

Leptomastix dactylopii How. and *Coccidoxenoides perminutus* (Timberlake) were found to be effective in suppressing the populations of *P. citri* on pomegranate (Mani and Krishnamoorthy 2000). In a pomegranate orchard at Bangalore North, initial samples collected on 1st June 1996 yielded the two encyrtid parasitoids (i.e.) *Leptomastix dactylopii* How. and *Coccidoxenoides perminutus* but in small numbers. At that time, mean number of mealybugs per plant (four shoots) was 1,280.50. *C. perminutus* was always found to emerge in large numbers than *L. dactylopii* from all the samples collected during the study period. A mean maximum of 92.10 adults of *C. perminutus* had emerged from the samples collected on 21st March 1996. In the case of *L. dactylopii*, a mean maximum of 21.10 adults were recovered from the samples collected on 15th March. Both the parasitoids were active up to the end of March 1996. Only the drosophilid predator *Cacoxenus perspicax* (Knab) was collected in very negligible numbers. Due to build up of parasitoids especially *C. perminutus*, the population of *P. citri* had declined from 128.50 on 1st March to 8.10 on 3rd April, 1996. The mealybug ceased to a problem from April 1996 onwards. Though *L. dactylopii* and *C. perminutus* were found together, the latter one played a dominant role in suppressing *P. citri* on pomegranate.

Coccidoxenoides perminutus

Leptomastix dactylopii

Parasitized mealybug

In the Soviet Union, the main parasitoid of *P. citri* is *Anagyrus pseudococci* (Gir.), which occurs in the south of European Russia and in Soviet Central Asia and which destroys up to 75 % of the coccid population in areas not treated with insecticides (Niyazov 1969).

47.4.3 *Maconellicoccus hirsutus*

Releases of the predator *C. montrouzieri* were found to be very effective in controlling *M. hirsutus* on pomegranate in India (Mani and Krishnamoorthy 1991).

47.4.4 *Ferrisia virgata*

Scymnus coccivora and *C. montrouzieri* were found to reduce the population of *F. virgata* in Tamil Nadu, India (Karuppuchamy 1994).

47.4.5 *Pseudococcus maritimus*

Mealybug biocontrol consists mainly of two kinds of parasitoids on *Pseudococcus maritimus*. The encyrtid parasitoids that help control mealybugs in grapes are also effective in pomegranates. Ladybird beetles with larvae similar in appearance to *Cryptolaemus* have been observed. The smaller encyrtid parasitoids first appear under the bark in the first mealybug generation. There are probably five parasitoid generations for each mealybug generation, as in grapes. The last parasitoid generation occurs in mealybugs which have already deposited half of an egg mass. The second encyrtid generation begins by parasitizing crawlers under the bark and on the leaves, including those protected by the *Dictyna* spider webs. The larger parasite typically attacks large mealybugs under the bark, so it appears late in each generation. Biological control is effective unless disrupted by Lannate or by ants (Devin et al. 2006).

47.5 Use of *Verticillium lecanii*

Verticillium lecanii is known to infect the mealybugs infesting pomegranate in India. It is a cosmopolitan fungus on insects. *V. lecanii* is known as "white- halo" fungus because of the white mycelial growth on the edges of infested insects. The conidia (spores) of *V. lecanii* are slimy and attach to the cuticle of insects. The fungus infects insects by producing hyphae from germinating spores that penetrate insect integument, and the fungus then destroys the internal contents and insects die. Treatments were imposed after the initiation of sufficient infestation of mealybug in nymphal stage. It is seen from Table 4.1 that, all the doses of *V. lecanii* i.e. 2–6 g/l of water effectively checked the built-up of mealybug population up to 10 days after application and these treatments were found significantly superior over the untreated control at 3,7 and 10 days after application. All the *V. lecanii* treatments could not cause mortality of the pest at 2 days after application. The pest mortality was less (22.61–43.28 %) at 3 days after application than that (39.32–84.28 %) was observed at 7 days after application. It indicated that *V. lecanii* acts slow initially and required at least 3 days to cause lethal effect. On the basis of effectiveness of *V. lecanii* 4 g/l of water seemed to be optimum for the effective management of mealybugs on pomegranate (Kulkarni et al. 2007). Effectiveness of *V. lecanii* conidia and filtrates against *Planococcus citri* in vitro was reported by Gonzalez et al. (1995).

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Fruit Crops: Ber

48

M. Mani

48.1 Species

Mealybugs are injurious to ber (*Zizyphus mauritiana* L.) in India, Egypt, and Jordan etc (Table 48.1).

48.2 Damage

In recent years, mealybugs have become an increasing threat to the cultivation of ber in peninsular India. Mealybugs become serious pests in Maharashtra, Andhra Pradesh, Karnataka, Tamil Nadu and Gujarat in India. Severe infestation of mealybugs and subsequent development of sooty mould affect the growth and fruiting capacity of ber and quality of fruits (Butani 1973). The infestation with *M. hirsutus* on the growing point has led to the malformation of shoots and leaves at Bijapur in India. On an average, there were 80.6 colonies per plant, each colony having 17.8 individuals. On an average, there were 80.6 colonies per plant, each colony having 17.8 individuals. Similarly 15.4 egg masses covered with white waxy mealy matter were observed per plant. Based on the market price of infested and healthy fruits, there was a net monetary loss of Rs. 25,800/ha accounting for 33.33 % loss due to mealybug infestation (Balikai and Bagali 2000). The oriental mealybug *Planococcus lilacinus* appeared in serious form on ber in 1990 and 1991 in Bangalore North (Mani and Krishnamoorthy 1996).

M. hirsutus on Ber

N. viridis on Ber

Ovisac of *N. viridis* opened revealing pink eggs

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Table 48.1 List of mealybugs recorded on ber in different countries

Species	Country	Reference
Cataencoccus mazoensis (Hall)	Zimbabwe	Ben-Dov (1994)
Cococcidohystrix (Centrococcus) insolitus (Green)	India	Williams (2004)
Crisicoccus hirsutus (Newstead)	India	Williams (2004)
Ferrisia virgata (Ckll)	–	Ben-Dov (1994)
Heliococcus ziziphi Borchenius	China	Ben-Dov (1994)
Maconellicoccus (=Phenacoccus) hirsutus (Green)	Egypt	Hall (1926)
	India	Mani (1993); Patil et al. (1996); Mani et al. (2007)
	Pakistan	Williams (2004)
Nipaecoccus viridis (Newstead)	Jordan	Meyerdirk et al. (1988)
	India	Shah et al. (1981); Mani (1993)
	Pakistan	Williams (2004)
	Iraq	EL Haidari et al. (1976)
Niapecoccus filamentosus (Cockrell)	–	Ben-Dov (1994)
Planococcus citri (Risso)	India	Mani (1993)
Planococcus lilacinus (Ckll.)	India	Tandon and Verghese (1987); Mani (1993); Mani et al.(2007)
Pseudococcus sp.	U.K.	Barnes (1935)
Pseudococcus hibisci Hall	Egypt	Hall (1921)

48.3 Natural Enemies

The parasitoids namely *Angyrus dactylopii* (How.), *Anagyrus mirzai* Agarwal, *Alamella flava* Agarwal, *Gyranusoidea flava* Shaffee et al., *Coccophagus* sp., *Chartocerus* sp. and the predators *A. dactylopii* (How.), *A. mirzai* Agarwal, *Alamella flava* Agarwal, *Gyranusoidea flava* Shaffee et al., *Coccophagus* sp., *Chartocerus* sp. and three predators were recorded on *N. viridis* infesting ber in India. Among them, *Anagyrus* spp. and *Spalgis epeus* are of considerable importance. Two parasitoids *Coccidoxenoides perminutus* (Timberlake) and *Allotropa* sp. and the predator *Cryptolaemus montrouzieri* (Mulsant) were recorded on *P. citri* infesting ber. The parasitoid *Aprostocetus purpureus* (Cam.) and the lycaenid predator *S. epeus* were also recorded on *P. lilacinus* (Mani 1993).

48.4 Management

The mealybugs on ber are difficult to control with insecticides. On the other hand, they are more amenable for biological control by parasitoids and predators. The mealybugs on ber were kept under check by a complex of natural enemies in Iraq (EL Haidari et al. 1976). Releases of *C. montrouzieri* supplement the local natural enemies in controlling all the four mealybug species on ber in India (Mani 1993; Mani and Krishnamoorthy 1996; Mani et al. 2007).

Chartocerus sp.

Anagyrus indicus

48.4.1 *N. viridis*

Infestation on *N. viridis* was noticed in August in Bangalore North on 12-year-old trees of the variety Umran. Mean mealybug population was 128.5 prior to the suspension of insecticidal sprays and release of the predator *C. montrouzieri*. The activity of the predator was observed throughout the study. Grubs were seen feeding on *N. viridis* 15 days after release and a maximum population of 4.5 grubs per sample was observed 45 days after release. The population of the local natural enemies especially *Anagyrus* spp. started building up attacking *N. viridis* heavily. By the first week of October, the mealybug population declined to very low level and subsequently the pest disappeared (Mani 1993). In Jordan, *Anagyrus indicus* Shaffee et al. was introduced to suppress the mealybug *N. viridis* on *Zizyphus* sp. (Meyerdirk et al. 1988).

48.4.2 *Macinellicoccus hirsutus*

Following the appearance of the pink mealybug *M. hirsutus*, the coccinellid predator *Cryptolaemus montrouzieri* Muls. was also observed along with the mealybugs on ber in India. There was reduction in the population of the mealybug from 62.50/plant on January 1, 2002 to 0.85/plant on January 21, 2002. No other natural enemy except *C. montrouzieri* was observed on *M. hirsutus*. There was no significant influence of abiotic factors on the mealybug population during the study period. The decline in the mealybug population on ber was attributed due to the predatory activity of *C. montrouzieri* (Mani et al. 2007).

48.4.3 *Planococcus citri*

Planococcus citri was observed on ber plants in December 1990 in Bangalore North. The mealybug population ranged from 186 to 263 with a mean of 242.5 per sample. Initial samples revealed the absence of *L. dactylopii* but *C. perminutus* and *C. montrouzieri* were observed in December. The activity of *L. dactylopii* was seen only a month after the release, and continued up to the end of February 1991. The local parasitoid *C. perminutus* had emerged in large numbers, and a maximum of 40.3 per sample was observed in the second week of February. *C. perminutus* rather than *L. dactylopii* was mainly responsible for the control of *P. citri* (Mani 1993).

48.4.4 *Planococcus lilacinus*

The parasitoid *Aprostocetus purpureus* (Cam.) and the lycaenid predator *S. epeus* were recorded on *P. lilacinus* (Mani 1993). There was reduction in numbers of *P. lilacinus* from 45.40/shoot in December 1994 to 0.40/shoot in first week of January 1995 due to the predation of *S. epius* in Karnataka (Mani and Krishnamoorthy 1996).

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49 Fruit Crops: Custard Apple

M. Mani

49.1 Species

Mealybugs are highly injurious to custard apple (*Annona* spp.) in India (Mani and Krishnamoorthy 1989). Murray (1982) reported high level of infestation with *P. citri* on custard apple trees in Australia. In Caribbean islands, both *Annona squamosa* and *A. muricata* were found severely infested with *M. hirsutus* (Kairo et al. 2000) (Table 49.1).

49.2 Damage

Fruits are completely covered with mealybugs. When the population explodes, the mealybugs are seen on the trunk and leaves but rarely. They cover the entire fruit reducing the market value. Severe mealybug infestation causes heavy economic losses (Mani and Krishnamoorthy 1989).

Fruit damage by *F. virgata*

Fruit damage by *P. citri*

Fruit damage by *M. hirsutus*

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Table 49.1 List of mealybugs recorded on custard apple in different countries

Mealybug species	Region/country	Reference
Dysmicoccus brevipes (Cockrell)	Thailand	Williams (2004)
Dysmicoccus grassii (Leonardi)	Neotropical region	Ben-Dov (1994)
Dysmicoccus lepelleyi (Betrem)	Indonesia & Malaysia	Williams (2004)
Dysmicoccus neobreipes Beardsley	India, Philippines & Vietnam	Williams (2004)
	Hawaii	–
Dysmicoccus viatorius sp.n	Philippines	Williams (2004)
Exallomochlus hispidus (Morrison)	Indonesia	Williams (2004)
Ferrisia virgata (Cockerell)	India & Pakistan	Williams (2004); Mani and Krishnamoorthy (1989); Dorge and Murti (1970); Savaliya et al.(2008)
Formicoccus (Panoccoides) robustus Ezzat & McConnell comb	India	Williams (2004)
Maconellicoccus hirsutus (Green)	Caribbean islands	Kairo et al. (2000)
	India, Indonesia, Philippines, Singapore, Thailand & Vietnam	Williams (2004); Mani and Krishnamoorthy (1989); Babu and Azam (1987); Murthy and Babu (1996)
	Florida	Hodges et al. (2005)
Niapecoccus agathidis Williams	Guadeloupe	Ben-Dov (1994)
Niapecoccus filamentosus (Cockrell)	–	Ben-Dov (1994)
Niapecoccus nipae (Makell)	–	Ben-Dov (1994)
Paracoccus interceptus Lit.	Philippines	Williams (2004)
Paracoccus marginatus Williams and Granara de Willink	Florida	
	Caribbean	Meyerdirk and Kauffman (2001)
Planococcoides nijalensis (Laing)	–	Ben-Dov (1994)
Planococcus lilacinus (Cockrell)	Indonesia, Malaysia & India	Williams (2004); Shukla and Tandon (1984b)
Planococcus citri (Risso)	India	Mani and Krishnamoorthy (1989)
	Australia	Murray (1982)
Planococcus minor Maskell	India, Malaysia & Philippines	Williams (2004); Shukla and Tandon (1984b)
Pseudococcus viburni (Signoret)	–	Ben-Dov (1994)
Pseudococcus cryptus Hempel	Philippines & Malaysia	Williams (2004)
Pseudococcus jackbeardsley Gimpel and Miller	Vietnam	Williams (2004)
	India	Shylesha (2013)
	Hawaii	Beardsley (1986)
Pseudococcus lepelleyi Betrem	Java	Williams (2004)
Pseudococcus longispinus (Targioni Tozzetti)	–	Ben-Dov (1994)
Pseudococcus maritimus (Ehrhorn)	Nearctic & Neotropical	Ben-Dov (1994)
Rasrococcus spinosus (Robinson)	Malaysia	Williams (2004)
Rasrococcus iceryoides (Green)	India	Williams (2004)
Rasrococcus invadens Williams	–	Ben-Dov (1994)
Trionymus lonipilosus De Lotto	Tanzania	Ben-Dov (1994)

49.3 Seasonal Activity

In peninsular India, mealybug population started appearing in the last week of May and continued up to November. Peak infestation coincided with fruiting phase. In Andhra Pradesh (India), the greatest populations of *M. hirsutus* were found on *A. reticulata* in June (Murthy and Babu 1996). The pest prefers dry weather and heavy incidence often occurs following periods of prolonged drought.

49.4 Natural Enemies

The parasitoids namely *Anagyrus dactylopii* How. and *Aenasius advena* Compere were collected from *M. hirsutus* and *F. virgata*, respectively but parasitism did not exceed 5 % in both cases. *Cryptolaemus montrouzieri* Muls. and *Spalgis epeus* Westwood are found feeding on the custard apple mealybugs in India (Mani and Krishnamoorthy 1989). Mealybug predators (especially *Oligochrysa lutea* (Wlk.), *Cryptolaemus montrouzieri* Muls. and *Syrphus* sp.) were recorded on *P. citri*. Parasitism of *P. citri* by *Leptomastidea abnormis* (Gir.), was low, and was unaffected by banding in south-eastern Queensland (Murray 1978).

49.5 Management

49.5.1 Mechanical

The application of sticky bands to the trunks of custard apple trees in south-eastern Queensland reduced the numbers of ants (*Pheidole megacephala* (F.)) in the trees and resulted in lower, though still unacceptably high, levels of infestation by *Planococcus citri* (Risso) (Murray 1978).

49.5.2 Chemical

Application of 0.1 % malathion applied at 6.5 litres/tree caused the greatest reduction in numbers of the striped mealybug *Ferrisia virgata* (Ckll.) (Dorge and Murti 1970). Dimethoate, phosphamidon, monocrotophos and dichlorvos, all at 0.05 %, gave the best control of *Planococcus minor (P. pacificus)* on custard apple (*Annona squamosa*) However, when cost was also considered, phosphamidon and dichlorvos were recommended for the control of the pest (Shukla and Tandon 1984a). Spraying of diazinon or monocrotophos at 0.1 % or 5 % neem seed kernel extract or 3 % neem oil suspension was found effective against custard apple mealybugs (Jayaraj and Ananthan 2009). **Buprofezin can also be tried against the custard apple mealybugs.**

49.5.3 Biological Control

More than one species of mealybug commonly occur at a time on custard apple in peninsular India. The Australian ladybird beetle *Cryptolaemus montrouzieri* Mulsant is highly polyphagous known to prey on many species of mealybug species on custard apple. Releases of *C. montrouzieri* were made @ 30 larvae/plant twice at 15 days interval resulted in the mealybug population (*F. virgata* and *M. hirsutus*) decline from 2450.90/plant in June to 5.20 in August during 2000. In the custard apple orchards, *C. montrouzieri* effectively controlled the mealybugs within 75 days (Mani and Krishnamoorthy 2007). In Queensland (Australia), *C. montrouzieri* was found colonized on *P. citri* in custard apples (Smith 1991).

Leptomastix dactylopii is excellent parasitoid of *P. citri*. In India, the exotic *L. dactylopii* was recovered in smaller numbers from *P. citri* infesting custard apple in 2004 after initial release made in citrus orchards 1983 in the same location (Mani et al. 2007). However in 2006, the parasitoid was recovered in large numbers from *P. citri* infesting custard apple causing up to 70 % parasitism. Presence of *L. dactylopii* indicated that there is some scope of exploiting *L. dactylopii* in the suppression of *P. citri* infesting custard apple in India. In Australia also, *L. dactylopii* played a major role in suppressing *P. citri* on custard apple (Smith 1991).

Crypyolaemus

Spalgis epeus

Cocoons of *L. dactylopii*

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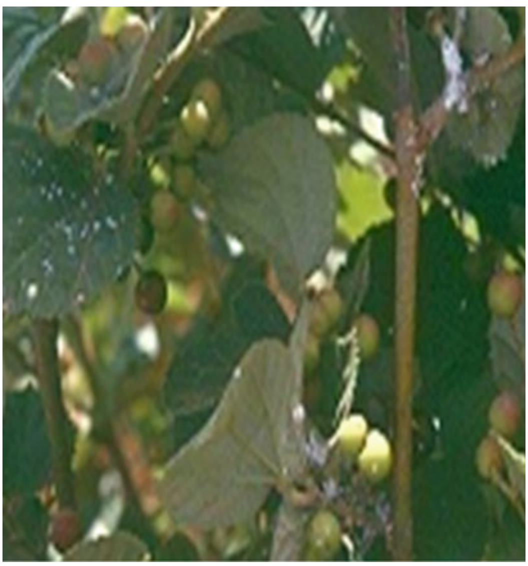
50 Fruit Crops: Phalsa

M. Mani

Phalsa (*Grewis asiatica* Linn.) is cultivated in certain pockets of northern and peninsular India. The pink hibiscus mealybug, *Maconellicoccus hirsutus* (Green), is known to occur on the leaves, flowers and fruits of phalsa in India. The coccinellid *Cryptolaemus montrouzieri* Musant and the lycaenid *Spalgis epeus* Westwood were found clearing the populations of the mealybugs on phalsa in the field (Mani and Krishnamoorthy 1996).



Mealybug damage to phalsa

Cryptolaemus clearing the mealybugs

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51 Fruit Crops: Litchi

M. Mani

Mealybugs are injurious to litchi (*Litchi chinensis*) in Thailand, China, Japan, Indonesia, Singapore etc (Table 51.1).

Table 51.1 List of mealybugs recorded on Litchi in different countries

Mealybug species	Country	Reference
Dysmicoccus lepelleyi (Betrem)	Thailand	Williams (2004)
Paracoccus interceptus Lit.	Thailand	Williams (2004)
Planococcus litchi Cox	China, Japan & Thailand	Ben-Dov (1994)
Planococcus lilacinus (Cockrell)	Vietnam	Williams (2004)
Pseudococcus viburni (Signoret)	–	Ben-Dov (1994)
Pseudococcus baleiteus Lit.	Indonesia & Thailand	Williams (2004)
Pseudococcus cryptus Hempel	Singapore	Williams (2004)
Planococcus litchi sp. nr.	–	Cox (1989)
Pseudococcus comstocki (Kuwana)	–	CIE (1975)
Pseudococcus jackbeardsleyi Gimpel and Miller	China	http://www.plantwise.org/KnowledgeBank/Datasheet.aspx?dsID=45087

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52 Fruit Crops: Jackfruit

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52.1 Species

Mealybugs are injurious to Jackfruit (*Artocarpus heterophyllus*) in India, Vietnam, Bangladesh, Malaysia, Sri Lanka, Tonga, Caroline islands, Solomon islands etc (Table 52.1).

52.2 Damage

In India, severe infestation of the spherical mealybug was observed on shoots of jack fruit. The mealybugs suck the sap, leading to drying of shoots in severe cases; fruits were also covered with mealybugs (Mani and Krishnamoorthy 1997).

F. virgata on foliage

N. viridis damage to shoot & fruit

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Table 52.1 List of mealybugs recorded on Jackfruit in different regions

Mealybug species	Region/Country	Reference
Dysmicoccus grassii (Leonardi)	Neotropical region	Ben-Dov (1994)
Dysmicoccus neobreipes Beardsley	Thailand	Williams (2004)
Ferrisia virgata (Cockerell)	India	Ghose (1961)
	Yemen	Marotta et al. (2001)
Hordeolicoccus nephalii (Takahashi)	Vietnam	Williams (2004)
Maconellicoccus hirsutus (Green)	–	Ben-Dov (1994)
Niapecoccus viridis (Newstead)	India	Ghose (1961); Saha and Ghosh (2001); Mani and Krishnamoorthy (1997)
	Bangladesh & Malaysia	Williams (2004)
Paracoccus marginatus Williams and Granara de Willink	Sri Lanka	Galanihe et al. (2010)
	Malaysia	Mastoi et al. (2011)
	India	Mani Chellappan (2011)
Phenacoccus madeirensis Green	–	Ben-Dov (1994)
Planococcoides robustus (Ezzat & NcConnel)	–	Ben-Dov (1994)
Planococcus minor Maskell	Malaysia	Williams (2004)
Pseudococcus colliculosis Williams & Watson	Tonga	Ben-Dov (1994)
Pseudococcus longispinus (Targioni Tozzetti)	–	Ben-Dov (1994)
Pseudococcus marshallensis Beardsley	Caroline islands	Ben-Dov (1994)
Pseudococcus solomonensis Williams	Solomon islands	Ben-Dov (1994)
Rasrococcus invadens Williams	–	Ben-Dov (1994)
Rasrococcus spinosus (Robinson)	Malaysia	Williams (2004)

Table 52.2 *Nipaecoccus viridis* and its natural enemies on Jack fruit (Mani and Krishnamoorthy 1997)

Date of sampling	No. of healthy mealybugs/shoot (*N. viridis*)	No. of natural enemies emerged/shoot (Mean ± S.D.)	
		A. dactylopii	*C. perspicax*
8-3-1996	24.96 ± 3.18	16.46 ± 2.52	0.42 ± 0.14
18-3-1996	16.15 ± 2.47	15.07 ± 2.02	1.53 ± 0.37
27-3-1996	0.10 ± 0.02	0.58 ± 0.23	0.22 ± 0.03

SD standard deviation

52.3 Management

Local natural enemies are able to check *N. viridis* in India. The natural enemy complex consisted of a primary parasitoid, *Anagyrus dactylopii* (How.) (Encyrtidae, Hymenoptera) and a drosophilid predator *Cacoxenus perspicax* (Knab). A maximum of 16.46 and 1.53 of *A. dactylopii* and C. *perspicax* respectively were collected on 8th March and 21st March respectively. Mealybug population declined from 24.96 on 8th March to 0.10 on 27th March (Mani and Krishnamoorthy 1997) (Table 52.2).

Angyrus dactylopii

Cacoxenus perspicax

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Vegetable Crops

53

A. Krishnamoorthy and M. Mani

53.1 Tomato (*Lycopercicon esculentum)*

Mealybugs are injurious to tomato in several countries (Table 53.1). *Phenacoccus solenopsis* Tinsley was found to be an important pest of tomato in North, Central and South zones in India (Mohindru et al. 2009).

53.1.1 Damage

Mealybugs remove the sap from plants and cause them to become weak. When mealybugs infest tomato plants, they leave behind a honeydew residue that attracts other insects, such as ants. The pants are covered with black sooty mould. Plants suffering from mealybug infestation will begin to turn yellow. Mealybugs like *Maconellicoccus hirsutus* have toxic saliva that distorts plant growth and affects their aesthetic value. Economic damage by mealybugs on tomato was reported in Pakistan (Arif et al. 2009).

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53.1.2 Management

53.1.2.1 Chemicals

In the greenhouse, mealybugs (*Pseudococcus* spp.) on tomatoes were suppressed with the application of 20 % vermicompost extract (Arancon et al. 2007; Edwards et al. 2010). Repeated chemical treatments were needed to control *Pseudococcus viburni* in the Netherlands (Schoen and Martin 1999). In Hungary, synergized pyrethrins afforded the best control of *Pseudococcus maritimus* (Ehrh.). The insecticides methomyl, phorate and oxamyl gave very satisfactory and permanent control of mealybugs (Ordogh 1983). Insecticidal soaps effectively control mealybugs, by stripping them of their protective coating. Mealybugs on tomato are killed with the application of Dawn dish detergent. Home remedies are often preferred because they protect fruit from harsh chemicals (Angela LaFollette 2014).

53.1.2.2 Biological Control

Phenococcus solenopsis *Aenasius bambawalei* Hayat is a potential biocontrol agent causing parasitism up to 30 % in India (Mohindru et al. 2009). About 77 % parasitism by *A. bambawalei* was noted on *P. solenopsis* infesting tomato in Pakistan (Khuhro et al. 2011).

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Table 53.1 List of mealybugs recorded on tomato in different countries

Species	Region/Country	Reference
Coccidohystrix insolita (Green)	Karnataka, India	Gopalakrishna Pillai et al. (2011)
Dysmicoccus boninensis (Kuwana)	Brazil	Mark and Penny (2005)
Dysmicoccus neobreipes Beardsley	–	Ben-Dov (1994)
Ferrisia consobrina Williams & Watson	Australian, Ethiopian, Neotropical & Pacific region	Ben-Dov (1994)
Ferrisia virgata (Cockerell)	Bangladesh	Ben-Dov (1994)
Maconellicoccus hirsutus (Green)	USA	–
Paracoccus lycopersici Ezzat & McConnel	Mexico	Ben-Dov (1994)
Paracoccus marginatus (Williams and Granara de Willink)	India	Tanwar et al. (2010); Mani Chellappan (2011); CPPS (2012); Agrawal (1953)
	Ghana	Cham et al. (2011)
	Florida	Walker et al. (2003)
	Sri Lanka	Galanihe et al. (2010)
	Hawaii	Ronald et al. (2007)
Phenacoccus madeirensis Green	–	Ben-Dov (1994)
Phenacoccus manihoti Matile-Ferrero	Africa	http://www.cabi.org/isc/datasheet/40173
Phenacoccus parvus Morrision	Ethiopian, neotropical & Pacific region	Ben-Dov (1994)
	India	Williams (2004)
	Queensland	Swarbrick and Donaldson (1991); Marohasy (1997)
Phenacoccus solani Ferris	–	Ben-Dov (1994)
Phenacoccus solenopsis Tinsley	Punjab (India)	Mohindru et al. (2009)
	Pakistan	Arif et al. (2009)
	Brazil	Culik and Gullan (2005)
	India	Gopalakrishna Pillai et al. (2011); Ashwathanarayana Reddy and Asosh Kumar (2004); Anand Persad and Ayub khan (2006); Suganthi et al. (2009)
	Brazil	Mark and Penny (2005); Culik and Gullan (2005)
Planococcus citri (Risso)	UK	Shariful and Jahan (1993)
	Bangladesh	–
Pseudococcus maritimus (Ehrh.)	Hungary	Ordogh (1983)
	USA	Gimpel and Miller (1996), CIE (1980)
Pseudococcus elisae Borkhsenius	Hawaii	Beardsley (1986)
	Kiribati, Tuvalu, Papua New Guinea, Philippines, Indonesia, Brunei, Malaysia & Thailand	Williams (1988)
Pseudococcus jackbeardsley Gimpel and Miller	Malaysia	Williams (2004)
	Hawaii	Beardsley (1986)
Pseudococcus viburni (Signoret)	Netherlands	Schoen and Martin (1999)
	France	Kreiter et al. (2005)
	Brazil	Mark and Penny (2005)
	Sri Lanka	Williams (2004)
Rhizoecus falcifer Kunckel d Herculais	–	Ben-Dov (1994)

Coccidohystrix insolita Tomatoes grown in polyhouse were observed to be attacked by two species of mealybugs, *Ph. solenopsis* and *C. insolita* in Bangalore North. *Phenococcus solenopsis* was the predominant mealybug attacking all parts of the plants. The mealybug population was reduced with the release of Australian ladybird predator, *Cryptolaemus* grubs to 6.4–7.0 mealybugs/plant as compared to 176.4 mealybugs/plant in the check. The insecticides such as buprofezin, profenophos and spirotetramat were also found to be equally effective, and on par with *C. montrouzieri* in controlling the *Ph. solenopsis* (Gopalakrishna Pillai et al. 2011).

Ph. solenopsis on tomato

Ph. madeirensis on tomato

Cryptolaemus larva

Paracoccus marginatus The parasitoid *Acerophagus papayae* Noyes could be used to control *Pa. marginatus* on tomato in India as it proved to be highly effective against the above mealybug infesting other crops.

Pseudococcus viburni Two potential biological control agents, the predator *Cryptolaemus montrouzieri* and the parasitoid *Leptomastix epona*, were considered for the use in controlling the mealybug *Ps. viburni* infesting tomato in Netherlands (Schoen and Martin 1999; Germain et al. 2003). Biological control of *Ps. viburni* was undertaken in greenhouses in France using a parasitoid wasp from Chile (Kreiter et al. 2005).

Planococcus citri *Anagyrus pseudococci* is potential parasitoid of *Planococcus citri* infesting tomato (Shariful and Jahan 1993).

53.2 Brinjal/Egg Plant/Aubergine

Mealybugs are injurious to brinjal in many countries (Table 53.2). The brinjal mealybug *C. insolita* has been recorded in Afrotropical: Kenya, Madagascar, Rodriques Island (Mauritius), South Africa, Tanzania, Zanzibar; Australasian: Western Samoa; Oriental: Bangladesh, Burma (=Myanmar), India, Laos, Pakistan, Philippines, Sri Lanka, Thailand, Vietnam; Palaearctic: China, Saudi Arabia (Ben-Dov 2013). *Coccidohystrix insolita* has been a serious pest of brinjal (*Solanum melongena*) in many parts of India including Bihar (Lall et al. 1976), West Bengal, (Chaudhuri 1976) and Kerala (Gopinathan et al. 1982). Economic damage by mealybugs on brinjal was reported in Pakistan (Arif et al. 2009).

Damage Both nymphs and adult mealybugs suck the sap from leaves and tender shoots. Heavy clustering of mealybug *C. insolita* usually is seen under surface of leaves as a thick mat with waxy secretion. They also excrete copious amount of honey dew on which the fungus sooty mould grow. Affected plants appear sick and black, resulting in reduced fruiting capacity. If the flower blooms are attacked, the fruit set is affected. When the fruits are infested, they can be entirely covered with the mealybug. The infestation may lead to fruit drop or the fruits remain on the shoots in a dried and shrivelled condition. It is also a notorious pest of stored potato tubers. The stored tubers are found to be infested during July and October, when sprouting of the buds takes place. *Coccidohystrix insolita* was active in September-March on brinjal but found during April-August on alternative wild host plants such as *Solanum nigrum* and *Solanum xanthocarpum*, and had a mean life-cycle of 15.06 days in India (Lall et al. 1976).

Table 53.2 List of mealybugs recorded on eggplant

Mealybug species	Region/country	Reference
Coccidohystrix insolita (Green)	Philippines	Lit et al. (1998)
	Bangladesh, India, Sri Lanka, Thailand	Lall et al. (1976); Williams (2004); Krishnamoorthy and Mani (1996)
	Guam	Moore et al. (2014)
	Western Samoa	Williams and Watson (1988)
Ferrisia virgata (Cockerell)	Philippines	Lit et al. (1998)
	India, Malaysia	Williams (2004)
	Pakistan	
Maconellicoccus hirsutus (Green)	India	Anand Persad and Ayub khan (2006)
	Trinidad	Francis et al. (2012)
Paracoccus marginatus (Williams and Granara de Willink)	Ghana	Cham et al. (2011)
	Florida	Walker et al. (2003); Miller and Miller (2002)
	Sri Lanka	Galanihe et al. (2010)
	Palau	Muniappan et al. (2006)
	Hawaii	Ronald et al. (2007)
	Malaysia	Mastoi et al. (2011)
	Puerto Rico	Pantoja et al. (2007)
	Caribbean	Meyerdirk and Kauffman (2001)
	India	CPPS (2012); Mani Chellappan (2011); Tanwar et al. (2010)
Paracoccus solani Ezzat & McConnel	Australia, Peru, Costa Rico	Ben-Dov (1994)
Peliococcus trsipinosus (James)	Kenya	Ben-Dov (1994)
Phenacoccus madeirensis Green	–	Ben-Dov (1994)
	Pakistan	Williams (2004)
Phenacoccus parvus Morrision	Ethiopian, neotropical & Pacific region	Ben-Dov (1994)
Phenacoccus solani Ferris	–	Ben-Dov (1994)
Phenacoccus solenopsis Tinsley	Pakistan	Arif et al. (2009)
	India	Jagadish and Shadakshari (2009); Tanwar et al. (2010)
Planococcus citri (Risso)	Florida	–
	Bangladesh	http://www.aappbckv.org/journal/archive/6%20Sudden%20outbreak% 20of% 20mealybug.pdf
Planococcus lilacinus (Cockrell)	–	Ben-Dov (1994)
Planococcus minor (Maskell)	Philippines	Lit et al. (1998)
	India	Williams (2004)
Pseudococcus longispinus (Targioni Tozzetti)	Africa	http://www.infonet-biovision.org/default/ct/94/pests

53.2.1 Natural Enemies

A total of 23 species of hymenopterous parasitoids (Noyes 2013), fungus *Metarhizium anisopliae* (Chaudhuri 1976)*, Fusarium equiseti* (Corda) Sacc. (Gopinathan et al. 1982), predators, *Anegleis cardoni* (Weise); *Hyperaspis maindroni Sicard, Nephus regularis Sicard, Spalgis epeus* (Westwood) (Ben-Dov 2013), *Cryptolaemus montrouzieri* (Puttarudriah and Channa Basavanna 1953) are associated with *C. insolita*. *Anisochrysa bonensis* (Okaomota), *Brumoides suturalis* (Fabricius)*, Hyperspis maindroni*, *Leptomastix nigrocoxalis* Compere, *Leptomastix lyciae* Noyes and Hayat were known to attack *C.*

insolita in Karnataka, India (Krishnamoorthy and Mani 1996). The fungal pathogen *Neozygites fumosa* (Speare) Remaudiere & Keller was observed on the mealybug, *Coccidohystrix insolita* infesting egg-plant in Philippines (Villacarlos 2000).

Coccidohystrix insolita on brinjal leaf

Varietal Tolerance Five aubergine lines/varieties were screened for resistance to *C. insolita*. An accession PI-381272-2 was found to be resistant to *C. insolita* (Lit et al. 1998).

53.2.2 Management

Chemicals It is advocated to spray any one of the following insecticides at 15 days intervals: dimethoate (Lall et al. 1976), malathion 0.1 % (Bhatti et al. 1975), profenofos 50EC @ 1 ml/l to control *Coccidohystrix insolita*. The fruit yield and return per rupee invested on plant protection were also high in dimethoate 30EC @ 0.5 ml/l + NSKE 3 % (17.13 t/ha and 20.08) followed by profenofos 50EC @ 0.5 ml + azadirachtin 1EC @ 1 ml/l (15.67 t/ha and 15.18) (Saminathan et al. 2010). Castor-oil-based soft soaps were as effective as fish oil soap recording 74.30–77.14 % reduction in the population of *Ph. solenopsis* as compared to 88.6 % reduction with imidacloprid and spinosad (David et al. 2010).

53.2.3 Biological Control

Coccidohystrix insolita A single larva of *C. montrouzieri* was known to consume about 1100 nymphs of *C. insolita*. Release of *C. montrouzieri* gave excellent control of *C. insolita* in Andhra Pradesh (Tirumala Rao and David 1958) and Karnataka (Krishnamoorthy and Mani 1996) in India.

Paracoccus marginatus Heavy infestation can cause defoliation and even death of the plant. Two rounds of spraying were given starting from flowering stage at an interval of 10 days using knapsack hydraulic sprayer (Aspee®, Mumbai) with a spray fluid volume of 500 l ha^{-1}. Application of *Pseudomonas fluorescens* @ (10 g l^{-1}) against *Pa. marginatus* in brinjal recorded 72 % reduction in the mealybug population 10 days after first spray and 80 % reduction after the second spray. *Pseudomonas fluorescens* treatment gave significantly higher yield than *B. bassiana*. Significant difference was also observed on the yield of brinjal between the control plot (20.50 t ha^{-1}) and other treated plots. Spinosad and Fish oil rosin soap (FORS) recorded the highest yield of 38.50 t ha^{-1}, 35.25 t ha^{-1} respectively, followed by *P. fluorescence* (26.15 t ha^{-1}), *B. bassiana* (25.92 t ha^{-1}) and combination of *P. fluorescence* and *B. bassiana* (25.80 92 t ha^{-1}). Interestingly, higher BCR was observed for FORS treatment (6.71) with a net income of Rs. 299,985/– (Janaki et al. 2012). The parasitoid *Acerophagus papayae* Noyes could be effectively used for the suppression of *Pa. marginatus* on brinjal.


Paracoccus marginatus on eggplant

53.3 Okra

Mealybugs are injurious to okra in Pakistan, India, Sri Lanka, Bangladesh, Ghana, Trinidad etc (Table 53.3).

Damage Both nymphs and adults suck the sap from leaves, flower buds, petioles, twigs, fruits and even from the stem of the plants. The insect heavily sucks the sap from the plant and renders it weak, feeble and dehydrated. In severe cases development of sooty mould takes on honeydew produced by mealy bugs. The sooty mould reduces the photosynthetic ability of the plants. The fruits infested with mealybugs are inferior in the marketability.

***Ph. Solenopsis* on okra**

Pa. marginatus on okra

***M. hirsutus* infesting okra**

Table 53.3 List of mealybugs recorded on okra in different countries

Mealybug species	Country	Reference
Ferrisia virgata (Cockerell)	–	http://www.plantwise.org/KnowledgeBank/Datasheet.aspx?dsid=23981
Phenacoccus solenopsis Tinsley	Pakistan	Mustafa et al. (2009); Arif et al. (2009)
	Hisar, Haryana, India	Sharma (2007)
	Maharashtra, India	Sharma et al. (2008)
	Punjab, India	Satnam Singh et al. (2012)
	Karnataka, India	Jagadish and Shadakshari (2009)
Paracoccus marginatus (Williams and Granara de Willink)	Coimbatore, India	CPPS (2012)
	Sri Lanka	Galanihe et al. (2010)
	Ghana	Cham et al. (2011)
Maconellicoccus hirsutus (Green)	India	Singh and Ghosh (1976); Mani (1986)
	USA	–
Planococcus citri (Risso)	Bangladesh	http://www.aappbckv.org/journal/archive/6%20Sudden% 20outbreak% 20of% 20mealybug.pdf
Planococcus minor (Maskell)	Trinidad	Francis et al. (2012)

53.3.1 Management

Phenacoccus solenopsis To check the spread of mealybug, the weeds infested with mealybugs growing adjacent to road sides, pathways, water channels and waste lands should be removed. In case of severe infestation, spraying with 1.25 l of profenophos 50EC or 2.0 l of quinalphos 25EC or 625 g of thiodicarb 75WP in 500 l of water is recommended. The hymenopterous parasitoid, *Aenasius bambawalei* was able to parasitize *Ph. solenopsis* up to 70–80 % on okra (Sharma 2007). *Brumus suturalis* F. was collected on *Phenococcus* sp. from the fields of the cotton, okra in Sindh Agriculture University, Tandojam (Khuhro et al. 2008). Spraying of insecticides if parasitized mealybug mummies are observed is to be avoided.

Healthy *Ph. solenopsis on* okra

Mealybug parasitized by *A. bambawalei*

Paracoccus marginatus The parasitoid *Acerophagus papayae* could be effective for the suppression of *Pa. marginatus* on brinjal and other crops bordering brinjal fields.

M. hirsutus *Cryptolaemus montrouzieri* can be used to control *M. hirsutus* infesting okra.

53.4 Chow-Chow

The oriental mealybug, *Planococcus lilacinus* was observed in severe form on Chow-chow (*Sechium edule*) in Bangalore North during October 1994. Due to release of the coccinellid predator *Cryptolaemus montrouzieri*, the mealybug population was reduced from 149.3 to 6.1/plant in 42 days while the mean population of natural enemies increased from 0.3 to 3.8/plant. The reduction of mealybug population in chow-chow field was mainly due to the combined action of *C. montrouzieri* and other local natural enemies including *Scymnus coccivora* and the drosophilid *Cacoxenus persipicaux* (Krishnamoorthy and Mani 1998).

Chow–chow fruit showing infestation by *Pl. lilacinus*

53.5 Beans

In New Caledonia, the mealybug *Ferrisia virgata* on the beans (*Phaseolus*) was controlled by *C. montrouzieri* (Cockerell 1929).

53.6 Peas

C. montrouzieri is used to control the mealybugs on peas. The reduction in insect attachment force, on plant surfaces covered with the crystalline wax, is explained by the decrease of the real contact area between setal tips of beetle *C. montrouzieri* and the substrate (Gorb et al. 2008).

53.7 Cauliflower

The incidence of mealybug *Planococcus lilacinus* (Cockrell) on cauliflowers was reported. Severe infestation led to stunted plant growth, withering and reduced flower size (Loganathan and Suresh 2001). *Phenacoccus parvus* was found infesting cauliflower growing close to infested *Lantana camara* in Queensland (Swarbrick and Donaldson 1991).

53.8 Chillies

Paracoccus marginatus on *Capsicum annum* in Ghana (Cham et al. (2011), Hawaii (Ronald et al. 2007), India (Mani Chellappan 2011), Sri Lanka (Galanihe et al. (2010), and on *Capsicum fructescens* in Ghana (Cham et al. (2011), Florida (Walker et al. 2003) and Palau (Muniappan et al. 2006) were reported. *Phenacocus solenopsis* was also found infesting.

Capsicum annuum L. in India (Tanwar et al. 2010). *Phenacoccus manihoti* Matile-Ferrero was recorded on capsicum in Zaire (Leuschner et al. 1978). *Pseudococcus maritimus* (Ehrhorn) has been reported on peppers. Bougainvillea mealybug *Phenacoccus peruvianus* was recently found infesting chilli peppers in Los Angeles County (http://ucanr.edu/blogs/pestnews/ index.cfm?tagname=Bougainvillea%20mealybug).

Pa. marginatus on hot pepper [Capsicum](Gimpel and Miller, 1996)

Ph. peruvianus on chilli peppers (Photo by Gevork Arakelian)

53.9 General Management of Mealybugs in Vegetables

Plant protection measures are of limited effectiveness against mealybugs because of its habit of hiding in crevices and the waxy covering of its body. Mealybug control often involves the control of caretaking ants that are important for the proper development of mealybugs. Without the ants, the populations are small and they spread to new areas and fields would be slow and free from serious infestations of mealybugs. Therefore, management of mealybugs often includes the control of ant species (Table 53.4).

Table 53.4 List of mealybug occurring on different vegetable crops

Mealybug species	Vegetables	Region/Country	Reference
Chlorozococcus pusillus (De Lotto)	Potato	Kenya, Uganda	Ben-Dov (1994)
Chlorozococcus pusillus (De Lotto)	Sweet potato	Kenya, Uganda	Ben-Dov (1994)
Coccidohystrix insolita (Green)	Potato	Pakistan	Williams (2004)
Dysmicoccus boninsis (Kuwana)	Sweet potato	–	Ben-Dov (1994)
Dysmicoccus brevipes (Cockerell)	Potato	Africa	http://www.infonet-biovision.org/default/ct/94/pests
		India	Khan (1984)
	Capsicum	–	Ben-Dov (1994)
	Artocarpa utilis	–	Ben-Dov (1994)
Dysmicoccus neobreipes Beardsley	Pumpkin	–	Ben-Dov (1994)
Dysmicoccus cucurbitae sp. n.	Pumpkin	India	Khan (1984)
Dysmicoccus lepelleyi (Betrem)	*Artocarpus edulis*	–	Williams (2004)
Dysmicoccus grassii (Leonardi)	Chow chow	Neotropical region	Ben-Dov (1994)
Dysmicoccus lepelleyi (Betrem)	*Artocarpus edulis*	Asia	Williams (2004)
Dysmicoccus neobrevipes Beardsley	Onion	Philippines	Williams (2004)
Eupersia gerbace Danziga	Onion	Korea, Mongolia	Ben-Dov (1994)
Ferrisia consobrina Williams &Watson	Potato	Australian, Ethiopian, Neotropical & Pacific region	Ben-Dov (1994)
	Phaseolus vulgaris	–	Ben-Dov (1994)
Ferrisia virgata (Ckll)	*Cucurbita maxima* Pumpkin, *Cucurbita pepo*	–	http://www.plantwise.org/KnowledgeBank/Datasheet.aspx?dsid=23981
	Sweet potato	–	http://www.plantwise.org/KnowledgeBank/Datasheet.aspx?dsid=23981
	cowpea	–	http://www.plantwise.org/KnowledgeBank/Datasheet.aspx?dsid=23981
	Okra, sweet potato, pumpkin	–	http://www.plantwise.org/KnowledgeBank/Datasheet.aspx?dsid=23981
	Dolichos, *Coccinia indica*	–	Ben-Dov (1994)
Formicoccus (Panoccoides) robustus Ezzat & McConnell comb	Pumpkin	Pakistan	Williams (2004)
Geococcus coffeae Green	Chillies	–	Ben-Dov (1994)
	Sweet potato	India	Williams (2004)
	potato	–	Ben-Dov (1994)

(continued)

Table 53.4 (continued)

Mealybug species	Vegetables	Region/Country	Reference
Heliococcus phaseoli (Laing)	Phaseolus	Sierra Leone	Ben-Dov (1994)
Maconellicoccus hirsutus (Green)	*Phaseolus vulgaris*, *Brassica oleracea*, Pumpkin, Squash, Tomato	USA	–
	Sweet potato	Bangladesh	–
	Dolichos	–	Ben-Dov (1994)
	Artocarpus altilis	Caribbean	Etienne et al (1998)
	Artocarpus communis		(*manatee.ifas.ufl.edu/comm-hort/pdf/pest-topics/InsectPHMHosts.pdf*)
Macrocepicoccus loranthi Morrison	Drumstick	Guyana	Ben-Dov (1994)
Nipaecoccus nipae (Maskell)	Potato	Bangladesh	Begum and Begum (1995)
Nipaecoccus viridis (Newstead)	Potato	India	David and Ananthakrishnan (2004); Williams (2004)
Paracoccus ferrisi Ezzat & McConnel	Chillies	Mexico	Ben-Dov (1994)
Paracoccus burnerae (Brain)	Potato	Ethiopian region	Ben-Dov (1994)
Paracoccus marginatus Williams and Granara de Willink	*Luffa cylindrical*	Ghana	Cham et al. (2011)
	Curcubita sp.	Ghana	Cham et al. (2011)
		Palau	Muniappan et al. (2006)
	Benincasa hispida	India	Mani Chellappan (2011)
	Dolichos lablab	India	Mani Chellappan (2011)
	Achyranthus aspera	India	Tanwar et al. (2010)
	Amaranthus	India	Mani Chellappan (2011)
	Phaseolus vulgaris	USA	–
	Cucumis melo	Florida	–
	Brassica oleracea	Maldives	Williams (2004)
	Peas	India	–
Phenacoccus madeirensis Green	Potato	–	Ben-Dov (1994)
	Amaranthus	–	Ben-Dov (1994)
Phenacoccus parvus Morrision	potato	Ethiopian, neotropical & Pacific region	Ben-Dov (1994)
	Amaranthus	Ethiopian, neotropical & Pacific region	Ben-Dov (1994)
	Chillies	India	Williams (2004)
Phenacoccus pumilus Kritshenko	Amaranthus		Ben-Dov (1994)
Phenacoccus solenopsis Tinsley	Several vegetables	Pakistan	Arif et al. (2009)
Phenacoccus solani Ferris	Potatoes stored on a farm	Oklahoma	Anonymous (1979)

(continued)

Table 53.4 (continued)

Mealybug species	Vegetables	Region/Country	Reference
Planococcus citri (Risso)	*Brassia oleracea, Cucumus melo*, pumpkin	–	Ben-Dov (1994); Williams (2004)
Planococcus kraunhiae (Kuwana)	Faba bean & Broad bean	–	Narai and Murai (2002)
Planococcus lilacinus Cockerell	*Brassica oleracea*	India	David and Ananthakrishnan (2004); Williams (2004)
Planococcus minor (Maskell)	Potato	Thailand	Williams (2004)
	Amaranthus	Trinidad	Francis et al. (2012)
	Sweet potato	Trinidad	Francis et al. (2012)
	*Dioscore*a sp.	Trinidad	Francis et al. (2012)
	Colocasia sp.	Trinidad	Francis et al. (2012)
	Pumpkin	India	Anand Persad and Ayub khan (2006)
	Cucumber, lettuce, pepper, pumpkin, and tomato, asparagus, beans, beets, cabbage	Florida	http://entnemdept.ufl.edu/creatures/orn/mealybug/mealybug.htm
	Brassica oleracea, Pumpkin, Chow chow, Chillies	–	Ben-Dov (1994)
	Sweet potato	Sri Lanka	Williams (2004)
Pseudococcus calceolarieae (Maskell)	Potato	–	Ben-Dov (1994)
Pseudococcus elisae Borchsenius	Potato	Pacific region and Southern Asia	Williams (1988)
Pseudococcus jackbeardsley Gimpel and Miller	Chillies	Brunei	Williams (1988)
	Potato, Ivory gourd	Hawaii	Beardsley (1986)
Pseudococcus longispinus (Targioni Tozzetti)	Several Vegetables	Many countries	Gillani et al. (2009)
	Potato	Israel	Wysoki et al. (1977)
	Potato	–	Ben-Dov (1994)
	Chillies	–	Ben-Dov (1994)
Pseudococcus trukensis Bearsley	Bread fruit	–	Ben-Dov (1994)
Pseudococcus viburni (Signoret)	Potato	UK	Copland et al. (1993)
	Potato	South America	Charles (2011)
	Beet root, pumpkin, Chow chow	–	Ben-Dov (1994)
Rasrococcus iceryoides (Green)	Dolichos	–	Ben-Dov (1994)
	Pumpkin	India	Williams (2004)
Vryburgia brevicruris (McKenzie)	Potato	Australia, California, Israel	Ben-Dov (1994)
	Phaseolus vulgaris	Australia, California & Israel	Ben-Dov (1994)

53.10 Mechanical and Cultural Control

The practices include removal of heavily infested shoots and fruits and destroying them, proper sanitation in polyhouses and in the field, use of clean planting materials will help in preventing the mealybug infestations and removal of alternate host as well as weed plants in and surrounding areas.

53.11 Biological Control

Biological control of mealybugs is a promising, most effective long term solution and alternative to chemical control in commercial green house crops to mealybug infestations to a large extent and also to limited scale in the fields. A number of natural enemies, including several parasitoids and predators are known to attack mealybugs even when their population densities is low and they continue to attack the mealybugs, keeping their population at low level or wipe out the mealybug population. Biological control by release of predators has been proved very successful. The important predators of mealybug nymphs are coccinellid beetles such as *Cheilomenes sexmaculata, Scymnus coccivora* and *Nephus regularis.* Among predators, Australian ladybird beetle *Cryptolaemus montrouzieri* has been used successfully to reduce large populations of mealybugs in India. It is considered as one of the important predator of many mealybug species occurring in greenhouses and interior landscapes. The other biocontrol agents reported to be found effective against mealybugs are *Anagyrus pseudococci, Leptomastix dactylopii, Coccidoxynoides perminutus* for *Planococcus citri* and *Anagyrus kamali* for *Maconellicoccus hirsutus*. The microbial agents *Verticillium lecanii* and *Beauveria bassiana* are also effective during high humid months in reducing the populations of mealybugs. Identity of mealybugs and selection of correct biocontrol agents play a major role in suppressing the mealybugs.

53.12 Chemical Control

Chemical insecticides cannot be out rightly rejected from mealybug pest control schedule. But selection of insecticides, which are comparatively safe to the insect natural enemies, should be taken into consideration. Mealybug management includes locating the ant colonies and destroying them with drenching of chlorpyriphos 20 EC @ 2.5 ml/l or dusting with malathion; spot treatment with any recommended insecticides such as chlorpyriphos 0.05 % or carbaryl 0.05 % or fenitrothion 0.05 %; spraying with insecticidal soap or horticultural oil or fish oil resin soap @ 2 ml/l of water; soil drenching with imidacloprid 200 SL through drip irrigation @ 400 ml/ac; foliar spray with IGR buprofezin @1.25 g 1 g/l after 30 days of soil drenching; when parasitized mealybugs or predators are present, spraying with dichlorvos @ 2 ml/l, dimethoate @ 2 ml/l, chlorpyiphos @ 2 ml/l, imidacloprid @ 0.75 ml/l at 15 days interval and; use of dichlorvos (0.2 %) in combination with fish oil rosin soap (25 g/l) as spray.

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Tuber Crops

54

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Mealybugs are injurious to tuber crops, mainly cassava (*Manihot esculenta*), and to some extent to taro (*Colocasia esculenta*), yam (*Dioscorea* spp.), sweet potato (*Ipomea batatas* Lam.), tannia (*Xanthosoma sagittifolium*), elephant foot yam (*Amorphophallus paeoniifolius*), yam bean (*Pachyrrhizus erosus*), and enset (*Ensete ventricosum*).

54.1 Cassava

54.1.1 Species

Mealybugs are highly injurious in South America, Africa, India, Hawaii, Philippines, and Thailand (Table 54.1). According to Williams (1978), 10 species of mealybugs are known in the world on cassava, and 6 species of mealybugs known on cassava in West Africa. Mealybugs are most injurious in South America. In the 1970s, the cassava mealybug appeared and threatened to decimate the African cassava industry (Greathead 1978). An account of mealybugs attacking cassava in Neotropics and Africa is given by Cox and Williams (1981). *Paracoccus marginatus* (Williams and Granara de Willink) invaded several countries and caused severe damage to cassava (tapioca), particularly in India (Shylesha et al. 2011). *Stictococcus vayssierei* (Richard [Homoptera: Stictococcidae]), wrongly called as cassava root mealybug, is really cassava root scale (http://www.cabi.org/iscbeta/datasheet/118988). According to Parsa et al. (2012), a total of 24 species of mealybugs are known to attack *Manihot esculenta*. A list of mealybug species reported on cassava in different regions is given in table. Among the mealybug species, *Phenacoccus manihoti*, *Phenacoccus herreni*, and *Paracoccus marginatus* are reported to cause heavy loss to the cassava industry.

54.1.2 *Phenacoccus manihoti*

The cassava mealybug, *Phenacoccus manihoti* (Hemiptera: Pseudococcidae), is one of the most severe pests of cassava in the world. *Phenacoccus manihoti*, the neotropical species (South America), was accidentally introduced to Africa

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Table 54.1 List of mealybug species reported on cassava in different regions

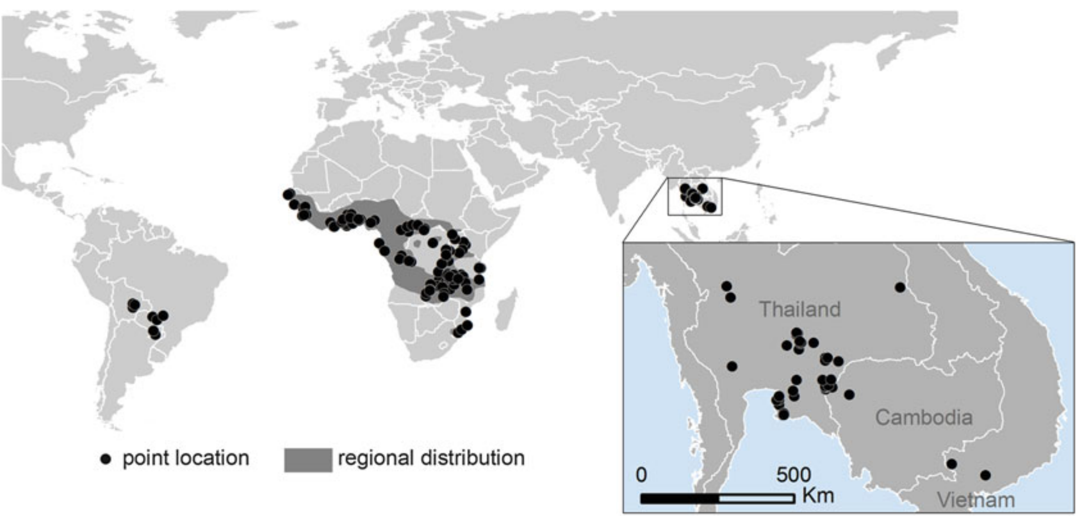
Mealybug species	Country/Region	Reference
Dysmicoccus bispinosus (Beardsley)	Neotropical region	Ben-Dov (1994)
Dysmicoccus brevipes (Cockerell)	–	Ben-Dov (1994)
Ferrisia consobrina (Williams and Watson)	–	Ben-Dov (1994)
Ferrisia tereani (Williams and Granara de Wilink)	Argentina	Ben-Dov (1994)
Ferrisia virgata (Cockerell)	India	Williams (2004)
	Congo	Matile-Ferrero (1978)
	Colombia	Castillo and Bellotti (1990)
Maconellicoccus hirsutus (Green)	The United States	*manatee.ifas.ufl.edu/comm-hort/pdf/pest-topics/InsectPHMHosts.pdf*
Paracoccus marginatus (Williams and Granara de Willink)	Ghana	Cham et al. (2011)
	India	Mani Chellappan (2011)
	Sri Lanka	Galanihe et al. (2010)
	Palau	Muniappan et al.(2006)
	Puerto Rico	Pantoja et al. (2007)
	Florida	Miller and Miller (2002)
	Indonesia	Muniappan et al. (2008)
	Malaysia	Mastoi et al. (2011)
	Thailand	Saengyotl and Burikam (2011)
Phenacoccus gossypii (Tinsley)	Colombia	Milena Varela et al (1982)
Phenacoccus herreni (Cox and Williams)	Latin America	Dorn et al.(2003a)
	South America	Calatayud et al. (2001)
	Colombia	Castillo and Bellotti (1990)
	Northeastern Brazil	Bento et al. (2000)
	Colombia	Castillo and Bellotti (1990)
Phenacoccus madeirensis (Green)	Malawi	Borowka et al (1997)
	Colombia	Castillo and Bellotti (1990)
	India	Shylesha and Sunil Joshi (2012)
Phenacoccus manihoti (Matile-Ferrero)	Tanzania	Mtambo (1995)
	Zambia	Chakupurakal et al. (1994)
	Zimbabwe	Giga (1994)
	Ghana	Cudjoe et al. (1992)
	Congo	Reyd and le Ru (1992)
	Ibadan, Nigeria	Schulthess et al. (1991)
	Sierra Leone	James (1987)
	Gabon	Boussienguet et al. (1991)
	Zaire	Hennessey et al. (1990)
	Bolivia, Brazil, and Paraguay	Lohr et al (1990)
	Ivory Coast	Minko and Bekon (2005)
	Zambia	Chakupurakal et al. (1996))
	Malawi	Borowka et al. (1997)
	Colombia	Castillo and Bellotti (1990)
	Uganda	Nweke (2010)
	Hawaii	Beardsley (1978)

(continued)

Table 54.1 (continued)

Mealybug species	Country/Region	Reference
Phenacoccus solenopsis (Tinsley)	The United States	Ben-Dov et al.(2012)
Planococcus citri (Risso)	Congo	Matile-Ferrero (1978)
Planococcus furcisetosus (Mamet)	–	Ben-Dov (1994)
Planococcus minor (Maskell)	Trinidad	Francis et al.(2012)
Pseudococcus elisae (Borchsenius)	The Philippines	Lit et al.(1990)
Pseudococcus longispinus (Targioni Tozzetti)	–	Ben-Dov (1994)
Pseudococcus mandio (Williams)	Paraguay, Bolivia, and Brazil	Pegoraro and Bellotti (1994)
Pseudococcus maritimus (Ehrhorn)	Nearctic and neotropical	Ben-Dov (1994)
Pseudococcus viburni	–	Ben-Dov (1994)
Puto barberi (Cockerell)	Neotropical	Ben-Dov (1994)

in the early 1970s, and it has become naturalized throughout sub-Saharan Africa. *Phenacoccus manihoti*, an oligophagous mealybug, is considered as the major pest on an international scale (Matile-Ferrero 1978; Neuenschwander et al. 1991; Williams and Granara de Willink 1992; Zeddies et al. 2001).



Distribution of *P. manihoti* on cassava Parsa et al. (2012)

Phenacoccus manihoti Ants attending cassava mealybug

Damage to cassava by *P. manihoti*

54.1.3 Damage

Damage includes destruction of terminal shoots and expanded leaves by sucking of sap (and possibly by the introduction of a salivary toxin), leading to short internodes, small leaves, and sometimes die-back. The economic damage is partly from the loss of fresh leaves (which are edible) and partly from the loss in root yield. In some parts of Bas-Zaire, complete defoliation of cassava plants by the mealybug was observed (Ezumah and Knight 1978). When *P. manihoti* feeds on cassava, it causes severe distortion of terminal shoots, yellowing and curling of leaves, reduced internodes, stunting, and weakening of stems used for crop propagation. The mealybug feeding reduced new leaf production, and assimilation and allocation of dry matter to storage roots. Yield of severely infested cassava plants was lost between 9 % and 46 % during the dry season. At the beginning of the rainy season, mobilization of reserves from storage roots for regrowth caused temporary root yield losses of up to 75 %. Yield losses at harvest, measured 12 months after planting, were 52–58 % in infested plants (Schulthess et al.

1991). In the absence of its natural enemies and other control measures, this damage can reduce yields by more than 80 % (Nwanze 1982).

54.1.4 Varietal Susceptibility

No cassava cultivars are known to be fully resistant to *P. manihoti* (Calatayud and Le Rü 2006). However, the Incoza variety was the most tolerant, followed by the Moudouma and Zanaga varieties. Dikonda, Kataoli, 3 M8, and 1 M20 were highly susceptible (Tertuliano et al. 1993). The resistant clone 70,453 slows down the buildup of mealybug populations and tolerates well the attack by mealybugs in Zaire (Anonymous 1985).

54.1.5 Ecology

In Ibadan, population peaks of *P. manihoti* usually occurred during the second half of the dry season (January–April). *Apoanagyrus lopezi* was the only natural enemy that was found during the whole year, and also in high densities (Hammond et al. 1987). In Congo, temperature appeared to be the most influential factor on the development time and on the capacity for increase, which was highest (0.214) at 30 °C and 75 % RH. Variations in abundance appeared to be related primarily to the thermal conditions prevailing during the outbreak. Early multiplication of mealybug, beginning in July, under the influence of low temperature, would thus occur slowly, each generation being distinct with clearly defined intervals in between, whereas a late outbreak occurring under the influence of high temperatures would develop more dramatically, with a rapid succession of generations (le Ru and Fabres 1987) 1985. It was found that intensity of rainfall seemed to be the most effective factor, causing about a 22 % reduction. Duration of rainfall had a lower effect, and rain lasting 50 min or less caused less than 10 % reduction (le Ru and Iziquel 1990a). *Phenacoccus manihoti* spread in Zaire occurs over an area of 560,000^2 km, mainly in regions with a dry season of at least 90 days. Within the region, the pest occurs principally in areas having low green-leaf biomass, toward the end of the dry season. Mealybug populations reached catastrophic levels mostly during prolonged periods of drought. The exotic parasitoid *A. lopezi* has spread over 130,000^2 km in western Zaire and southern Shaba, where no further mealybug outbreak has since been recorded (Hennessey et al. 1990). In Nigeria, predicted yield losses in wet years were small, because rainfall suppressed the population of *P. manihoti* directly and enhanced the ability of the plant to compensate for the feeding damage. In contrast, losses in dry years were higher because of the direct negative effects of water stress on photosynthesis, which were compounded by the much larger population of *P. manihoti* that developed. In Nigeria, the introduced encyrtid parasitoid *A. lopezi* is the most important factor controlling the population of *P. manihoti* in the dry season, and rainfall, directly or possibly via diseases, during the rainy season. *A. lopezi* regulates *P. manihoti* in Nigeria, despite the disruptive effect of rain-induced mortality, drought effects on host abundance, and predation by native coccinellid beetles (Gutierrez et al. 1988). Severely infested cassava plants were lost between 9 % and 46 % during the dry season, compared to the pest-free plants. At the beginning of the rainy season, mobilization of reserves from storage roots for regrowth caused temporary root yield losses of up to 75 % (Schulthess et al. 1991). The population of *Ph. manihoti* was extremely low in all areas of Bolivia, Brazil, and Paraguay, but there was a period of increase from August to December (Lohr et al. 1990). In the Congo, during the wet season, torrential rain kept the populations at a low level by washing the insects (especially the crawlers) off the plants. In the dry season, populations built up rapidly, and outbreaks occurred, but these were rapidly reduced by the corresponding increases in the populations of natural enemies and in interspecific competition for the food plants, from which many of the leaves had fallen, as a result of the outbreaks (Fabres 1981). In Zaire, the most important factor favoring multiplication and intensifying injury to the plants was hot dry weather and dry eroded soil. The most effective control measures are therefore any cultural ones that help to conserve soil moisture, such as erosion control, elimination of brush fires, and use of organic material as mulch or incorporated into the soil (Ezumah and Knight 1978).

54.1.6 Natural Enemies

Explorations for the natural enemies of *P. manihoti* within its native range in South America (Bolivia, Brazil, and Paraguay) revealed the presence of four hymenopterous parasitoids (*Angyrus* sp. nr. *pullus*, *Parapyrus manihoti* sp.nr., *Apoanagyrus diversicornis* (Howard) (*Epidinocarsis diversicornis*), *Apoanagyrus (=Epidinocarsis) lopezi* (DeSantis), twelve predators, and one entomopathogenic fungus (Table 54.2), out of which the parasitoid *Apoanagyrus lopezi* appeared to be one of the most promising (Lohr et al. 1990; Pijls and Van Alphen 1996; Noyes 1984). *Apoanagyrus lopezi* takes 18 days to complete one generation (Odebiyi and Bokonon-Ganta 1986).

54.1.7 Pathogens

The epizootiology of the entomogenous fungus *Neozygites fumosa* (Speare) in the populations of the *P. manihoti* was observed in the Congo in 1987. The development of the epizootic appeared to be more closely related to the frequency of rainfall than to total rainfall. Conditions were highly favorable when the air humidity was consistently greater than 90 % for at least 5 h per day (le Ru and Iziquel 1990a; le Ru 1986).

Table 54.2 *List of natural enemies recorded on P. manihoti, F.virgata,* and *Ph.solenopsis* infesting cassava

Species	Country	References
Phenacoccus manihoti		
Hyperaspis marmottani (Fairm.)	Nigeria	Umeh (1983)
Hyperaspis senegalensis hottentotta (Mulsant)	Congo	Kiyindou et al. (1990)
Hyperaspis raynevali (French)	Congo	Reyd and le Ru (1992)
Hyperaspis aestimabilis (Mader)	Malawi	Borowka et al. (1997)
Hyperaspis pumila (Mulsant)	Nigeria	Iheagwam (1981)
Hyperaspis onerata (Mulsant)	Zaire and Congo	Bennett and Greathead (1978)
Ceratochrysa antica (Wlk.)	Nigeria and Angola	Barnard and Brooks (1984)
Chrysopa sp.	Nigeria	Iheagwam (1981)
Exochomus flaviventris (Mader)	Central Africa	le Ru and Makosso (2001)
	Congo	Kiyindou et al. 1990)
Exochomus troberti (Mulsant)	Malawi	Borowka et al. (1997)
Exochomus flavipes (Thunberg)	Gabon	Boussienguet (1986)
Exochomus concavus (Fursch)	Congo	Fabres and Matile-Ferrero (1980)

(continued)

Table 54.2 (continued)

Species	Country	References
Nephus vetustus (Weise)	Gabon	Boussienguet (1986)
Coccodiplosis citri (Barnes)	Gabon	Boussienguet (1986)
	Congo	Fabres and Matile-Ferrero (1980)
Dicrodiplosis manihoti sp.n	Congo and Senegal	Harris (1981)
Cacoxenus perspicax (Knab.)	Gabon	Boussienguet (1986)
Allobaccha eclara (Curran)	Gabon	Boussienguet (1986)
Diomus hennesseyi (Fiirsch)	Malawi	Borowka et al. (1997)
Scymnus couturier G.	Ivory Coast	Minko and Bekon (2005)
Spalgis lemolea (Druce)	Nigeria	Iheagwam (1981)
Cardiastethus exiguus (Popp)	Congo	Fabres and Matile-Ferrero (1980)
Ferrisia virgata		
Blepyrus insularis (Cam.) *Aenasius advena* (Comp.)	Congo	Fabres and Matile-Ferrero (1980)
Phenacoccus gossypii		
Scymnus sp., *Chrysopa* sp., *Coccidophilus* sp., *Ocyptamus stenogaster* (Will.), and *Kalodiplosis coccidarum* (Felt.).	Colombia	Milena Varela et al. (1982)

54.1.8 Management

54.1.8.1 Chemicals

Dimethoate, monocrotophos, diazinon, methidathion and methidathion + bromopropylate were more effective against *P. manihoti* as foliar sprays (Akinlosotu 1983; Anonymous 1989; Atu and Okeke 1981a). Ten months after application, methidathion, phosphamidon, and diazinon had significantly increased tuber yields, giving 25.6, 26.3, and 32.3 t/ha, respectively, compared with 17.9 t/ha for the control (Atu and Okeke 1981b). Three applications of neem kernel water extract (NKWE) at weekly intervals protected cassava against established early-instar nymphs of *P. manihoti* (Mourier 1997).

54.1.9 Biological Control

In the 1970s, the cassava mealybug *P. manihoti* appeared and threatened to decimate the African cassava industry, and Greathead (1978) had outlined the biological control program to be followed in Africa. To tackle the mealybug problem, two species of *Apoanagyrus* have been introduced from South America into Africa as biological control agents against the cassava mealybug *Ph. manihoti* in 1981. About 50, 000 adults of *Apoanagyrus* (formerly known as *Epidinocarsis lopezi*) were released in Congo, Gambia, Guinea-Bissau,

Parasitoids of *Phenacoccus manihoti*

Apoanagyrus lopezi

Apoanagyrus diversicornis

Nigeria, Rwanda, Senegal, Togo, Zaire, and Zambia during 1981–1984 for the biological control of *Ph. manihoti* on cassava. Later, they were introduced into cassava fields in over 100 locations throughout sub-Saharan Africa. *Apoanagyrus lopezi* was released in Nigeria in November 1981. The spread of the parasite in a large cassava-growing area of Nigeria was at 5–170 km/year, and became established in 16 African countries. A reduction in the number of mealybugs to below the injury level was observed in every zone colonized by *A. lopezi*. In those zones, mealybug populations reached peak densities of 10–20 per terminal cassava shoot or less, as compared with more than 1500 per shoot before the introduction of the parasite. The introduction of this parasitoid into Africa in the 1980s reduced high infestations by 90 %, becoming a highly successful case of classical biological control. *Apoanagyrus lopezi* is an efficient biological control agent across several ecological zones of the African cassava (Neuenschwander and Hammond 1988). The wasp has been effective in bringing the mealybug under control and reduces yield loss by 2.5 t per hectare. The successful control of the cassava mealybug problems has raised cassava yields and turned cassava into a cash crop that is now spreading throughout Africa. Zeddies et al. (2001) calculated the total costs and benefits of this biological control program for 27 African countries over a 40-year period (1974–2013) under different scenarios, such as transport, loss of crop, and even the price of maize as a possible substitute. Based on the total cost of biological control at US$ 47 million, the benefits from different scenarios range mainly from 199:1 (or US$ 9.4 billion) to 430:1 (or US$ 202 billion) (Williams and Granara de Willink 1992). Each dollar spent on the mealybug control project brought returns worth at least US$150 to the farmer. The overall economic benefit of controlling the mealybug has been estimated at between US$9 billion and US$20 billion. Pedigo (1999) commented that the tremendous success is credited with preventing the malnutrition of millions of Africans and may well be the most important example of classical biological control ever.

54.1.10 Congo

Three severe outbreaks of *Ph. manihoti* have occurred since 1976. *Phenacoccus manihoti* populations declined greatly in the second year after the release of *A. lopezi*. (Hennessey and Muaka 1987; Hennessey et al. 1990).

54.1.11 Nigeria

Apoanagyrus lopezi was imported in 1981 from Paraguay into Nigeria for the biological control of *Ph. manihoti* (Lema and Herren 1985). Within 3 years, it dispersed over 200,000 km^2 in southwestern Nigeria, occupying 70 %–98 % of all fields (Herren et al 1987). The impact assessment revealed that 89 % of all sampled cassava tips had no individuals of *P. manihoti* at all (Neuenschwander and Hammond 1988; Hammond and Neuenschwander 1990).

54.1.12 Gabon

The exotic encyrtid parasitoid *Apoanagyrus lopezi* was introduced in Gabon for the biological control of the cassava mealybug *Ph. manihoti* in 1986. The establishment of the parasitoid after introduction showed a speed of dispersal of 70–120 km/year (Boussienguet et al. 1991).

54.1.13 Ghana and Ivory Coast

P. manihoti in Ghana and Ivory Coast. *P. manihoti* populations were significantly lower where *A. lopezi* had been present. In the savanna zone, tuber yield losses due to *P. manihoti* in the absence of *A. lopezi* were tentatively estimated at 463 g/plant in the savannah zone. When *A. lopezi* was present, the increase in yields was 228 g/plant or about 2.48 t/ha in the savannah region (Neuenschwander et al. 1989).

54.1.14 Malawi

P. manihoti was confirmed damaging cassava in Nkhata Bag, Malawi, and *Apoanagyrus lopezi* was introduced in 1985. Parasitism by *Apoanagyrus lopezi* rose to 50 % (Nyirenda 1988). Wherever *Apoanagyrus lopezi* had been present for 2 years or more, *P. manihoti* populations were reduced by seven times (Neuenschwander et al. 1991).

54.1.15 Tanzania

The endoparasitic wasp, *Apoanagyrus lopezi*, was introduced into Tanzania in 1988. By 1991, *A. lopezi* was well established in all regions, and the population of *P. manihoti* declined, and has since remained low (Mtambo 1995).

54.1.16 Zambia

From 1984 onward, parasitoid *A. lopezi* and some coccinellid predators were released into Zambia. Between 1986 and 1990, populations of *P. manihoti* declined by, on average, 5.8 times, and the biological control of the *P. manihoti* in Zambia was successful (Chakupurakal et al. 1994).

54.1.17 Southeast Asia

P. manihoti remains a threat to the cassava areas of southern Asia. *P. manihoti* was first detected in Thailand in 2008 (Winotai et al 2010). Yields during the March/April 2010 harvest reported a drop of about 25 %, and economic losses resulting from mealybug damage were expected to be 2.8 billion Baht. With the appearance of the mealybug, the Department of Agriculture estimated losses of 40 %–50 %, adding up to more than US$150–200 million in crop damage in the first year alone. Further, it was also detected in Vienam, *Lao PDR*, Cambodia, Myanmar, and threatens to engulf regions of cassava-growing plots. Cassava-growing areas of southern China, Indonesia, and Philippines are considered vulnerable (Muniappan et al. 2009; Wu and Wang (2011).

Cassava stem infested with *P. manihoti* in Thailand.

Apoanagyrus lopezi from Benin to Thailand

A. lopezi (500) that once saved Africa's cassava farmers was brought on a flight from Benin to Bangkok. The Department of Agriculture is now raising and releasing a quarter of a million wasps in Thailand. The first official release began in July in the country's northeast Tony Bellotti. Instead of 10 years, it takes only a year or so to respond (Paul Cox 2010).

54.1.18 *Phenacoccus herreni*

P. herreni causes yield losses in cassava in South America, attacking the young shoots and causing rosetting, stunting, and shoot and stem malformations (Bellotti 1983).

54.1.19 Ecology

The mealybugs are spread largely by wind and by the movement of infested plant material (Bellotti 1983). *P. herreni* densities in Colombia were highest in the dry season. Mealybug densities had declined sharply with the onset of rains (Van Driesche et al. 1990).

54.1.20 Varietal Resistance

In Colombia, six clones (CM 2177–2, SG 100–54, SG 250–3, CM 6068–3, CM 5263–1, and SM 540–8) were identified tolerant or moderately resistant to *P. herreni*, which can cause yield losses up to 88 % (Bellotti and Vargas 1991).

54.1.21 Natural Enemies of *P. herreni*

Parasitoids In Colombia, *P. herreni* was found parasitized by the encyrtids *Acerophagus coccois* (Smith) and *Anagyrus (Epidinocarsis) diversicornis*. The combined action of the parasitoid species present caused 54.9 % mortality in the mealybug population as estimated by a new analytical method (Van Driesche et al. 1990; Castillo and Bellotti 1990). In Colombia, the main parasite was *Anagyrus* sp. (9.2 %) in 1981 and *Acerophagus coccois* (73 %) in 1982.

Acerophagus coccois

Aenasius vexans

(Bellotti 1983). Preferential oviposition by *Anagyrus diversicornis* and *Acerophagus coccois* was second and third instar nymphs and adult mealybugs.

Predators Six species of coccinellids, including *Hyperaspis notate* and *H. onerata*, were discovered in cassava fields infested with *P. herreni* in Colombia (Carrejo et al. 1991; Castillo and Bellotti 1990; Sullivan, et al.(1991). The syrphid *Ocyptamus* sp. was frequently found consuming eggs of *P. herreni* (Castillo and Bellotti 1990). In Colombia, the main predator was found to be *Ocyptamus stenogaster* (Will.) forming 68 % of all natural enemies in 1981 and *Kalodiplosis coccidarum* (Felt) (11.6 %) in 1982 (Bellotti 1983).

Fungi *P herreni*, in May 1994, at Cruz das Almas, Bahia, Brazil, were found to be infected with *Neozygites fumosa* (Delalibera et al. 1997). In Colombia, a pathogenic fungus, *Cladosporium* sp., was observed on *P. herreni*, being most effective at high host densities (Bellotti 1983).

54.1.22 Management

Three encyrtid parasitoids, *Apoanagyrus diversicornis* (Howard), *Aenasius vexans* (Kerrich), and *Acerophagus coccois* (Smith), are used to control the cassava mealybug *P. herreni* in South America (Calatayud et al. 2001; Dorn et al. 2003a). For efficient field application, it is suggested to release *A. vexans* and *A. coccois* late in the morning, during its period of increasing activity (Dorn et al. 2003b). A multispecies (*A. vexans* and *A. coccois*) approach to biological control of *P. herreni* may yield best results.

In six states in northeastern Brazil, the mealybug *P. herreni* causes considerable damage to cassava. Several native natural enemy species were found associated with the pest in Brazil but did not provide adequate control. Exotic encyrtid parasitoids were imported and released in fields in the states of Bahia and Pernambuco. *Apoanagyrus diversicornis* was introduced from Colombia, and *Acerophagus coccois* and *Aenasius vexans* were introduced from Venezuela. By the end of 1996, a total of 35,930 parasitoids had been released. In Bahia, *A. diversicornis* was recovered at 130, 234, 304, and 550 km from its release site after 6, 14, 21, and 33 months, respectively. *Acerophagus coccois* was recovered at 180 km from its release site, 9 months after release. *Aenasius vexans*, however, did not disperse at all, despite being consistently recovered at its release site. In Pernambuco, 9010 parasitoids were released from October 1995 onward. *Acerophagus coccois* and *Aenasius vexans* were recovered up to 40 km from the release sites after 3 and 5 months of their initial releases, respectively (Bento et al. 1999). The impact studies conducted between 1994 and 1997 indicated that at least 85 % of the parasitoids found in those fields were composed of the recently introduced species *Apoanagyrus diversicornis*, *Aenasius vexans*, and *Acerophagus coccois. Apoanagyrus diversicornis* was found in all fields during most of the experimental period, whereas *Acerophagus coccois* and *Aenasius vexans* were only found in the fields where they had been released. *Apoanagyrus diversicornis* outcompeted *Aenasius vexans* in Sao Goncalo, but not *Acerophagus coccois* in Itaberaba. The concerted action of the three introduced parasitoids and the native natural enemies was sufficiently efficient to control *P. herreni* at low levels in the fields (Bento et al. 2000).

54.2 *Paracoccus marginatus*

Paracoccus marginatus (PMB), a polyphagous pest, is native of Central America/ Mexico, infesting more than 60 species of plants invaded over 50 countries. In India, it was first reported on cassava from Tamil Nadu during 2008 (Muniappan et al. 2008), infesting a wide list of agricultural and horticultural crops, including cassava/tapioca. Though *Paracoccus marginatus* was reported on cassava in more than nine countries, only in India, particularly in Tamil Nadu and Kerala, the cassava crop was found severely damaged.

Acerophagus papayae

Damage to cassava

Paracoccus marginatus

Heavy clustering of mealybugs was seen under the leaf surface, giving the appearance of a thick mat with waxy secretion. They excrete copious amount of honeydew that attracts ants and helps in the development of black sooty mould, which inhibits the plant's ability to manufacture food. This pest infests all aerial parts of the plant. Infestation at the initial stage is observed on the leaf, particularly on the ventral surface and petiole, and later it spreads to stems and branches. Heavy infestation causes leaf-shedding and yield loss. The mealybug infestation varied from 50 to 90 % in cassava, resulting in a monetary loss of Rupees 220 crores in cassava alone in Tamil Nadu.

54.2.1 Management

A comprehensive integrated pest management practices, viz., early detection by timely monitoring, removal and destruction of affected plants and weeds, conserving natural enemies like predacious coccinellid beetles, lepidopteran predator, *Spalgis epeus*, and need-based application of insecticides were developed. Even after adoption of IPM, the population of papaya mealybug was found to increase at a faster rate for want of efficient natural enemies, since the pest is invasive (introduced from other country), and the chemical control is short-lived and farmers have to spray once in a fortnight.

Severe infestation of *P.marginatus* was observed on cassava in Namakkal, Salem, and Dharmapuri districts of Tamil Nadu state (Sakthivel and Qadri 2010), besides Coimbatore, Karur, Erode, Thirupur, and Trichy districts. Since *Acerophagus papayae* has provided excellent control of *P.marginatus* in many countries, it was imported from Puerto Rico in June 2010, and releases were made in Tamil Nadu in 2010.

Population densities of papaya mealybug on cassava and percent parasitism in the three sampling sites before and after release of parasitoids are given in Table. Heavy population load of 38.70, 43.85, and 41.21 numbers/5 cm^2 was recorded in Salem, Dharmapuri, and Namakkal districts, respectively. No parasitism was observed in a pre-release survey in all three locations. An average of 6.08 % parasitism and 11.51 % reduction in papaya mealybug was recorded. The mealybug population had declined uniformly, corresponding to the gradual increase in percent parasitism at 2nd, 3rd, 4th, and 5th months in all three locations. The average population of papaya mealybug from the tapioca gardens was eliminated up to 93.15 % at 6th month corresponding to 76.33 % parasitism. Parasitism by *A. papayae* accounted for 80.89–94.31 %. It is concluded that the release of *A. papayae* at 200 individuals per location alone is sufficient to eradicate the population of papaya mealybug, rather than the application of chemicals (Sakthivel 2013). Similar control of the mealyugg was achieved with the release of *A.papayae* in other districts, namely, Trichy, Erode (Divya 2012), and Karur (Vijay 2010) in Tamil Nadu, India.

Tapioca is a major tuber crop of Kerala, and its yield was reduced considerably by the infestation of *P.marginatus*. In Kerala, total area for tapioca cultivation is 75,000 ha, and production is 30 t/ha. The mealybug infestation affected the tapioca production to a great extent. Due to the release of Acerophagus papaya in 2011, tapioca crop was saved. Approximate cost of cultivation is Rs. 50,000/ha, and the income is Rs. 3 lakhs/ha/year (at Rs. 10,000/t). Thus, the net savings is 2.5 lakhs/ha and 1.8 crores/year in Kerala, with the release of *Acerophagus papaya* (Lyla, personal communication). Central Tuber Crop Research Institute, Trivandrum (CTCRI) developed bioformulations "SHREYA" and 'NANMA," which are very effective against *P.marginatus* (http://www.yentha.com/news/view/4/bio-pesticides-developed-from-tapioca-leaves).

54.3 *Phenacoccus gossypii*

Large populations of the mealybug *Phenacoccus gossypii* (Tns. & Ckll.) had built up on cassava in the Llanos Orientales, Colombia.. Seven species of parasitoids, of which the most important was *Anagyrus* sp., and 18 species of predators were observed in the field. The most effective of the predators in controlling the populations of *Ph.*

gossypii were *Scymnus* sp., *Chrysopa* sp., *Coccidophilus* sp., *Ocyptamus stenogaster* (Will.), and *Kalodiplosis coccidarum* (Felt.) (Milena Varela et al.1982).

54.4 Sweet Potato

Paracoccus marginatus is known to attack a variety of crop plants, including sweet potatoes. The mealybugs feed, often in groups, on the underside of leaves. Feeding on leaves by sucking out tissue fluid, they release a poison into the plant tissue and secrete a sticky, sweet substance, called honeydew. Where honeydew falls, a black fungal growth called sooty mould develops. Although this fungus does not harm plants directly, it blocks out sunlight essential for the plant growth. The mealybug infestations lead to stunted growth, discoloration, malformed foliage, and defoliation of sweet potato plants. To control papaya mealybugs on sweet potato plants, gardeners should begin with a biological approach by releasing natural enemies, particularly *Acerophagus papayae*. For severe infestations, applications at twice the normal rate of a pesticide, with an active ingredient such as carbaryl or malathion, offer some control, particularly when used alongside cultural measures (Tarah Damask What Causes White Bumps on Sweet Potato Leaves? (http://homeguides.sfgate.com/causes-white-bumps-sweet-potato-leaves-42692.html). Sweet potatoes are known to be infested with mealybugs in storage.

Mealybugs on sweet potato

54.5 Yam – *Dioscorea* spp.

Three species of mealy bugs, including *Planococcus lilacinus* (Cockerell), *P. citri*, and *P. dioscorea* have been reported to evoke a devastating impact on the yam tubers (Morse et al. 2000). Postharvest loss of tubers of yams and aroids due to pests and diseases has ever been havoc. In warehouses and storage huts, insect pests are the more serious menace to stored tubers and often more important than storage diseases. Damage inflicted by the insects facilitates the entry of pathogens; besides, pests themselves indulge in spreading microbial contamination.

Mealybug damage to *Dioscorea*

Feeding activity of the mealybugs not only makes the tubers unattractive and unmarketable but also predisposes them to rot (Vasquez and Buyser 2007; Rajamma et al. 2002). Infestation of mealybugs leads to qualitative and quantitative deterioration of the tubers, which culminates in the unacceptability and low-profile marketability of the tubers (Chomchalow, 2003). Palaniswami and Pillai (1989) and Korada et al. (2010) reported the qualitative and quantitative deterioration of tubers of yams and aroids due to the infestation by mealybugs. Palaniswami et al. (1982) reported the incidence of *Ferrisia virgata* (Cockerell) on sweet yam (*Dioscorea dumetorum*). They desap the leaves, and the high incidence of this pest causes drying of leaves and withering.

54.6 Elephant Foot Yam (*Amorphophallus paeoniifolius*)

Amorphophallus paeoniifolius, popularly known as elephant foot yam, is an important tropical tuber crop in India. Mealybug (*Rhizoecus amorphophalli*), a soft-bodied insect, infests the corms, both in storage and in the field (Misra et al. 2013). *Rhizoecus amorphophalli (*Betrem) was widely distributed in South Asia, infesting many tuber crops (Williams 2004). Mealybugs are seen in clusters on the stem, petiole, and leaf, particularly on the lower side. Infestation is high during warm and dry periods. Usually, the *Amorphophallus* seed corms are harvested during the dry season, after the crop is fully matured. During this period, mealybugs enter soil cracks and holes formed after drying of the pseudostem, and infest the corms. Infestation becomes severe when the corms are left for longer periods in the soil during the dry season. Mealybug is a pest that thrives in hot and humid conditions. When the temperature is more than 30 °C, its infestation is severe, and increases with rising temperature and humidity. Tubers are stored in storehouses, after harvesting, until further use. During storage, *Rhizoecus amorphophalli* (Betrem) causes 10–15 % loss of tuber. In the absence of mealybug control measures, mealybug numbers increased by 4–5 times during the storage period. The pest affected the quality of the corms and reduced subsequent field establishment and crop growth. Infestation also affects the corms' ability to sprout, which then affects subsequent production and productivity. Two species of mealybugs *Ps.citriculus* (Green) and *Rhizoecus* sp. (Bit) are found together, and they suck and desap the cell contents of the tubers (Palaniswami (1999). The field infestation ranged from 6 to 45 %. Mealybugs multiplied during high temperature and humidity. They cover the tuber surface with powdery mealy substances. Severely infested tubers shriveled, adversely affecting the quality and marketability. Several methods have been tried for controlling mealybugs. Rubbing of infested corms with a dry cloth /soft brush, and forcefully washing the corms with water are some of the management practices which are recommended. However, re-infestation after some time is common when using these techniques. If the storage was for planting purpose, the corms should be treated with fenitrothion (0.05 %) + mancozeb (0.2 %). (http://odisha.gov.in/e-magazine/Orissareview/2008/Sept-Octo-2008/engpdf/64-66.pdf). A two-instalment spray/drench application of imidacloprid spaced 3–4 weeks apart resulted in complete control with zero phytotoxicity noted on any of the very mixed collection (http://www.aroid.org/aroidl-archive/showthread.php?id=3696). CTCRI-developed bioformulations "SHREYA" and 'NANMA" are very effective against the pests. Spraying neem oil at a concentration of 2 % at 15 days interval was found effective to reduce the incidence (http://www.yentha.com/news/view/4/bio-pesticides-developed-from-tapioca-leaves).

Though pesticides are effective in controlling mealybugs, they can be hazardous to human health and the environment. Salt (NaCl) solution (1000 ppm), cow urine, cow dung slurry (2 kg of cow dung in 1 L of water), and clay slurry (1 kg of clay in 1 L of water) treatments were effective in reducing mealybug numbers and the associated corm damage. However, availability of cow urine, cow dung, and clay slurry limits their usage. Common salt is cheap, widely available, and easy to use in treating the corms prior to storage. Relative to untreated corms, those treated with salt solution recorded greater emergence when field-planted, as well as producing plants with more vigorous growth (Nedunchezhiyan et al. 2011). *Cryptolaemus montruzieri* was found predating on *Rhizoecus amorphophalli* in the storage. It is recommended to maintain a temperature range between 25 °C and 30 °C in the elephant foot yam storage houses, as this temperature is most congenial for development, activity of *C. Montrouzieri*, and for successful control of mealybugs. Approximately two to three numbers of *C. montrouzieri* are required for each infested tuber to control mealybugs. Accordingly, the predator can be released in storage godowns. As there is also natural parasitization of mealybugs by *Anomalicornia tenuicornis* (Mercet) (Encyrtidae, Hymenoptera), *C. montrouzieri* and *A. tenuicornis* together can contribute to the successful control of mealybug in storage, making the tubers suitable for planting during subsequent times (Misra et al. 2013).


Mealybugs on elephant foot yam

54.7 Yam Bean

Yam bean (*Pachyrrhizus erosus* (L) Urban), otherwise called potato bean, is grown for its starchy root. The stripped mealybug *Ferrisia virgata* (Cockerell) infestation was found infesting on yam bean seed crop in Orissa State, India. At the time of infestation, the crop was in fruiting stage. The plants were full of immature young pods. The initial infestation was found on the lower side of the bottom leaves. Soon, it was seen on growing points and young immature pods. Initially, the infested parts were full of white mealy substances. Later, the apical meristem and other growing parts turned black. The young pods were curled inward and blackened. The other infested parts also slowly blackened and dried. Dry weather due to low rainfall, high relative humidity followed by low relative humidity, and high variation in maximum and minimum temperatures (diurnal variation) during the year 2011 might be responsible for the outbreak of *F. virgata* on yam bean. (Nedunchezhiyan et al. 2014).

Yam bean infested with *Ferrisia virgata*

Lower number of infested pods per plant, higher number of uninfested pods/plant, seeds/pod, 100-seed weight, seed yield/plant, and seed yield (kg/ha) were observed with the application of two sprayings of acephate 0.03 % (spray fluid 250 L/ha) (Nedunchezhiyan et al. 2014).

54.8 Enset

Presently, more than 12 million people in Ethiopia depend on enset as a source of food. Its production is strongly hampered by the enset root mealybug *Cataenococcus ensete* (Williams and Matile-Ferrero) in Ethiopia (Addis et al. 2008). Enset plants infested with mealybugs have a retarded growth and dried lateral leaves. The insects attack all plant age groups, but symptoms are more severe on 2-to-4 years old enset plants. Enset root mealybugs are found on roots and corms. Early infestations by root mealybugs can be easily overlooked, because they live underground, and no visual symptoms will be observed on the plant parts above the ground, until extensive damage has been made to the roots and corm (Hara et al. 2001). However, during periods of extreme drought, the mealybugs tend to move toward the corm when some of the roots drought. The dispersal mechanism of enset root mealybugs is facilitated by the movement of infested suckers, farm implements during cultivation, repeated transplanting operations, and association with ants. The population density of the mealybugs was significantly ($p < 0.05$) higher on the roots than the corms. Enset root mealybugs were found up to a soil depth of 60 cm and up to 80 cm from the corm. In addition, about 90 % of the mealybugs were found within a 60 cm radius from the plant (Addis, 2008).

54.8.1 Management

Repeated ploughing and sanitation of enset fields has also been reported as a control option for reducing enset root mealybug population numbers (Tadesse et al. 2003). Application of farmyard manure (20 kg plant-1 year-1) resulted in vigorously growing plants with lower population numbers of enset root mealybugs (Anonymous 2002). Among the insecticides tested, chloropyrifos and diazinon have shown promising results for its control and eradication (Tadesse 2006). Soil drenching with diazinon 60 % EC and chlorpyrifos 48 % EC caused at least 98 % mortality, both under field and greenhouse conditions (Tadesse et al. 2010). Still, cost-effective and user-friendly control measures for the enset root mealybug have not yet been developed (Tadesse 2006) (Table 54.3).

Table 54.3 List of mealybugs recorded on tuber crops other than cassava

Crop and Mealybug species	Country	Reference
Ipomoea batatas (Sweet potato)		
Ferrisia virgata (Cockerell)	Guam	IIse Schreiner (2000)
	Bangladesh	http://www.aappbckv.org/journal/archive/6%20Sudden%20outbreak% 20of% 20mealybug.pdf
Geococcus coffeae (Green)	India	David and Ananthakrishnan (2004)
Maconellicoccus hirsutus (Green)	USA	*manatee.ifas.ufl.edu/comm-hort/pdf/pest-topics/InsectPHMHosts.pdf*
Phenacoccus solenosis (Tinsley)	Ethiopia	http://www.ppse.org.et/index.php?option=com_content&view=article&id=40:selonopsis-mealybug-phenacoccus-solenosis-tinsley-hompotera-pseudococcidae-a-new-threat-to-cotton-production-in-ethiopia&catid=7:-news&Itemid=3

(continued)

Table 54.3 (continued)

Crop and Mealybug species	Country	Reference
Paracoccus marginatus (Williams and Granara de Willink)	Texas	Tarah Damask (http://homeguides.sfgate.com/causes-white-bumps-sweet-potato-leaves-42692.html)
	Florida	Walker et al. (2003)
	Palau	Pest Alert (2003)
	Ghana	Cham et al. (2011)
Planococcus kenyae (LePelley)	Africa	http://www.infonet-biovision.org/default/ct/94/pests
Planococcus minor (Maskell	Trinidad	Francis et al. (2012)
Tannia (*Xanthosoma sagittifolium* (Schott))		
Maconellicoccus hirsutus (Green)	The United States	*manatee.ifas.ufl.edu/comm-hort/pdf/pest-topics/InsectPHMHosts.pdf*
Taro -*Colocasia esculenta*		
Dysmicoccus brevipes (Cockerell)	–	Ben-Dov (1994)
Dysmicoccus neobreipes (Beardsley)	The Philippines	Williams (2004)
Ferrisia virgata (Cockerell)	–	http://www.plantwise.org/KnowledgeBank/Datasheet.aspx?dsid=23981
Geococcus coffeae (Green)	–	Ben-Dov (1994)
Maconellicoccus hirsutus (Green)	Trinidad	http://www.ncipmc.org/phmb/elson.cen.umontreal.ca/revue/phyto/1999/v80/n2/706185ar.pdf
	The United States	*manatee.ifas.ufl.edu/comm-hort/pdf/pest-topics/InsectPHMHosts.pdf*
Paracoccus marginatus (Williams and Granara de Willink)	Kerala	Mani Chellappan et al. (2013)
Planococcus minor (Maskell)	The United States	http://www.invasive.org/caps/host.cfm?host=5369
	Trinidad	Francis et al. (2012)
	India	Ben-Dov (1994);Williams (2004)
Pseudococcus longispinus (Targioni Tozzetti)	The United States	http://www.plantwise.org/KnowledgeBank/Datasheet.aspx?dsid=45079
	Africa	http://www.infonet-biovision.org/default/ct/94/pests
	India, Indonesia	Williams (2004)
Rasrococcus invadens (Williams)	–	Ben-Dov (1994)
Rhizoecus amorphophalli (Betrem)	India	Williams (2004)
Yam (*Dioscorea*)		
Maconellicoccus hirsutus (Green)	The United States	*manatee.ifas.ufl.edu/comm-hort/pdf/pest-topics/InsectPHMHosts.pdf*
Planococcus furcisetosus (Mamet)	Nigeria,West Indies	Ben-Dov (1994)

(continued)

Table 54.3 (continued)

Crop and Mealybug species	Country	Reference
Planococcus halli (Ezzat and McConnell)	Africa and the West Indies	Cox and Wetton (1988)
	Florida	https://edis.ifas.ufl.edu/in947
Planococcus minor (Maskell)	Trinidad	Francis et al. (2012)
Planococcus kenyae (Le Pelley)	Africa	http://www.infonet-biovision.org/default/ct/94/pests
Planococcus halli (Ezzat and McConnell)	Ibadan, Nigeria	Akinlosotu (1984)
Planococcus dioscoreae (Williams)	Solomon islands	Ben-Dov (1994)
Rasrococcus invadens (Williams)	Malaysia	Ben-Dov (1994);Williams (2004)
Rhizoecus amorphophalli (Betrem)	India	Williams (2004)
Elephant foot yam (*Amorphophallus paeoniifolius*)		
Paracoccus marginatus (Williams and Granara de Willink)	Kerala, India	Mani Chellappan et al. (2013)
Pseudococcus cryptus (Hempel)	India	Williams (2004)
Rasrococcus iceryoides (Green)	India	Williams (2004)
Enset (*Ensete ventricosum*)		
Cataenococcus ensete (Williams and Matile-Ferrer)	Ethiopia	Addis et al. (2008)

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55 Ornamental Plants

V. Sridhar, L.S. Vinesh, and M. Mani

Mealybugs are worldwide pests of ornamental plants grown indoors and outdoors. Both greenhouse and open cultivated grown ornamentals are commonly attacked by different mealybugs. In recent years, mealy bugs have become an increasing threat to the cultivation of several ornamentals in India (Jhansi Rani 2001; Mani and Krishnamoorthy 2003). Mealybug infestation reduces vigour and growth of the foliage which reduces the beauty of ornamental plant and affects marketability (Hamlen 1975). Mealybugs are a quarantine problem on exported foliage and flowers. Mealybugs cost growers and retailers millions of dollars per year in control costs and crop damage (Gullan and Kosztarab 1997). An exhaustive list of mealybugs on various ornamentals from different parts of the world has been documented by Mattiuz et al. (2006), Cham et al. (2011) and Arif et al. (2009) (Table 55.1).

55.1 Hibiscus

The greatest mealybug host diversity is found in *Hibiscus* spp. *Maconellicoccus hirsutus* (Green), *Coccidohystrix insolita* (Green), *Planococcus citri* (Risso), *Phenacoccus solani* Tinsley and *Paracoccus marginatus* Williams and Granara de Willink are some of the important mealybugs recorded on this crop.

55.1.1 *Maconellicoccus hirsutus*

Hibiscus rosa-sinensis is a preferred and economically important host of *M. hirsutus* also popularly known as pink hibiscus mealybug (PHMB), and is considered as a prolific pest that injects a toxin at the point of feeding, causing severe distortion of leaves and stunted growth (Vitullo et al. 2009). Severe outbreak of *M. hirsutus* was noticed on ornamentals around Cairo in 1920. Biological control is the best option for the suppression of the pink hibiscus mealybug. The parasitoid *Anagyrus kamali* Moursi and Australian ladybird beetle, *Cryptolaemus montrouzieri* Musant are the best-known natural enemies to keep PHMB under check. *Anagyrus kamali* has been reported to be an outstanding natural enemy in Egypt, Hawaii, Caribbean islands and Florida, and is able to dramatically suppress pink hibiscus mealybug populations. The introduction of *C. montrouzieri* was facilitated by India into Caribbean islands to control *M. hirsutus* on several ornamental plants including hibiscus (Gautam 2003).

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Table 55.1 List of some mealybugs recorded on different ornamental plants

Mealybug species	Host plant	Region/country	Reference
Chaetococcus bambusae (Maskell)	Ornamental bamboo	Florida	Hodges and Hodges (2004)
Delottococcus confusus (De Lotto)	Protea, Leucospermum	Portugal	Passarinho et al. (2006); Leandro et al. (2006)
Dysmicoccus boninsis (Kuwana)	Canna	–	Ben-Dov (1994)
Dysmicoccus mackenziei Beardsley	Heliconia	Neotropical region	Ben-Dov (1994)
Exallomochlus hispidus (Morrison)	Hibiscus	Malaysia	Williams (2004)
Ferrisia virgata (Cockerell)	Ornamentals	Philippines	Lapis (1970)
	Bauhinia purpurea	India	Mani (2008)
	Sida rhombifolia	India	Kumar and Sheela (2002)
	Croton, *Dracaena*	–	http://www.plantwise.org/KnowledgeBank/Datasheet.aspx?dsid=23981
	Ixora	India	Williams (2004)
	Acalypha bicolor, Codiaeum variegatum & Nerium	India	Vijay and Suresh (2013); Ben-Dov (1994); Suresh and Mohanasundaram (1996)
	Croton, Dracaena	–	http://www.plantwise.org/KnowledgeBank/Datasheet.aspx?dsid=23981
	Durantha	India	Sakthivel et al. (2012)
	Acalypha bicolor	India	Vijay and Suresh (2013)
Ferrisia virgata (Cockerell)	Hibiscus, Crotons & Gladiolus	–	Ben-Dov (1994)
		India	Williams (2004)
Geococcus coffeae Green	Nerium, Canna	–	Ben-Dov (1994)
	Coleus	India	Williams (2004)
	Canna	Malaysia	Williams (2004)
Heliococcus danzigae Bazarov	Rose	Palaearctic region	Ben-Dov (1994)
Hypogeococcus barbarae Rau	Aster	New York	Ben-Dov (1994)
Hypogeococcus pungens Granara de Willink	Cacti	Puerto Rico, Caribbean and Mexico	Helmuth et al. (2010)

Lankacoccus ornatus (Green)	Jasmine	India	Williams (2004)
Maconellicoccus hirsutus (Green)	Ornamental plants	Caribbean islands	Matile-Ferrero and Etienne (1996)
	Alpinia purpurata, Allamanda cathartica	Caribbean islands	Etienne et al. (1998)
	Ornamental plants	Mexico	Gonzalez-Gaona et al. (2010)
	Ornamental trees	California	Castle and Prabhaker (2011)
	Nerium, *Acalypha*, *Bauhinia*, *Cassia* & *Clerodentron*	Egypt	Hall (1920)
	Allamanda, Angelica, Anthurium, Croton, Bougainvillea, lily, Heliconia, Ixora Hibiscus & oleander	Florida	http://entnemdept.ufl.edu/creatures/orn/mealybug/mealybug.htm
	Clitoria & Crotalaria,	–	Ben-Dov (1994)
	Clerodendron & Hibiscus	India	Williams (2004)
	Hibiscus	Indonesia, Malaysia, Philippines & Thailand	Williams (2004)
Nipaecoccus filamentosus (Cockerell)	Clerodendron	–	Ben-Dov (1994)
Nipaecoccus nipae (Makell)	Canna & Redginger	–	Ben-Dov (1994)
Nipaecoccus viridis (Newstead)	*Nerium oleander*	India	David and Ananthakrishnan (2004)
	Alcea rosea, Asparagus, *Clerodendrum, Euphorbia & Nerium*	–	http://www.plantwise.org/KnowledgeBank/Datasheet.aspx?dsid=36335
	Clerodendron	Malaysia	Williams (2004)
Palmicultor lumpurensis (Takahashi)	Ornamental bamboo	Florida	Hodges and Hodges (2004)
Paracoccus burnerae (Brain)	Hibiscus	Ethiopian region	Ben-Dov (1994)

(continued)

Table 55.1 (continued)

Mealybug species	Host plant	Region/country	Reference
Paracoccus kajiadoensis (De Lotto)	Crotons	Kenya	Ben-Dov (1994)
Paracoccus marginatus Williams and Granara de Willink	Amaranthus, Allamanda, Nerium, Plumeria, Anthurium, Tagetes, Zinnia, Tecoma, Codiaeum, Jatropha & Michelia	India	Chellappan et al. (2013)
	Adiantum, Caesalpinia, Codiaeum, Euphorbia, Hibiscus, Plumeria, Taberbaemontana, Vinca, Crossandra	India	Selvaraju and Sakthivel (2011)
	Plumeria, Acalypha, Codiaeum, Jatropha, Euphorbia, Nerium, Allamanda, Cassia, Hibiscus, Malvaviscus, Lagerstroemia & Plumbago	Ghana	Cham et al. (2011)
	Hibiscus	Florida	Walker et al. (2003); Miller and Miller (2002)
		Sri Lanka	Galanihe et al. (2010)
		Malaysia	Mastoi et al. (2011)
		Puerto Rico	Pantoja et al. (2007)
		Indonesia	Muniappan et al. (2008)
		Hawaii	Ronald et al. (2007)
		Palau	Muniappan et al. (2006)
		Indonesia	Muniappan et al. (2008)
		Guam	Meyerdirk et al. (2004)
	Durantha plumeri	India	Sakthivel et al. (2012)
Paraputo jasmini (De Lotto)	Jasmine	Kenya	Ben-Dov (1994)
Peliococcus manifectus Borchsenius	Chrysanthemum	Italy, Sweden	Ben-Dov (1994)

Phenacoccus artemisiae Ehrhorn	Lotus	California	Ben-Dov (1994)
Phenacoccus asteri Borchsenius	Aster	Taiwan	Ben-Dov (1994)
Phenacoccus madeirensis Green	Hibiscus, Acalypha, Tagetes & Codiaeum	India	Vijay and Suresh (2013)
	Hibiscus	–	Ben-Dov (1994)
	Chrysanthemum	USA	Chong et al. (2003)
	Alcea rosea	Mauritius	Williams and Matile-Ferrero (2008)
	Acalypha & Hibiscus	Nigeria	Akintola and Ande (2009)
	Acalypha bicolor	India	Vijay and Suresh (2013)
	Gerberra, crotons, Aster	–	Ben-Dov (1994)
Phenacoccus manihoti Matile-Ferrero	Ornamental rubber & *Manihot glaziovii*	Nigeria	Iheagwam (1981)
	Hibiscus	China	Wu et al. (2010)
Phenacoccus avenae Borchsenius	Ornamental bulbs	Netherlands	Hofker et al. (1991)
Phenacoccus defectus Ferris	*Echeveria* spp.	Britain	Malumphy (1997)
Phenacoccus madeirensis Green	*Cestrum nocturnum*	India	Shylesa and Sunil Joshi (2012)
Phenacoccus parvus Morrison	Clerodendron	–	Ben-Dov (1994)
	Cestrum diurnum	Florida	Williams and Hamon (1994)
	Chrysanthemum	India	Williams (2004)
Phenacoccus pumilus Kritshenko	Dianthus	–	Ben-Dov (1994)
Phenacoccus salviacus Moghaddam	*Atraphaxis* sp.	Iran	Moghaddam and Alikhani (2010)

(continued)

Table 55.1 (continued)

Mealybug species	Host plant	Region/country	Reference
Phenacoccus solani Ferris	*Hibiscus rosasinensis*	India	Vijay and Suresh (2013)
	Ornamentals	Florida	Hamlen (1975)
	Durantha	India	Selvaraju and Sakthivel (2011)
	Aster	–	Ben-Dov (1994)
Phenacoccus solenopsis Tinsley	Nerium, Chrysanthemum, Helianthus, Tagetes, Euphorbia, Croton, Asparagus, Hibiscus, Clerodendron, Duranta, Althaea, Celosia, Rose Crossandra, Salvia Gomphrena, Acalypha, Codiaeum, Lawsonia & Bougainvillea	India	Vijay and Suresh (2013); Nagrare et al. (2009); Saini et al. (2009); Vennila et al. (2012)
	Celosia, Polyalthia, Tabernaemontana, Calendula, Aphelandra, Nerium, Plumeria, Chrysanthemum, Tagetes, Tecoma, Cassia, Quisqualis, Setcreasia, Ipomoea cairica, Acalypha, Croton, Lagerstroemia, Hibiscus, Malvaviscus, Bougainvillea, Jasmine, Rose, Gardenia, Hamelia, Cestrum, Clerodendron & Duranta	Pakistan	Arif et al. (2009)
	Acalypha & Hibiscus	Nigeria	Akintola and Ande (2009)
Planococcoides nijalensis (Laing)	Clerodendron	–	Ben-Dov (1994)

Planococcus citri (Risso)	Coleus & Philodendron	Texas	Chandler (1980)
	Greenhouse ornamentals	Bulgaria	Tsalev (1970)
	Kalanchos blossfeldiana	Shanghai	Tang et al.(1992)
	Coleus	California	Laflin et al.(2004)
	Glasshouse ornamentals	Poland	Labanowski (2009)
	Alpinia purpurata	–	Hara et al.(1997)
	Codiaeum & Gardenia	Bangladesh	Ullah and Parveen (1993)
	Rose	–	Laflin and Parrella (2004)
	Nerium,Philodendron, Stephanitis, Canna, Acalypha, Crotons, Bogainvillea & Jasmine	–	Ben-Dov (1994)
	Clerodendron	Thailand, Vietnam	Williams (2004)
	Ixora	India	Williams (2004)
Planococcus ficus (Signoret)	Ornamentals	Bulgaria	Pencheva and Gerasimova (2006)
Planococcus furcisetosus Mamet	Nerium	–	Ben-Dov (1994)
Planococcus japonicus Cox	Rhododendron	–	Ben-Dov (1994)
Planococcus kraunhiae (Kuwana)	Nerium	Taiwan, China & Japan	Ben-Dov (1994)
Planococcus lilacinus (Cockrell)	Rhododendron	–	Ben-Dov (1994)
	Gladiolus	India	Williams (2004)
Planococcus minor (Maskell)	Acalypha, Red ginger	–	Ben-Dov (1994)
	Crotons, Canna, Plumeria	India	Williams (2004)
	Clerodendron	Malaysia & Thailand	Williams (2004)
Planococcus vovae (Nasonov)	*Juniperus communis*	Poland	Golan and Jaskiewicz (2002)

(continued)

Table 55.1 (continued)

Mealybug species	Host plant	Region/country	Reference
Polystomophora arakensis Moghaddam	*Atraphaxis* sp. and *P. salviacus*	Iran	Moghaddam and Alikhani (2010)
Pseudococcus adonidum (L.)	Greenhouse ornamentals	Bulgaria	Tsalev (1970)
Pseudococcus calceolariae (Green).	Ornamentals	Bulgaria	Pencheva and Gerasimova (2006)
	Nerium, Rhododendron & Rose	–	Ben-Dov (1993)
Pseudococcus comstocki (Kuwana)	*Clivia miniata*	Beijing	Dong (1993)
	Ornamental trees	Korea	Kwon GiMyon et al. (2002)
	Syringa	China	Cheng Hong and Yan ShanChum (2011)
	Rhododendron	–	Ben-Dov (1994)
Pseudococcus sp.	Ornamental palms	Cuba	Rivero Aragon et al. (2000)
Pseudococcus cryptus Hempel	Pistacia & Nerium	Israel	Ben-Dov (1993)
	Crotons	Philippines	Williams (2004)
	Dendrobium	Singapore	Williams (2004)
Pseudococcus jackbeardsley Gimpel and Miller	Nerium, Jasmine, Cordyline, *Streptocarpus,* Jasmine & Chrysanthemum	India	Shylesha (2013); Mani et al. (2013)
	Aglaonema, Hibiscus, Dieffenbachia, Red ginger	Hawaii	Beardsley (1986)

Pseudococcus longispinus (Targ)	*Draceana* sp.	–	Mari et al. (2007)
	Ornamental plants	Alexandria	El-Minshawy et al. (1974)
	Ornamentals	Florida	Hamlen (1975)
	Ornamental species	Israel	Wysoki et al (1977)
	Polyscias, Pachira, *Dracaena*	Korean Peninsula	Kwon GiMyon et al. (2002)
	Glasshouse ornamental potted plants	Poland	Labanowski (2009)
	Cycad & Phormium tenax	California, USA	Laflin et al. (2004)
	Ornamental plants	Craiova	Tuca et al. (2010)
	Jasmine	Sri Lanka	Williams (2004)
	Nerium, Plumeria	Malaysia	Williams (2004)
	Hibiscus	–	Ben-Dov (1994)
Pseudococcus neomaritimus Beardsley	Hibiscus, Crotalaria, Acalypha	Kirbati & Marshall islands	Ben-Dov (1994)
Pseudococcus maritimus (Ehrh.)	Greenhouse ornamentals	Bulgaria	Tsalev (1970)
	Howeia forsteriana	Hungary	Ordogh and Takacs (1983)
	Glasshouse ornamentals	Poland	Labanowski (2009)
	Gladiolus	Brazil	Paiva et al. (2005)
Pseudococcus occidus De Lotto	Nerium	Ethiopian	Ben-Dov (1994)
Pseudococcus orchidicola Takshashi	Heliconia	New Zealand and Pacific region	Ben-Dov(1994)
Pseudococcus viburni (Signoret)	Pittosporum, Hoya carnosa	Italy	Tranfaglia (1972/73)
	Plant families (especially Liliaceae and Iridaceae)	California, USA	Laflin et al. (2004)
	Jasmine	–	Ben-Dov (1994)
Pseudococcus trukensis Bearsley	Hibiscus	Caroline islands	Ben-Dov (1994)

(continued)

Table 55.1 (continued)

Mealybug species	Host plant	Region/country	Reference
Puto barberi (Cockerell)	Woody ornamental plants	Las Palmas and El Faro, Gran Canaria & Spain	Malumphy (2010)
	Acalypha, Croton, Coleus	Neotropical	Ben-Dov (1994)
Rastrococcus iceryoides Green	Plumeria, Croton, Euphorbia, Caesalpinia	–	Ben-Dov (1994)
	Euphorbia, Leucas	India	Vijay and Suresh (2013)
	Cycas sp.	–	Ben-Dov (1994)
	Hibiscus, Crotons, Rose & Cassia	India	Williams (2004)
	Hibiscus, Crotons	Malaysia	Williams (2004)
Rastrococcus invadens Williams	Nerium, Plumeria, Roses	Nigeria	Ivbijaro et al. (1992)
	Acalypha hispida	Nigeria	Akintola and Ande (2006)
	Heliconia, Ixora	–	Ben-Dov (1994)
Rastrococcus spinosus (Robinson)	Plumeria	Malaysia	Williams (2004)
Rastrococcus vicorum Williams & Watson	Plumeria	Malaysia	Williams (2004)
Rhizoecus americanus (Hambleton)	Chrysanthemum & Hibiscus	Nearctic, neotropicalaearctic region	Ben-Dov (1994)
Rhizoecus arabicus Hambleton	*Gasteranthus atratus*	Florida	Hamon (1982)
Rhizoecus dianthi Green	African violet & Chrysanthemum	California and other countries	Ben-Dov (1994)
Rhizoecus falcifer Kunckel d Herculais	Aralia, stephanis, chrysanthemum, lotus, hibiscus & Jasmine	–	Ben-Dov (1994)
Rhizoecus hawaiiensis (Hambleton)	Coleus	Hawaii	Ben-Dov (1994)

Rhizoecus hibisci Kawai & Takagi	Cryptanthus	Florida	Anonymous (1978)
	Cuphea, Hibiscus, Pelargonium	Japan	Anonymous (1978)
	Hibiscus rosa-sinensis	Tokyo	Kawai and Takagi (1971)
		Florida	Anonymous (1979)
	Nerium, hibiscus	Puerto Rico, Japan	Ben-Dov (1994)
Rhizoecus kondonis Kuwana	Nerium, Chrysanthemum,	California, Japan &China	Ben-Dov (1994)
Spilococcus leucopogi (Brittin)	Ornamental plants	Bulgaria	Pencheva and Gerasimova (2006)
Spilococcus eriogoni (Ehrhorni)	Asparagus	California, Mexico	Ben-Dov (1994)
Spilococcus mamillariae (Bouche)	Ornamentals	Many countries	Ben-Dov (1994)
Spilococcus pressus Ferris	Nerium &Aster	California	Ben-Dov (1994)
Vryburgia amaryllidis (Bouche)	Plant families (Liliaceae and Iridaceae)	California & USA	Laflin et al. (2004)
	Ornamental plants	Bulgaria	Pencheva and Gerasimova (2006)
Vryburgia bechuanae (Brain)	Geranium	South Africa	Ben-Dov (1994)
Vryburgia brevicruris (McKenzie)	Asclepiadaceae and other succulents	Belgium	Ronse and Matile-Ferrero (1991)

Hibiscus shrub heavily infested

M. hirsutus on hibiscus

Various developmental stages of *M. hirsutus*

(Courtesy: Dale Meyerdirk, APHIS)

Maconellicoccus hirsutus was known to attack several ornamental crops in the Mariana Islands. The predator *C. montrouzieri* supplemented *Anagyrus kamali* and *Allotropa mecrida* sp. in maintaining population density of *M. hirsutus* below the economic threshold at all locations (Reddy et al. 2009). After field releases of *C. montrouzieri* in May and July 1996 for control of *M. hirsutus* on ornamental hibiscus in Port of Spain, Trinidad, the mealybug population fluctuated from 8 to 20 weeks, continuing, at a decreasing levels. The population of *C. montrouzieri* declined for the first 2 weeks, and then increased to a peak of 6 weeks after release. The predator population declined at about the same time as the pest (McComie et al. 1997). In India, *Spalgis epeus* Westwood is the common natural enemy found on mealybugs infesting hibiscus. *Cryptolaemus montrouzieri*, when released @ 20 grubs/plant, reduced mealybug populations from 84.3/plant in March to 0.9/plant in May (Mani and Krishnamoorthy 2008).

Biocontrol agents for *M. hirsutus*

C. mountrouzieri

Anagyrus kamali

According to Lai Yi-Chun and Chang Niann-Tai (2007), all *C. montrouzieri* introduced were killed and removed in 132.5 min by ants particularly *Pheidole megacephala* (Fabricius) and *Tapinoma elanocephalum* (Fabricius) in Taiwan. In Queensland, Australia *C. montrouzieri* was recovered on *M. hirsutus* infesting *Hibiscus rosa-sinensis* (Goolsby et al. 2002). Since its accidental introduction into the island of Grenada in 1994, *A. kamali* and *C. montrouzieri* were highly effective in bringing PHMB populations under control (Sagarra and Peterkin 1999).

Invasion by *M. hirsutus* in Puerto Rico could be restricted to less economic impact due to the timely introduction of *A. kamali* and *Gyranusoidea indica* (Michaud and Evans 2000). Efforts were made in 1922 to control *M. hirsutus* on ornamentals with *Cryptolaemus montrouzieri* introduced from France (Hall 1927). *M. hirsutus* was found on ornamental hibiscus in Egypt in 2000–2001. Among several parasitoids recovered from PHMB, a gregarious parasitoid, *Allotropa mecrida* was by far the most abundant parasitoid attacking PHMB in Egypt. Primary parasitoids made up 94.9 % of the total parasitoids emerging while 5.1 % were secondary (Gonzalez et al. 2003).

55.1.2 *Planococcus citri*

Planococcus citri causes severe damage to *Hibiscus rosasinensis*. *Cryptolaemus montrouzieri* was effective for the management of this mealybug in India (Mani et al. 2011).

55.1.3 *Coccidohystrix insolita*

Coccidohystrix insolita was recorded on *H. rosa-sinensis* (Suresh and Mohanasundaram 1996 and Williams 2004). Mealybug population declined from 145.6/plant in February to 0.6/plant in April 2003. There was 99.6 % reduction in the population of *C. insolita* within 60 days of appearance of the laycaenid predator, *S. epeus* (Mani and Krishnamoorthy 2008). *Cryptolaemus mountrouzieri* was also found effective against this mealybug on hibiscus (Mani 2008).

55.1.4 *Phenacoccus solenopsis*

Phenacoccus solenopsis causes devastating damage on *H. rosa-sinensis* (Babasaheb 2012). *Hibiscus syriacus* was one of the most preferred hosts for *P. solenopsis* (Dhawan et al. 2010). A mean infestation of 96.4 % was reported in Pakistan by Abbas et al. (2010).

According to Arve et al. (2011), the population of *P. solenopsis* on hibiscus was observed throughout the year with its peak activity from first fortnight of October to first fortnight of December. The nymphs and adult female mealybugs were preyed by two predators *Spalgis epeus* (Westwood) and *Scymnus coccivora* (Ayyar 1963). *Cryptolaemus montrouzieri* gave excellent control of *P. solenopsis* on Hibiscus after 4 months of release in 2007 at Pune, India (Mani 2008). *Aenasius bambawalei* Hayat was found parasitizing the *Ph. solenopsis* on hibiscus in Bangalore North. *Hibiscus rosa-sinensis* L. was found seriously infested with *Phenacoccus solenopsis* in Guangzhou, Guangdong Province, China (Wu and Zhang 2009) and Iran (Moghaddam and Bagheri 2010).

Pl. citri

Ph. solenopsis

C. insolita

Ph. madeirensis

55.1.5 *Paracoccus marginatus*

Acerophagus papayae (Noyes and Schauff) is found very useful to control *P. marginatus* on several crops including Hibiscus (Shylesha et al. 2011).

55.2 Coleus

Planococcus citri was known to damage ornamental coleus (*Solenostemon scutellarioides* = *Coleus blumei* (Bentham) (Ghorbanian et al. 2011). Yang JinSong and Sadof (1995) reported that nymphs of *P. citri* developed most rapidly and adult females produced more eggs on red-variegated plants as compared with green counterparts. Yang JinSong and Sadof (1997) indicated that population growth rates (r_m) of the parasitoid *Leptomastix dactylopii* How. (a parasitoid of *P. citri*) were higher on red-variegated and green-plants than on yellow-variegated plants (*Solenostemon scutellarioides*). Cloyd and Sadof (2000) reported higher attack of the parasitoid on caged plants as the number of citrus mealy bugs increased. Hogendorp et al. (2006) reported the greatest egg loads, were larger in size, and had the shortest developmental times in citrus mealy bugs receiving the high nitrogen fertilizer concentrations (200 and 400 ppm). Hogendorp et al. (2009) indicated that applying silicon-based fertilizers, like potassium silicate had no effect on the population of *P. citri* infesting coleus. *Cryptolaemus montrouzieri* was used to control the mealybug *P. citri* on coleus (Garcia and O'Neil 2000). *Planococcus citri* on *Coleus blumei* was reduced or eliminated by two applications of Temik granules at 0.005 g a.i./pot giving complete control. Acephate at 150 ppm as a single soil drench gave good results, and was easy to apply (Lindquist 1979). *Coccidohystrix insolita* was recorded on *Coleus aromaticus* and *C. variegatum* (Suresh and Mohanasundaram 1996; Williams 2004).

55.3 China Aster

Phenacoccus parvus Morrison was recorded feeding mainly on collar region and subterranean plant parts. About 25 % of the plants were infested making the plant stunted without bearing flowers (Sridhar et al. 2012). *Phenacoccus parvus* Morrison was identified for the first time in Australia after it was found causing severe damage to Lantana at Gatton, Queensland, in the winter of 1988; it must have spread quite rapidly in the summer of 1988–1989 and is now widespread throughout the Lockyer Valley (Campbell 1990).

55.4 Chrysanthemum

The Madeira mealybug, *Ph. madeirensis,* has become an increasingly damaging pest on chrysanthemum (*Dendranthema grandiflorum*) (Chong et al. 2003). *Phenacoccus parvus* incidence on chrysanthemum was recorded from Orissa (Williams 2004). *Pseudococcus jackbeardsleyi* Gimpel and Miller was also reported on chrysanthemum in India (Shylesha 2013).

Ph. madeirensis

Ph. solenopsis parasitized by *Aenasius bambawalei*

55.5 Poinsettia

Striped mealybug *Ferrisia virgata* (Ckll.) is the major mealy bug infesting *Poinsettia* (*Euphorbia*) *pulcherrima*. The plants of poinsettia were completely cleared of this mealybug with release of *C. montrouzieri* (Mani et al. 2011).

55.6 Caladiums

Ferrisia virgata is the major pest on Caladiums. Mealybugs on foliage were controlled best by four sprays at weekly intervals by permethrin or oxamyl. Diflubenzuron was also found to be effective against *F. virgata*. Permethrin provided the most effective control of the mealybugs 21 days after dip treatment of tubers of Caladiums (Price 1979).

55.7 Clerodendron

Planococcus citri is the common mealy bug on *Clerodendron phillippinum* (Mani and Krishnamoorthy 2003). *Leptomastix dactylopii* (How.) is an effective parasite that can be utilized to control this mealybug.

Mealybugs on Rose

Poinsettia with *F. virgata*

Clerodendron with *P. citri*

55.8 Dieffenbachia

Planococcus citri is the major pest on Dieffenbachia. Diazinon, oxamyl, malathion, acephate and butocarboxim were found highly effective in controlling *P. citri* on potted plants of *Dieffenbachia exotica* (Chandler 1980). Three applications over 4 weeks of Enstar 5E [kinoprene] at 8 or 16 oz/100 gal and Zoecon Houseplant Mist (Enstar + resmethrin) at the recommended rate reduced the number of citrus mealybugs (*P. citri*) on *Dieffenbachia* sp. from initial populations of 304–329/plant to 6.2, 0 and 13/plant, respectively, 5 weeks after the first application (Lindquist 1981).

55.9 Schefflera

Four applications over 3 weeks of Enstar 5E at 8 or 16 oz/100 gal and Zoecon Houseplant Mist at the recommended rate, Safer's Insecticidal Soap at 400 oz/100 gal and Murphy's Oil Soap (a non-insecticide preparation) at 800 oz/100 gal reduced the number of citrus mealybugs on *Schefflera* sp. from 139–261/plant to 3.8, 3.8, 4, 5.5 and 13.2/plant, respectively, 4 weeks after the first application (Lindquist 1981).

55.10 Gladiolus

Damage by *F. virgata* begins in the field on underground corms during dry conditions and carries on to storage. Nymphs and adults damage corms by sucking the sap causing shrivelling and drying of affected corms. Prompt collection and destruction of infested parts reduces spread of the pest. Crawling of ants on plants is the sign of beginning of mealy bug infestation. Spraying should be taken up at this stage. Sprays of methyl parathion 0.04 % or dimethoate 0.04 % or acephate 0.1 % at 15 days interval effectively controls mealybug infestation (Jhansi Rani 2001). *Pseudococcus maritimus* (Ehrhorn) and *Dysmicoccus* sp. are also known to attack gladiolus.

55.11 Saxifrages

Pseudococcus vibruni (Pseudococcus obscures) (Essig) is known to infest *Saxifraga longifolia*. The ability of this mealybug to reproduce at low temperatures constitutes a serious threat to growers of saxifrages. Exposed colonies can be removed by hand or sprayed with malathion or nicotine, while concentrated colonies are best controlled with a systemic insecticides such as dimethoate or formothion (Southgate 1974).

55.12 Jasmine

The pseudococcid, *Rastrococcus iceryoides* (Green) was observed in Bangalore infesting leaves of *Jasminum rigidum*. The lycaenid *Spalgis epeus* was observed feeding voraciously on *R. iceryoides* (Vasundhara et al. 1990). *Pseudococcus longispinus* (Targioni Tozzetti) was recorded in severe form on Jasminum sambac in India (Mani et al. 2011). Heavy populations of *Lankacoccus ornatus* (Green) have been reported as covering the leaves of *Jasminum* sp. in India. *Ferrisia virgata* and *Phenacoccus ornatus* were also reported on Jasmine (David and Ananthakrishnan 2004).

Jasmine with *P. longispinus*

Tube rose with *F. virgata*

P. minor on crotons

55.13 Tube Rose

Mealybugs particularly *Ferrisia virgata* and *Planococcus citri* have become increasing threat to tube rose cultivation in India (Mani and Krishnamoorthy 2007a; Shanthi et al. 2008). Following the release of *C. montrouzieri*, the mealybug population declined from 190 to 108/plant within 20 days during July–August 2002. On 30th and 40th day of release, the mealy bug population was further reduced to 50.45/plant and 4.87/plant, respectively. The plants were completely cleared of the mealy bugs with about 50 days after the release of the predator (Mani and Krishnamoorthy 2007a). *Dysmicoccus neobrevipes* (Cockerell) is known to attack severely the roots of tube rose in Bangalore North, India.

F. virgata on tube rose

Ph. madeirensis on Jasmine

55.14 Crossandra

Planococcus citri was observed infesting *Crossandra undulifolia* in India (Mani and Krishnamoorthy 2007b). The mealybugs suck the sap from leaves, stem, tender spikes, spikelets and developing buds. Heavy mealy bug infestation was observed on lower surface of leaves and inside the spikelets and they excrete honeydew leading to the development of sooty mould interfering with the photosynthetic activity of the plants. Following the release of *C. montrouzieri*, the plants were almost cleared of the mealy bugs by about 3 months in India (Mani and Krishnamoorthy 2007a).

Ph. madeirensis on crossandra

Ph. solenopsis on gerbera

Ps. jackbeardsley on Epipremnum

55.15 Crotons

Citrus mealybug, *Planococcus citri* is the major mealybug on crotons (*Codiaeum variegatum*). In 1952, *Cryptolaemus montrouzieri* was released along with some parasitoids for the management of this mealybug. The predator has survived for several generations but could not become permanently established (Bennett and Hughes 1959). *C. montrouzieri* was used to control *P. citri* on the crotons *Codiaeum variegatum* at Giza governorate, Egypt. After 3 months of releasing the predator, reduction rates reached to 100 % for all stages of the pest. The local natural enemies *Sympherobius amicus* Navas, *Scymnus syriacus* (Mars.) and *Chrysoperla carnea* (Stephens) and *Coccidoxenoides permintus* (Timberlake) were found feeding on *P. citri* infesting croton shrubs (Afifi et al. 2010). Crotons are also known to be severely damaged by several mealybugs in India. *Planocoocus minor* (Maskell) is a major pest on it. *C. montrouzieri* is effective to control the mealy bugs on crotons (Mani 2008). *Rastrococcus invadens* in Nigeria (Ivbijaro et al. 1992) and *Maconellicoccus hirsutus* in India (Manjunath et al. 1992) are also known to attack crotons.

Pa. marginatus on plumeria

Ph. madeirensis on acalypha

Pa. marginatus on acalypha

55.16 Acalypha

Striped mealy bug, *Ferrisia virgata* is the major mealybug species attacking *Acalypha macrophylla*. The coccinellid predator, *Cryptolaemus montrouzieri,* was used to control this pest in Giza region, Egypt and other places. The optimum release rate was 10 *Cryptolaemus* adults/shrub of Acalypha. The percentage of reduction of *F. virgata* reached 95.39 % (Attia and El-Arnaouty 2007). The coccinellid predator, when released at 20 larvae/plant, was found highly effective in clearing the mealy bug *F. virgata* and also *C. insolita* on acalypha within 2 months of its release in India (Mani 2008). At Sindh Agriculture University Tando Jam, the population of the longtailed *Ps. lonispinus* on *Acalypha* was negatively correlated with temperature. Top leaves of all these plants were preferred by mealybugs (Mari et al. 2007).

55.17 Heliconia

Dysmicoccus brevipes was recorded on *Heliconia* (Ben-Dov 1994). The aerial individuals are to be found mostly at the base of the leaves, which may have to be spread in order to make the bug's evidence. Maximum population of mealybug was noticed during hot climatic conditions and in plains, while hilly region and low temperature with high humid areas the pest incidence was very minimum. Severe infestation of *Planococcus citri* was found on *Heliconia* under nethouse conditions in India.

Ps. jackbeardsley
on chrysanthemum

F. virgata on Acalypha

Madeira mealybug
on Bromeliads

55.18 Clivia

Comstock mealy bug, *Pseudococcus comstocki* (Kuwana), is the major species infesting this bulbous ornamental *Clivia miniata.* In Beijing, *C. montrouzieri* was released on *Clivia miniata* to control this mealybug and there was 92 % reduction in numbers of *P. comstocki* per leaf (Dong 1993).

55.19 Oranamental Citrus

Citrus mealybug, *Planococcus citri,* a major mealybug pest on ornamental citrus was found feeding sporadically by *Cryptolaemus montrouzieri* in central Italy (Del Bene and Gargani 2006) and Netherlands (Hennekam et al. 1987).

55.20 Europrotea

Paracoccus marginatus infestations were managed by mass release of *C. montrouzieri* in Europrotea's plantation in Portugal (Leandro et al. 2006).

55.21 Bromeliad

Mealybugs are found devastating to bromeliads. They feed on the sap of bromeliads by puncturing the living tissues on leaves and roots causing significant damage to the plant. Mealybugs excrete a sticky substance called honeydew that is left behind on plant's surface. This sweet honeydew is highly desired by ants. Mealybug infestation, on bromeliad's leaves may begin to turn yellow and drop. The plant may experience distorted growth and the appearance of a black sooty mould may become present. If the infestation is small, use a cotton swab to swipe the mealybugs with Isopropyl Alcohol. It is also a good idea to wash the plant with a strong water spray to remove any residual eggs from the plants. Many outdoor pests are kept under control through the natural presence of predators. These soaps and oils are not toxic and work by suffocating the mealybugs. As a last resort, chemical insecticides can be used to remove a mealybug infestation.

55.22 Woody Ornamentals

Malumphy (2010) recorded *Puto barberi* (Cockerell) infesting woody ornamental plants from Spain and reviewed its host range, biology, geographical distribution and economic importance. *Pseudococcus calceolariae* (Maskell), a pest of ornamental woody plants, was first reported in Italy. Natural enemies *Cryptolaemus montrouzieri*, *Tetracnemoidea peregrina* (Compere), *Anagyrus fusciventris* (Girault) and *Tetracnemoidea brevicornis* (Girault) were considered for trials against *P. calceolariae*. Early instars can be controlled by means of light mineral oils combined with fenitrothion, methidathion or tetrachlorvinphos at low concentrations which do not affect parasitoids within the hosts, and affect the free-living stages of natural enemies (Laudonia and Viggiani 1986). Heavy predation by *Cryptolaemus montrouzieri* Muls. was observed on *Pseudococcus viburni* infesting *Cercis siliquastrum* in avenues in Turin (Arzone 1983).

55.23 Bougainvillea

Phenacoccus peruvianus Granara de Willink is native to South America (Argentina, Peru) and has been introduced to several countries including Almeria, Spain, France, Monaco and Spain, Portugal, the Balearic Islands, Corsica and Sicily. England Western Mediterranean on indoor plantings and on sheltered plants outdoors. It is commonly known as the bougainvillea mealybug because of its preference for this host. The mealybug populations damage the plants by causing necrosis of the foliage, leaf loss and die back. Being polyphagous, it also occurs on other woody ornamentals. They can move relatively quickly, or at least more quickly than most mealybugs encountered in Britain. Adult and nymph bougainvillea mealybugs mainly feed on the lower surfaces of the foliage, but are also found on the growing shoots, bark, and occasionally the upper leaf surfaces. It is advisable to check plants for pests such as mealybugs before purchase and before introducing them into a greenhouse or conservatory. Cultural control of bougainvillea mealybug can be achieved by removing and carefully disposing infested leaves and stems. The larvae of *Cryptolaemus* are available to gardeners and professional growers for the biological control of mealybugs. They are most effective in summer and need temperatures of at least 20 °C for a few hours a day. For chemical control, systemic insecticides can be used. For ornamental plants in greenhouses or conservatories, gardeners can use products containing thiacloprid, acetamiprid, thiamethoxam or imidacloprid (http://www.fera.defra.gov.uk/plants/publications/ documents/factsheets/bougainvillea.pdf).

55.24 Araucaria

Araucaria, gliricidia and several other trees grown in parks and avenues in Bangalore (India) have been found infested with the mealybug *Planococcus citri* (Risso). *C. montrouzieri* was the principal predator becoming abundant in April-May and October-November on these plants. In some cases up to 12,000 larvae of Cryptolaemus were encountered per tree. In such cases, though belated, they completely controlled the mealybugs (Manjunath 1986).

55.25 Sago Palm

Sago palms aren't palm trees at all—these attractive, low-growing plants are actually cycads. Sago palms are compact evergreen plants that make an attractive addition to home interiors. The plants are prone to mealybug infestations. Mealybugs are small, oval insects that use their sharp mouthparts to feed on the sap from sago palm foliage. Severe infestations can cause discoloured foliage, irregular growth and plant death. Mealybugs are easy to kill on sago palms with the proper treatment. In Bermuda, *C. montrouzieri* was liberated on sage palm infested with *Pseudococcus adonidum* (Linnaeus). Permanent establishment was not achieved, however despite the fact that small colonies survived for some months (Bennett and Hughes 1959). Inspect the foliage of sago palm carefully to identify where mealybugs are located on the plant. Soak a cotton swab in rubbing alcohol and rub the cotton swab over mealybugs on the infested palm to kill the bugs on contact. This treatment is effective for small numbers of mealybugs on a sago palm, but it is not practical to carry out when there are heavy infestations (http://www.ehow.com/how_12083815_kill-mealybugs-sago-palm.html).

55.26 Myoporum

In Morocco, *C. montrouzieri* was successful some times against *P. citri* on the hedge plant (Myoporum) but was effective against heavy infestations of *P. citri* when released in large numbers (Boughelier 1935).

55.27 MEALYBUG MANAGEMENT IN ORNAMENTALS

Chemical Control

- In Bulgaria, azinphos-methyl at 0.15 % and phenthoate at 0.08 % proved the most effective materials against the mealybugs. *Pseudococcus maritimus* (Ehrh.), *Ps. adonidum* (L.) and *Planococcus citri* (Risso) infesting ornamentals (Tsalev 1970).
- In Florida, acephate, oxydemeton-methyl and the insect growth regulator kinoprene were found highly toxic to *Pseudococcus longispinus* and *Phenacoccus solani* Ferris on ornamental plants. Overall reductions of *Rhizoecus floridanus* Hambleton by kinoprene and epofenonane were comparable to the insecticides acephate and oxamyl (Hamlen 1977).
- One application of ZR-777 (prop-2-ynyl 3, 7, 11-trimethyl-(2E,4E)-2, 4 dodecadienoate) at 1,000 ppm as foliar spray effectively reduces the mealybug populations on *Ardisia crispa*

(crenata) and *Gynura sarmentosa* (Hamlen 1975).

- Diazinon, oxamyl, malathion, acephate and butocarboxim all proved highly effective in controlling *Planococcus citri* on *Dieffenbachia exotica*, *Ficus benjamina*, *Coleus* sp. and *Philodendron cordatum* (Chandler 1980).
- This "cocktail" containing iminocloprid (growth regulator) + acephate (Systemic insecticide) was sprayed on an orchid and coleus heavily infested with mealybugs. Two months later, these plants were flourishing with no sign of mealybugs.
- Acephate (780 mg/litre) was found to reduce the populations of longtailed mealybug *Pseudococcus longispinus* to zero on *Asplenium bulbiferum* (hen and chicken fern), while imidacloprid reduced the infestation to 1–4 % fronds infested and mean of 0.5–2.5 mealybugs on the youngest infested frond (Martin and Workman 1999).
- In the Imperial Valley of California (USA), imidacloprid-treated and thiamethoxam-treated hibiscus plants were completely free of *Maconellicoccus hirsutus* (Castle and Prabhaker 2011).
- In Shanghai region 15 % aldicarb granules mixed in soil around the ornamental succulent *Kalanchos blossfeldiana* plant roots or 40 % omethoate 100x poured over the roots resulted in 97 % control or more of *Planococus citri* (Tang et al. 1992).
- In Poland, pirimiphos-methyl 50 EC and methidathion 40 EC are recommended to control *Planococcus vovae* (Nasonov) infesting common juniper, *Juniperus communis* (Golan and Jaskiewicz 2002).
- Horticultural oils kill all stages of the mealybugs that are present at application, and often give good control. Oil products labelled as summer, superior, or Volck oil are high grade and may be used on tolerant plants during either the growing or dormant seasons, but at different concentrations.
- Post-harvest dips in properly formulated oil-in-water emulsions of terpene oils such as limonene or essential oils such as peppermint oil or spearmint oil is advocated to control the mealybugs. Insecticidal soap containing 49.5 % potassium salts of fatty acids or TweenReg containing 100 % polysorbate 80 can be used to create aqueous, plant-safe emulsions of these oils that are effective in controlling waxy insect *Ps. longispinus*. When sodium lauryl sulfate and citric acid are included in the formulation, efficacy increases dramatically. Many types of ornamental plants tolerate these enhanced mixtures, which penetrate and kill mealybugs within seconds (Hollingsworth and Hamnett 2010).
- Using 1 % limonene (a citrus extract), 0.75 % APSA-80 and 0.1 % Silwet L-77, a semitransparent mixture (primarily a micro emulsion) was obtained that was safe for most plants and provided good control of mealybugs when sprayed or used in 1-min dips. Limonene has promise as a safe, natural pesticide for insect pests on tolerant plants. They caused no damage to ornamentals with thick, waxy leaves, such as palms, cycads, and orchids (Hollingsworth 2005).
- The mealybug *Phenacoccus solani* Ferris was effectively reduced with acephate and vydate on *Aphelandra squarrosa* (Hamlen 1977).

Biological Control

- Release the Australian ladybird beetle *Cryptolaemus montrouzieri* to control the mealy bugs on ornamentals in general (Mani and Krishnamoorthy 2003) and host specific parasitoids for the control of mealy bugs on ornamental crops.
- In a commercial greenhouse in Leiden, Netherlands, successful control of the pseudococcid *Planococcus citri* on Stephanotis plants was obtained with the coccinellid predators *Cryptolaemus montrouzieri* and *Nephus reunioni* (Fursch); and the encyrtid parasitoids *Leptomastix dactylopii* and *Leptomastidea abnormis* (Girault) during summer and autumn (Hennekam et al. 1987).
- Introduction of parasitoids *Leptomastidea abnormis* and *Leptomastix dactylopii* gave improved biological control of *Planococcus citri* in a large glasshouse stocked with a

variety of ornamental plants in the UK, supplementing that achieved by the coccinellid predator (Tingle and Copland 1988).

- *Leptomastix dactylopii* and *Leptomastidea abnormis* are used as biological control agents against *Planococcus citri* on ornamental plants in the greenhouse in the Netherlands (Alphen and van Xu 1990).
- The parasitoid *Anagyrus pseudococci* (Girault) is used to control *Planococcus citri* and *Pseudococcus affinis* (Maskell) on *Streptocarpus hybridus* or *Aeschynanthus ellipticus*. *Leptomastix dactylopii* was able to parasitize these mealybugs. *Cryptolaemus montrouzieri* gave good control of *Pseudococcus affinis* on *S. hybridus*, Citrus, Passiflora, potato and coffee, while *N. reunioni* gave good control on ornamental citrus but was less effective on *S. hybridus* (Copland et al. 1993).
- In the Southwest of Alentejo, releases of *Cryptolaemus montrouzieri* gave good control of mealybugs *Paracoccus* sp. and *Delottococcus* sp. infesting *Leucospermum* (Passarinho et al. 2006).
- Periodic releases of a green lacewing, *Chrysoperla rufilabris* (Burmeister) had reduced populations of the long-tailed mealybug, *Pseudococcus longispinus* (Targioni Tozzetti), infesting pothos ivy, *Epipremnum aureum* (Goolsby et al. 2000).

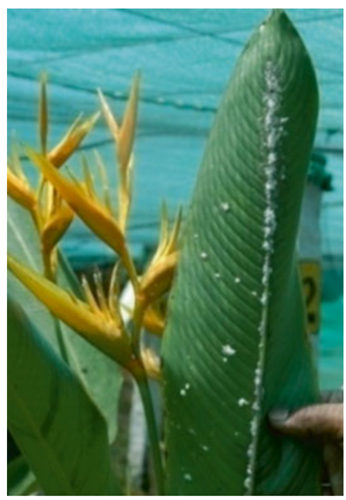
55.27.1 Pheromone-Based Management

Operational parameters of traps baited with the pheromones of three mealybug species namely *Ps. longispinus*, *Pl. citri* and *Ps. viburni* were optimized in nurseries producing ornamental plants. Traps Lures containing 25 microgram dose had effectiveness in the field for at least 12 week, were used to detect infestations of mealybugs season long and to track population changes in the field (Waterworth et al. 2011).

Ornamentals damaged by mealybugs

M. hirsutus on red ginger

P. lilacinus on Bhaunia



Pl. citri on Heliconia

Pl. citri on *Ixora* sp.

Ph. parvus on China Aster

F. virgata on *C. pulcherima*

Phenacoccus solenopsis on *Tagetes*

Ph. madierensis on *Tagetes*

Mealybugs on *Tithonia*

Ps. jackbearsley on nerium

F. virgata on nerium

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Orchids

56

N.K. Meena, R.P. Medhi, and M. Mani

56.1 Species

Mealybugs are serious pests of orchids (Table 56.1), and next to scale insects, they are probably the most difficult to control pests of orchids in homes and greenhouses. Nearly 300 species of mealybugs are known from Canada and the United States. Fortunately, only a few species are common or serious pests of orchid (Johnson 2014). The most important pest of this crop is the long-tailed mealybug *Pseudococcus longispinus* in California and Canada. In Hawaii, *P. longispinus* and *Dysmicoccus brevipes* are common on orchids (https://www.aos.org/Default.aspx id=511). The mealybugs problem are reported on many orchid species like *Cymbidium, Dendrobium, Cattleya, Calanthe, Phaius, Phalaenopsis, Pholidota*, etc., worldwide. Pineapple mealybug (*D.brevipes*), long-tailed mealybug (*P. longispinus*), jack beardsley mealybug (*Pseudococcus jackbeardsleyi*), obscure mealybug (*Pseudococcus viburni*), and orchid mealybugs (*Pseudococcus microcirculus* and *Pseudococcus dendrobiorum*) are the major species due to their occurrence in serious proportions in many parts of the world (Bronson 2009). Only *P. dendrobiorum* and *P. longispinus* are known to infest orchids in greenhouses of tropical and subtropical regions of India. In most of Canada and the United States, the long-tailed mealybug (*P. longispinus*) is probably the most common and problematic species on orchids, particularly in homes and greenhouses.

56.2 Nature of Damage

Mealybugs are not particular about their host, and probably all species of orchids are susceptible to mealybugs, especially when cultivated. The common mealybug species found attacking orchids are the citrus mealybug, *Planococcus citri,* and the long-tailed mealybug, *P. longispinus.* These sucking insects attack any part of the plant, but tend to stay tucked away at the junction of the leaf and stem. Severe infestations cause chlorotic areas to appear on the leaves, which may darken, causing the leaf to yellow and drop prematurely. After hatching, crawlers move to find suitable sites for feeding. They feed on the tender portions of the plants and also exude a white waxy substance on their body, which covers the entire body and gives a mealy appearance. Both nymphs and adults suck the sap from the attacked parts and resulted in loss of vigor and growth, shrinking of pseudobulbs, curling, wilting of plants, and also loss of leaves,

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Table 56.1 List of mealybugs reported on orchids in different regions

Mealybug species	Plants	Region/country	References
Crisicoccus orchidiradicis (Takahashi)	Orchids	Malaysia	Williams (2004)
Chryseococcus arecae (Maskell)	Dendrobium	New Zealand	Ben-Dov (1994)
Dysmicoccus orchidum sp.n	Dendrobium	India Thailand	Williams (2004)
	Phalaenopsis	Singapore, Indonesia	Williams (2004)
Hypogeococcus baharti (Miller)	Orchids	Mexico	Ben-Dov (1994)
Hypogeococcus gilli (Miller)	Orchids	Costa Rica	Ben-Dov (1994)
Hypogeococcus othnius (Miller &McKenie)	Orchids	Neotropical region	Ben-Dov (1994)
Hypogeococcus festerianus (Lizery Trelles)	Cactus	Australia, Italy	Ben-Dov (1994)
Hypogeococcus pungeans (Granara de Wilink)	Cactus	Neotropical region	Ben-Dov (1994)
Hypogeococcus spinosus (Ferris)	Cactus	Mexico, California, Japan	Ben-Dov (1994)
Maconellicoccus hirsutus (Green)	Orchids (*Laeliocattleya canhamiana alba*)	Caribbean islands	Gautam and Cooper (2003)
	Anthurium, Andraeanum, Dendrobium	–	http://manatee.ifas.ufl.edu/comm-hort/pdf/pest-topics/InsectPHMHosts.pdf
Paracoccus invectus sp.n	Orchids	Thailand	Ben-Dov (1994)
	Dendrobium	India	
Paracoccus interceptus (Lit.)	Dendrobium	India, The Philippines	Williams (2004)
Planococcus citri (Risso)	Orchids	Cuba	Diaz et al.(2004)
	Cacti	-	Ben-Dov (1994)
Planococcus dendrobii (Ezzat&Mc Connel)	Dendrobium	The Philippines, India, Thailand	Williams (2004)
Planococcus hasnyi (Ezzat&Mc Connel)	0rchids	South Africa	Ben-Dov (1994)
Planococcus minor (Maskell)	Anthurium	India	Williams (2004)
Planococcus hospitus (De lotto)	Orchids	Uganda	Ben-Dov (1994)

Mealybug species	Plants	Region/country	References
Planococcus phillipinensis (Ezzat&Mc Connel)	Orchids	The Philippines	Ben-Dov (1994)
Planococcus ovae (Nasanov)	Anthurium	Neotropical and Palaearctic region	Ben-Dov (1994)
Pseudococcus dendrobium (Williams)	Dendrobium	Australia,Indonesia	Ben-Dov (1994))
	Orchids	India	Williams (2004)
	Dendrobium	Indonesia	Williams (2004)
	Orchids	Malaysia	Williams (2004)
	Dendrobium	The Philippines	Williams (2004)
	Orchids	Sri Lanka	Williams (2004)
	Orchids	Korean Peninsula	Kwon GiMyon et al. (2002)
Pseudococcus jackbeardsley (Gimpel and Miller)	Dendrobium	Thailand	Williams (2004)
	Anthurium, Dracaena	Hawaii	Beardsley (1986)
Pseudococcus importatus (McKenzie)	Orchids	California	Ben-Dov (1994)
Pseudococcus microcirculus, *Ps. importatus*, *Ps. viburni*, *Dysmicoccus brevipes*, *Phenacoccus solani*	Orchids	California	https://www.aos.org/Default.aspx?id=511
Dysmicoccus brevipes (Cockerell), *Pseudococcus dendrobiorum*, *Pseudococcus jackbeardsley* (Gimpel and Miller) *Pseudococcus maritimus* (Ehrhorn)	Orchids	Hawaii	https://www.aos.org/Default.aspx?id=511
Pseudococcus dendrobiorum (Williams)	Cymbidium	India	–
Pseudococcus longispinus (Targioni Tozzetti)	Cattleya, Dendrobium, Bulbophyllum, Calanthe, Coelogyne, Phaius, Phalaenopsis, Oncidium	India	

(continued)

Table 56.1 (continued)

Mealybug species	Plants	Region/country	References
Pseudococcus microcirculus (McKenzie)	*Ansellia*, *Cattleya,* Oncidium	Northern Italy	Camporese and Scaltriti (1991).
	Orchids	California and Florida	Camporese and Scaltriti (1991)
Pseudococcus maritimus complex (*P. microcirculus* and *P. sorghiellus* (Forbes)	Orchids	The United States	Gimpel and Miller (1996)
Pseudococcus longispinus (Targioni Tozzetti)	Orchids Phalaenopsis	Germany	Lindemann and Richter (2007)
	Odontoglossum	France	Jullien (2009)
	Phalaenopsis	Taiwan	Yang (1997)
	Phalaenopsis	Indonesia	Williams (2004)
	Orchids	Canada and the United States	https://www.aos.org/Default.aspx?id=511
	Orchids	Cuba	Diaz et al.(2004)
Pseudococcus orchidicola Takshashi	Orchids	New Zealand and Pacific region	Ben-Dov (1994)

flower buds, flowers, and premature senescence. Such types of plants produce inferior quality flowers. In addition, mealybugs also produce honeydew, which makes the plant parts sticky, and provides a substrate for the development of sooty mould, which affects the rate of photosynthesis in plants. Some species of mealybugs play a role as vectors in the transmission of viral disease.

Mealybug damage to orchids

P. longispinus (Photo by Fowler)

Mealybug on *Dendrobium*

Ferrisia on orchids

Phalaenopsis with mealybug

Mealybug on *Angraecum*

Mealybug on *Cattleya*

Mealybug on *Lycaste*

Mealybug on *Cymbidium*

Mealybug on *Oncidium*

Mealybug infestation on Phaius flower bud

Mealybug on leaf sheath of *Phaius*

Mealybugon *Cattleya* leaf

All stages of the bug suck the sap from the plant parts and secrete honeydew. Sooty mould develops on the leaves in case of severe infestation. Attacked plants look withered, reduced in growth with chlorotic and deformed leaves. They prefer to live on roots deep in the media and are often only discovered when orchids are repotted, though they will also attack other parts of the plant, especially under the leaves. They will also hide in depressions on pots, in sheaths, and in newly emerging growths (http://www.bellaonline.com/articles/art66287.asp). Imported exotic plants are inspected to prevent the accidental introduction of mealybugs in Brazil (Camporese and Scaltriti 1991). The adult females and nymphs of *P. dendrobiorum* are known to infest leaves and roots of orchids in the greenhouses in the central part of the Korean Peninsula (Kwon GiMyon et al. 2002).

56.3 Seasonal Development

The orchids are generally grown in greenhouses or partially shaded net houses (under controlled conditions), wherein mealybug species are active in warm climate (temperature range 25–30 °C), but in cold climate, when temperature goes below 10 °C, these mealybug species become less active and hide in protected places, such as among roots, deep inside potting media, on pseudobulbs covering with scales, below leaf sheaths, and other tight places. In open field conditions, mealybugs are susceptible to a variety of natural enemies (predators and parasitoids), and weather factors (heavy rainfall, extremely high and low temperatures, wind velocity, etc.) help to keep the population low or below economic injury level.

56.4 Mode of Mealybug Spread

Orchids become infested with mealybugs in three different ways: purchase of infested planting material, movement from infested to uninfested plants, and windblown colonization. The occurrence of *P. microcirculus* is reported on the roots of orchids belonging to the genera Ansellia, Cattleya, and Oncidium in the greenhouses in northern Italy (Lombardy). The orchids involved had been recently imported from Brazil. With the entry of infested plants in an area where uninfested orchids are grown, juvenile mealybugs spread by crawling from one plant to another plant through operational tools, irrigating water, wind, pots, and potting media. Excess roots, dried leaves, pseudobulbs, and other wastage thrown during repotting in the nearby areas are other most important modes of transportation of mealybugs. Shifting of plants from one polyhouse to another polyhouse or from one place to another place also plays a role in the spreading of this pest. Sometimes, these mealybugs survive on unwanted plants (weeds), which provide suitable niche during unavailability of host or complete few stages of their life cycle during adverse conditions and then migrate on the orchids. Ants that are attracted by honeydew produced by mealybugs can also be spread by crawling from one plant to other plants.

56.5 Management

The common mealybug species found attacking orchids are the citrus mealybug, *Planococcus citri,* and the long-tailed mealybug, *P. longispinus*. Prompt collection and destruction of infested parts reduce the spread of the pest. It is very important to immediately start intervention as soon as these pests are spotted, or else, they might spread rapidly and could overtake the collection in a matter of weeks. If there are only a few mealybugs, a Q-tip dipped in isopropyl alcohol or toothbrush dipped in a pesticide solution can be used. For prevention of mealybugs, it is advised to remove old leaves and flower sheaths to eliminate the hiding places and allow easy inspection. New plants are to be checked carefully before adding them to the growing area. These mealybugs are yellow-coloured with a covering of white powdery wax. (https://www.aos.org/Default.aspx?id=511).

56.6 Insecticides

Persistent populations of mealybugs or infestation in many plants may demand the need for use of synthetic insecticides. There are several common, inexpensive, home-use andgarden-use pesticides labeled for ornamental plants. Insecticide formulations not labeled for ornamental plants are often mixed with solvents that aid in the application of the active ingredient for specific purposes. These solvents, not necessarily the insecticide itself, often produce phytotoxicity and may seriously damage or kill plants. Thus, any insecticide that is not specifically labeled for ornamental plants should never be used. Some of the more available and effective insecticides that come in various brand names are acephate, malathion, carbaryl, and diazinon. Pyrethrins and rotenone have limited effectiveness. Label directions should always be followed, and the minimum recommended concentration given in mixing directions should never be exceeded! Recommended solutions are based on extensive testing for selected pests and plants. Orchids are tough plants, but are sensitive to many chemicals, particularly under direct sunlight or high heat, and while certain species may not react to a given formulation, others may; so, testing is justifiable.

In case of severe infestation, uses of selective synthetic insecticides have great potential for mealybug management in orchids. Initially, two foliar sprays of chlorpyriphos 20 EC 2.5 ml/lit. at 15 days interval provided protection for ants that attract on plants due to honeydew secretion. There are few insecticides *viz*. acephate 75 SP 0.035 %, imidacloprid 17.8 SL 0.3 ml/lit., malathion 50 EC 2.5 ml/lit., bifenthrin 10 EC 0.25 %, and monocrotophos 36 EC 1.5 ml/lit, which were tested and found effective for the control of mealybugs in orchids. Monocrotophos 36 EC 0.02 % + phorate 10 G + neem cake can be recommended to control *Dysmicoccus brevipes* (Mandal 2009), and profenophos and methyl parathion on *P. solenopsis* (Mahalakshmi et al. 2010) can also be used for the mealybugs infesting orchids. Chemical insecticides generally produce phytotoxic symptoms on flowers; so, the basic rule is that any insecticide that is not specifically recommended/labeled for ornamental plants should never be used.

When ants are noticed on the plants, spraying should be taken up with dichlorvos (76 EC) 1 ml/l followed by profenofos (50 EC) @ 1.5 ml/l or methomyl (40 SP) 2 g/l or acephate (75 SP) 1.5 g/l. Pongamia oil or neem oil 10 ml/l are also effective in checking pest buildup in India. Neem oil (azadirachtin 0.03 % EC) @ 3–5 ml/lit, tobacco leaf extract 5 %, and Artimessia leaf extract 10 % were tested against mealybug on *Cymbidium* orchid and found effective for mealybug suppression. Lindemann and Richter (2007) stressed the use of Azadirachtin as biochemical control of *P. longispinus* on *Phalaenopsis* orchids.

56.7 Repotting

Even a light-to-moderate infestation of mealybugs should be of concern. These insects like to move into the potting media and feed on roots, or move off from the plant to find hiding places to lay eggs. Unless the roots are checked and the media changed, removal of mealybugs from only the upper plant portions is not a guarantee of success. The potting medium can harbor eggs and crawlers, so they should be disposed in a compost pile or in the garbage. When repotting, a close inspection, and, if necessary, a very gentle cleaning and spraying of the roots before repotting are essential (https://www.aos.org/Default.aspx?id=511).

56.8 Oils and Soaps

Horticultural oil, neem oil, mineral oil, and insecticidal soaps are effective for mealybug suppression. They are generally considered safe for humans, pets, and plants than the usual insecticides. None provide absolute control over mealybugs, but frequent use during the presence of crawlers can serve to reduce their populations dramatically. The main caution with these oil solutions is that they should never be applied to plants on hot days (85 ° F) or in direct sunlight, as to prevent burning of tissues (https://www.aos.org/Default.aspx?id=511).

56.9 Rubbing with Alcohol

As an orchid is a hard-leaved plant, gentle rubbing of leaves with cotton swabs dipped in 60–70 % isopropyl alcohol gives satisfactory results against mealybugs. If infestation occurred in the root zone, inside potting media, the plants should be removed immediately from the infested media, and the roots should be sprayed with chemical insecticides Further, repotting with fresh media provides control measures to the pest (https://www.aos.org/Default.aspx?id=511).

56.10 Growth Regulators and Chitin Inhibitors

These classes of insecticides have great potential for use in orchid pest management. Growth regulators are relatively expensive, but the cost per application is less than botanical oils. Kinoprene (tradename = Enstar II) is a synthetic form of juvenile hormone, which is highly important in insects at critical stages of their metamorphosis. The use of kinoprene interrupts the normal development of the insects, including mealybugs, scales, aphids, and whiteflies. This insect hormone appears safe for humans and pets under usual use precautions. Experience on its use in greenhouses and home collections suggest that this may be the best new-generation pesticide for controlling many orchid pests, including mealybugs. Bifenthrin and other growth regulators are also available for use on ornamentals, but little information is available for their use on orchids. Some of these new chemicals are very effective, but are also highly regulated, and may not be available in some states for noncommercial uses. Azadirachtin (trade names = Azatin and Neemazad) is a plant-derived chemical that is a chitin inhibitor. Chitin is a primary compound used by insects when developing their integument or exoskeleton. Azadirachtin reduces the insect's ability to properly develop its integument and causes mortality through incomplete development. There is little information available on this chemical for use on orchids, but more information is available on its use on a wide variety of ornamentals, and is labeled for greenhouse applications, but may be too expensive for most home greenhouse uses (https://www.aos.org/Default.aspx?id=511).

56.11 Biological Control

Use of natural enemies (parasitoids, predators, and pathogens) for the management of mealybugs is the most effective and long-term solution in any crop ecosystem. Biological control agents that are available commercially include a variety of tiny parasitic wasps, brown lacewings, green lacewings, and lady beetles. The coccinellid beetles like *Cheilomenes sexmaculata, Coccinella septempunctata*, and *Cryptolaemun montrouzieri* are important predators of mealybugs (Lindemann and Richter 2007). *Cryptolaemun montrouzieri* and *Chrysoperla carnea* larvae have been used as successful biological control agents of *P. longispinus* in potted *Phalaenopsis* orchids. *Cryptolaemus montrouzieri* was used to control *P. longispinus* on the orchids in Germany (Lindemann and Richter 2007). *Pseudococcus maritimus* is becoming serious on the orchids in India. *Cryptolaemus montrouzieri* can be tried against all the arboreal mealybug species.

56.12 General Management Practices

Heavy infestations of mealybugs, especially on many plants, require severe control methods using insecticides. On the extreme side, if a plant shows signs of decline from infestation, then it is seriously advised to destroy that plant, as the low likelihood of rejuvenating that plant may not justify the expense and effort of continued treatments. Also, destruction of a sick plant can be used to justify the purchase of a new and healthier plant. If the mealybugs persist for long periods of time (e.g., >9 months) even with the usage of the same insecticidal control method, then it means probably that the mealybugs might have developed a resistant population. The best resolution to this is to change the methods and chemicals. The same chemical should not be used more than three to four times sequentially. After isolating the infested plants, it is suggested to give them a thorough application of something different from what has been used. For example, if insecticide is used, then switch on to an oil, soap, or different insecticide. Resistance is not generally a problem with growth regulators, such as kinoprene. Generally, an insecticide not labeled for orchids should never be used. Whenever using oils, soaps, and insecticides, be thorough, change formulations frequently, and do not use less than the minimum concentration of mixture, or more than that is normally recommended. Too little of a chemical enhances resistance, while too high of a concentration may damage the plant. Unless you are a commercial grower rotating mixtures of chemicals, do not use chemicals prophylactically, that is, do not routinely use chemicals as a preventative, as it is a waste of chemical (and money!), and such use allows resistant mealybugs to develop. Finally, keep up the manual removal of all mealybugs, if possible. Mealybugs are an excellent example of pests that are easily transported and that create tremendous problems. Though most orchid keepers in North America obtain their plants from conscientious growers in either Canada or the United States, many persons do purchase plants while traveling, in exchange from friends, or from questionable sources. Everyone needs to be aware of the great potential of inadvertently dispersing species to new areas, particularly from international origins. There cannot be enough stress placed on the recommendation that all plants come from a reputable and quality grower, and are clean of pests.

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57 Medicinal Plants

V. Sridhar, L.S. Vinesh, and M. Mani

Mealybugs are injurious to several medicinal and aromatic plants. Though medicinal and aromatic plants play an important role in public healthcare globally, they are affected by several mealybug species. Incidence of *P. solenopsis* was observed on a wide range of medicinal plants. Symptoms of damage observed on these plants were twisted and dried leaves and shoot, white fluffy mass on stems, distorted or bushy shoots, presence of honeydew, black sooty mould, small deformed fruits, etc. (Chaudhary 2013). Various species of mealybugs recorded on medicinal plants and cropwise options for their management are presented below.

57.1 Aswagandha

Coccidohystrix insolita (Green) (=*Phenacoccus insolitus*; *Centrococcus insolitus*) is one of the key pests on Aswagandha (*Withania somnifera*) (Williams 2004). Since Aswagandha is a herbal medicine, application of synthetic chemicals leads to accumulation of toxic residues. Hence, organic pest management including very safe chemicals is the only option for this crop. Ravikumar et al. (2008) found the application of farmyard manure (FYM) (12.5 t/ha) + Azophos (2 kg/ha) + neem cake (1000 kg/ha) and need-based foliar application of neem oil (3 %) to be very effective in reducing the incidence of mealybug.

Striped mealybug, *Ferrisia virgata* (Cockerell) is another mealybug species, which causes damage on Aswagandha by sucking the sap from the lower surfaces of leaves and pods during October–February (Kumar 2007; Ramanna 2009). Maximum population of 18 mealybugs per plant was recorded during December 2008, and the infested leaves turned yellowish and dried up. Natural incidence of the predator *Cryptolaemus montrouzieri* was observed on this mealybug from Karnataka, India. Activity of predators gradually increased from November 2008 to January 2009 and then declined from February 2009 onward (Ramanna 2009). Solenopsis mealybug, *Phenacoccus solenopsis* (Tinsley), was reported on Aswagandha from Tamil Nadu (Selvaraju and Sakthivel 2011). Abbas et al. (2010) reported a mean infestation of 41 % by this mealybug on Aswagandha.

Papaya mealybug, *Paracoccus marginatus* (Williams Granara de Willink), an invasive pest was recorded in Tamil Nadu, India, in 2008, on papaya, and has attained the status of a serious pest on a wide range of host plants, including Aswagandha (Sakthivel et al. 2012; Selvaraju and Sakthivel 2011).

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57.1.1 Indian acalypha, *Acalypha indica*

Striped mealybug, *Ferrisia virgata* (Cockerell) is a major pest on *Acalypha indica*. Release of *Cryptolaemus montrouzieri* resulted in complete clearing of these mealybugs within 40 days of release (Mani 2008). *Coccidohystrix insolita* also damages this plant. *Spalgis epius* is the common predator recorded on these mealybugs. Other mealybugs recorded on this plant include *Phenacoccus solenopsis, P. madeirensis* and *Paracoccus marginatus* from Tamil Nadu (Selvaraju and Sakthivel 2011).

57.1.2 *Decalepis hamiltonii*

Mango mealybug, *Rastrococcus iceryoides* (Green), is observed as the major mealybug on this plant. Release of *Cryptolaemus montrouzieri* reduced mealybug population from 48.75/plant in January to 1.26/plant in March (Mani et al. 2011).

Cryptyolaemus feeding on *C. insolita* on coleus

Rastrococcus ceryoides on *Decalepis namiltoni*

57.1.3 Coleus

Medicinal coleus (*Coleus forskohlii*) is an important medicinal crop, which contains forskolin in their roots. *Coccidohystrix insolita* is the important pest on *C. forskohlii*, and also on *C. aromaticus* (Vijay and Suresh 2013a). Release of *C. montrouzieri* reduced mealybug population within 40 days (Mani et al. 2011) on *Coleus*.

57.1.4 Black night shade, *Solanum nigrum*

Solanum nigrum is an important ingredient in traditional Indian medicines. Papaya mealybug, *Paracoccus marginatus*, is an invasive pest recorded on black night shade in Tamil Nadu (Sakthivel et al. 2012; Selvaraju and Sakthivel 2011). *Phenacoccus solenopsis* is reported on *S. nigrum* from Tamil Nadu (Vijay and Suresh 2013a, b) and Pakistan (Arif et al. 2009).

57.1.5 Tulsi, *Ocimum sanctum*

Paracoccus marginatus in India is reported on *Ocimum sanctum* (Tanwar et al. 2010) and *P. solenopsis* on *O. basilicum* in Pakistan (Arif et al. 2009).

57.1.6 Turmeric, *Curcuma longa*

Papaya mealybug, *P. marginatus*, was reported on turmeric from Tamil Nadu (Selvaraju and Sakthivel 2011).

57.1.7 Neem, *Azadirachta indica*

In Tamil Nadu, India, *Pseudococcus gilbertensis* (Beardsley) (Karthikeyan et al. 1993) and *Paracoccus marginatus* (Sakthivel et al. 2012; Selvaraju and Sakthivel 2011) are known to attack neem. *Maconellicoccus hirsutus* was also reported on this plant by Williams (1986).

57.1.8 Sweet Indian Mallow, *Abutilon indicum*

Paracoccus marginatus and *Phenacoccus solenopsis* were reported on this crop from Tamil Nadu (Selvaraju and Sakthivel 2011), and *P. solenopsis* from Pakistan (Arif et al. 2009). Percentage infestation by *P. solenopsis* was recorded as 7.6 by Abbas et al. (2010) from Pakistan.

57.1.9 Indian gooseberry, *Phyllanthus emblica*

Spherical mealybug, *Nipaecoccus viridis*, is known to feed on this plant (Ramadasan and Harikumar 2011; Vijay and Suresh 2013a, b; Williams 2004). Of late, *E. officinalis* is grown widely for export purpose, for its medicinal properties, and is grown in all altitudes, and widespread occurrence was noticed in other parts of the country. *E. officinalis*, being grown as rainfed crop under water-stressed conditions, paved way for the multiplication of insects. Improper use of insecticides also resulted in increased incidence of mealybugs in *E. officinalis*. The population is higher in hot climatic conditions coupled with high relative humidity (Vijay and Suresh 2013a).

57.1.10 Indian Senna, *Cassia angustifolia*

Papaya mealybug, *Paracoccus marginatus*, an invasive mealybug, was recorded as a pest on this medicinal plant from Tamil Nadu (Selvaraju and Sakthivel 2011).

57.2 Gulancha, *Tinospora cordifolia*

Incidence of spherical mealybug *Nipaecoccus viridis* (Newstead) on *Tinospora cordifolia* was recorded from Bangalore, India (Saroja et al. 2013). This pest also attacks other medicinal crops, viz., *Leucas aspera*, *Mimosa pudica*, and *Phyllanthus emblica* (Vijay and Suresh 2013a; Williams 2004). Thick clusters of cotton-like masses were seen on leaves and vines. The mealybug population ranged at an average of 10–12 mealybugs per leaf. The infested leaves showed symptoms of chlorosis on leaves and drying. The honeydew excretion was heavy, which attracted ants, and served as a medium for sooty mould development (Saroja et al. 2013).

Nipaecoccus viridis on *T. cordifolia*

57.2.1 Lavender

Eriococcus munroi (Boratynski) is known to damage Lavender (*Lavandula spica*) in France (Matile-Ferrero and Germain 2004).

Apart from the various crops mentioned above, there are so many hosts recorded from different medicinal and aromatic plants for various mealybugs by different authors. Countries or places of their records with their host plants are presented in Table 57.1, along with the names of authors.

Table 57.1 Various medicinal and aromatic plants infested with different mealybugs

Mealybugs	Country/Medicinal plants, where recorded	References
Paracoccus marginatus (Williams Granara de Willink)	India	Selvaraju and Sakthivel (2011), Tanwar et al. (2010)
	Achyranthes aspera; *Alternanthera sessilis*: *Amaranthus viridis*; *Amaranthus spinosus*; *Boerhavia diffusa; Calotropis gigantea*; *Cassia angustifolia; Celosia argentea; Cleome gynandra*; *Cleome viscose*; *Crotalaria retusa*; *Glinus lotoides*; *Guettarda speciosa; Jatropha gossypiifolia*; *Leucas aspera; Lippia nodiflora*; *Physalis minimam*; *Phyllanthus fraternus*; *Phyllanthus amarus*; *Pulmonaria longifolia*; *Solanum xanthocarpum*; *Tephrosia purpurea; Trianthema portulacastrum*; *Tribulus terrestris*; *Wedelia chinensis; Canthium inerme*; *Phyllanthus niruri; Convolvulus arvensis; Commelina benghalensis*	
	India	Chellappan et al. (2013)
	Adhatoda vasica Nees, *Alstonia scholaris* (L.) R. Br., *Rauvolfia serpentina* (L.),Benth. Ex. Kurz, *Cyanthillium cinereum* (L.) H. Rob, *Bauhinia variegata*, *Ficus exasperate, Azadirachta indica, Ocimum sanctum*, *Couroupita guianensis, Indigofera tinctoria, Cassia occidentalis, Phyllanthus amarus, Phyllanthus fraternus, Datura stramonium*,	
	Ghana	Cham et al. (2011)
	Wedelia trilobata; Sida sp.	
Phenacoccus solenopsis (Tinsley)	India	Vennila et al. (2013), Vijay and Suresh (2013a) and Vijay and Suresh (2013b), Nagrare et al. (2009), Saini et al. (2009)

(continued)

Table 57.1 (continued)

Mealybugs	Country/Medicinal plants, where recorded	References
	Trianthema portulacastrum; *Commelina bengalensis; Sida cordifolia; Portulaca grandiflora; Corchorus trilocularis ;Boerhavia diffusa; Phyllanthus niruri; Acmella uliginosa; Abelmoschus ficulneu; Lactuca runcinata; Digera muricata; Asteracantha longifolia; Triumfetta rhomboidea; Pentanema indicum; Aerva lanata; Phyllanthus amarus; Sida acuta; Phyllanthus reticulatus; Corchorus trilocularis; Euphorbia geniculata; Portulaca oleracea; Acalypha india*; *Solanum trilobatum*; *Datura metel*; *Ocimum basilicum*; *Ocimum sanctum*; *Rhinocanthus nasutus*; *Andrographis paniculata*; *Solanum khasianum; Abrus precatorius*; *Artemisia nilagria*; *Solanum nigrum;Amaranthus* sp.; *Gymnea sylvestris*; *Vitex leooryxylon; Strilobanthus cilatus; Acerva lanata; Artemesia nilagiria*; *Vernonia cineria*; *Cassia occidentalis*; *Cleome viscosa*; *Eleusine indica*; *Coleus forskohli*; *Coleus aromaticus*; *Leucas aspera*; *Mentha longifolia*; *Piper longum*; *Plumbago zeylanica*; *Vitex negundo*; *Vitex leooryxylon*; *Tribulus terrestris*	
	India, Gujarat	Chaudhary (2013)
	Hibiscus sabdariffa, Hibiscus rosa- sinensis, Abutilon indicum, Sida cordata, Abelmoschus moschatus, Artemisia annua, Tagetus erecta, Tagetus minuta, Chrysanthemum maximum, Parthenium hysterophorus, Cestium dium, Datura metel, Withania somnifera, Solanum khasianum, Cestrurn noctumum, Solanum nigrum, Commiphora wightii, Murraya koenigii, Plantago indica, Tinospora cordifolia, Adhatoda vasica, Boerhaavia diffusa, Merremia turpethum, Rosa damascene, Vetiveria zizanioides,Cymbopogon fluxeouuses,Abrus precatorius, Desmodium gangeticum,Cyamopsis tetragonopoloba, Achyranthes aspera,Mimosa pudica,Crataeva nurvala, Plumbago zeylanica,Kicloxia incana, Kicloxia ossisima, Lantana camera,Gymnema syltvestre	
	Pakistan	Arif et al.(2009)
	Achyranthes aspera; *Amaranthus viridis*; *Phyllanthus niruri; Mentha longifolia*; *Ocimum basilicum*; *Portulaca oleracea; Datura metel; Solanum nigrum*	
Maconellicoccus hirsutus (Green)	India	Singh and Ghosh (1970); Ghose (1972), Fletcher (1919); Mani (1986); Rao et al. (1984); Babu and Azam (1987); Ghose (1961); Dutt et al. (1951); Balikai (1999); Balikai and Bagali (2000)
	Clerodendron infortunatum; Erythrina variegate; Eugenia jambolana; Glyricidia sepium; Hibiscus acetosella; Hibiscus cannabinus; Hibiscus sabdariffa; *Mikania cordata*; *Phyllanthus niruri*; *Portulaca oleracea; Portulaca quadrifida*; *Spondias dulcis; Zizyphus mauritiana*	

(continued)

Table 57.1 (continued)

Mealybugs	Country/Medicinal plants, where recorded	References
Dysmicoccus brevipes (Cockerell)	India	Vijay and Suresh (2013b)
	Ocimum sanctum	
Planococcus minor (Maskell)	*Ocimum sanctum*	Ben-Dov (1994)
Planococcus citri (Risso)	*Ocimum sanctum*	Ben-Dov (1994)
Paraputo odontomachi (Takahshi)	India, Philippines, Indonesia, Singapore and Vietnam	Williams 2004
	Garcinia	
Rastrococcus iceryoides (Green)	India	Vijay and Suresh(2013b)
	Leucas aspera	
Coccidohystrix insolita (Green)	India	Vijay and Suresh (2013b)
	Solanum khasianum	
	Coleus aromaticus	
Nipaecoccus sp., *Paracoccus* sp., and *Phenacoccus* sp.	Spain	Martinez et al. (2010)
	Lippia alba, L. geminate, Ocimum sanctum	
Nipaecoccus viridis	India	Williams (2004)
	Ocimum sanctum	
Rhizoecus dianthi (Green)	*Withania somnifera*	Ben-Dov (1994)
Nipaecoccus viridis (Newstead)	India	Vijay and Suresh (2013a)
	Leucas aspera, Mimosa pudica, and *Phyllanthus emblica*	
	India	Varshney (1992), Ben-Dov (1994), Williams (2004)
	Nerium oleander	
	Asia	Williams (2004)
	Embelica officinalis and *Leucas aspera*	
	Abrus precatorius	Ben-Dov (1994)

Rastrococcus iceryoides infested *Leucas aspera*

Nipaecoccus viridis infested *Phyllanthus emblica*

Ferrisia virgata on *Vinca rosea*

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58 Plantation Crops

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The plantation crops viz., coconut, arecanut, cocoa and tea are traditionally grown in India. The products and by-products of these crops form vital inputs for several industries and sustain livelihood for many million farm families. Infestation by insects form a crucial limiting factor in attaining the production potential of plantation crops. Among the sucking pest complex, mealy bugs, being polyphagous constitute a key biotic stress that reduce plantation crop yield significantly. Fifty-seven species of Pseudococcids have been recorded on palms (Table 58.1). Half of the Palmivorous species belong to the genera *Dysmicoccus, Planococcus, Pseudococcus* and *Rhizoecus. Among the wide array of mealy bug species, Dysmicoccus* has the most palmivorous species (eight) including three species known only from palms. The most commonly reported mealy bug pest of palms are highly polyphagous species, distributed worldwide and are primarily known as pests of crops other than palms. Classical examples include *Dysmicoccus brevipes, Nipaecoccus nipae* and *Pseudococcus longispinus*. Few mealybug species namely *Dysmicoccus hambletoni*, *Dysmicoccus cocotis*, *Dysmicoccus finitimus*, *Neosimmondsia hirsuta, Palmicultor palmarum*, *Phenacoccus sakai, Planococcoides anaboranae*, *Pseudococcus portiludovici*, *Tylococcus malaccensis*, *Crinitococcus palmae* and *Cyperia angolica* are almost restricted to palms.

58.1 Coconut

In coconut, nine important species of mealybugs are reported from India *viz. Palmicultor palmarum* Ehron. *Dysmicoccus cocotis* Maskell, *Pseudococcus longispinus* Targ. *Pseudococcus cryptus, Planococcus lilacinus, Pseudococcus microadonidam, Nipaecoccus nipae* Maskell, *Dysmicoccus finitimus* and *Rhizoecus* sp. In Guam, *Coccidohstrix insolita* was observed infesting coconut palm (Aubrey Moore et al. 2014). *Ferrisia virgata* is also known to infest coconut (http://www.plantwise.org/KnowledgeBank/Datasheet.aspx?dsid=23981).

58.1.1 *Palmicultor palmarum*

Palmicultor palmarum infests young seedlings especially when they are closely spaced or in nurseries and greenhouses. It does little damage to mature coconut palms but sometimes kills seedlings. It has been observed in dense aggregations on leaf axils especially on spindle/spear leaves and at the base of spear leaves. Red ants

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Table 58.1 Mealybugs recorded on Palms [Ben-Dov (1994), Howard et al. (2001)]

Mealy bug species	Palm hosts	Distribution
Chryseococcus arecae (Maskell)	*Rhopalostylis sapida*	Australia, New Zealand
Crisicoccus hirsutus (Newstead)	*Areca catechu*	India
Coccidohystrix insolita Green)	*Cocus nucifera*	Eastern Hemisphere, Guam
Crinitococcus palmae Ben-Dov	*Caryota* sp.	Philippines
Dysmicoccus boninsis (Kuwana)	*C. nucifera*	Pantropical
Dysmicoccus brevipes (Cockerell)	*Areca catechu, Carpentaria acuminata, C. nucifera, E. guineensis, Pheonix dactylifera, Rhapis, Roystonea & Sabal bermudiana*	Cosmopolitan (India, Indonesia, Malaysia, Maldives, Philippines, Sri Lanka)
Dysmicoccus cocotis (Mask ell)	*C. nucifera*	Oceania, India
Dysmicoccus finitimus Williams	*C. nucifera*	Southern Asia, Malaysia
Dysmicoccus furcillosus sp.n.	*Areca catechu*	India
Dysmicoccus neobrevipes (Beardsley)	*C. nucifera*	Tropical America, Oceania, Philippines
Dysmicoccus nesophilus Williams & Watson	*Balaka seemanni*	Oceania
Dysmicoccus papuanicus Williams & Watson	*C. nucifera*	New Guinea
Ferrisia consobrina Williams & Watson	*Metaxylon sagu*	Pantropical
Ferrisia virgata (Cockerell)	*C. nucifera & P. dactylifera*	Cosmopolitan
Formicoccus polysperes sp.n.	*Areca catechu*	India
Geococcus coffeae Green	*Chamaedorea*	Cosmopolitan
Laingiococcus painei (Laing)	*C. nucifera*	Oceania
Laminicoccus flandersi Williams	*Gronophyllum & Howea*	Australia, New Zealand
Laminicoccus vitensis (Green)	*C. nucifera & Roystonea regia*	Oceania
Leptococcus metroxyli Reyne	*C. nucifera & Metroxylon*	New Guinea
Maconellicoccus hirsutus (Green)	*P. dactylifera & P. sylvestris*	Cosmopolitan
Maculicoccus malaitensis (Cockrell)	*C. nucifera*	Oceania
Neosimmondsia esakii Takahashi	*Metroxylon amicarum & Ptychosperma ledermanniana*	Caroline Islands
Neosimmondsia hirsuta Laing	*C. nucifera*	Solomon Islands
Nipaecoccus agathidis Williams	*C. nucifera*	Guadeloupe
Nipaecoccus nipae (Maskell)	*Areca* sp. *Arenga saccharifera, Calyptrogyne, Chamaedorea, Chamaerops excelsus, C. nucifera, Gronophyllum, Howea belmoreana, Howea forsteriana, Livistona chinensis, Nypa fruticans, Pritchardia, Ptychosperma, Rhapis humilis, Sabal & Syagrus romanzoffiana*	Cosmopolitan
Nipaecoccus viridis (Newstead)	*C. nucifera*	India
Palmicultor palmarum (Beardsley)	*A. catechu, C. nucifera, Dypsis lutescens, Latania glaucaphylla, R. regia & Veitchia* sp.	Oceania, Asia, tropical America, Florida, Bermuda, Bangladesh, India, Malaysia, Maldives, Philippines, Vietnam
Paraputo kukumi Williams	*C. nucifera*	Solomon Islands

(continued)

Table 58.1 (continued)

Mealy bug species	Palm hosts	Distribution
Paraputo leveri (Green)	*C. nucifera*	Oceania, Papua New Guinea
Phenacoccus gregosus Williams & Granara de Willink	*Chamaedorea*	Mexico, Central America
Palmicultor guamensis (Beardsley)	*A.catechu*, *C. nucifera*	Neotropical & Pacific region
Phenacoccus sakai (Takahashi)	*N. fruticans*	Malaysia
Planococcoides anaboranae (Mamet)	*C. nucifera*	Madagascar
Planococcus citri (Risso)	*C. nucifera, Gronophyllum* sp., *P. dactylifera*	Cosmopolitan
Planococcus ficus (Signoret)	*P. dactylifera*	Cosmopolitan
Planococcus kraunhiae (Kuwana)	*Trachycarpus fortunei*	Asia, California
Planococcus lilacinus (Cockerell)	*C. nucifera & P. dactylifera*	Cosmopolitan
Planococcus minor (Maskell)	*A. catechu, B. seemannii*, & *C. nucifera*	Cosmopolitan
Planococcus nigritulus De Lotto	*P. dactylifera*	Tanzania
Plotococcus neotropicus Williams & Granara de Willink	*C. nucifera*	Tropical America
Pseudococcus cryptus Hempel	*C. nucifera, Areca catechu* & *E. guineensis*	Cosmopolitan
Pseudococcus longispinus (Targioni Tozzetti)	*A. catechu, Chamaedorea elatior, D. lutescens, C. nucifera, Dictyosperma album, Howea* sp., *Metroxylon sagu, Roystonea* sp. & *Phoenix canariensis*	Cosmopolitan
Pseudococcus microadonidum Beardsley	*C. nucifera*	Oceania, Seychelles
Pseudococcus portiludovici Mamet	*C. nucifera & Latania verschaffeltii*	Indian Ocean, Mauritius, Chagos Archipelago
Pseudococcus zamiae (Lucas)	*Howea* sp.	Australia
Rastrococcus iceryoides Green	*A. catechu*	Eastern Hemisphere, India
Rastrococcus neoguineensi Williams & Watson	*C. nucifera*	Indonesia, New Guinea
Rastrococcus spinosus (Robinson)	*C. nucifera*	South-East Asia
Rhizoecus americanus Ferris	*Areca* sp., *Chamaedorea elegans, D. lutescens, Coccothrinax argentata, Chamaedorea, Howea* sp., *Phoenix loureiri*	Tropical America, Italy
Rhizoecus californicus Ferris	*Rhopalostylis sapida*	New Zealand, California
Rhizoecus cocois Ben-Dov	*C. nucifera*	India
Rhizoecus falcifer Kiinckel d'Herculais	*Chaaerops humilis, Howea belmoreana, Howea forsteriana, P. canariensis, Phoenix roebelenii, Ptychosperma* sp., *Ptychosperma elegans, Sabal blackburniana*	Cosmopolitan
Rhizoecus floridanus	*D. lutescens, P. canariensis, S. romanzoffiana*	South-eastern USA
Rhizoecus hibisci Kawai & Takagi	*P. canariensis, Sabal* sp.	Japan, Puerto Rico
Tylococcus malaccensis Takahashi	*N. fruticans*	Malaysia
Xenococcus annandalei Silvestri	*C. nucifera*	Australia, New Guinea, South-East Asia, Malaysia, India

are mostly associated with this mealybug colony. It was introduced into Florida where it has been observed in leaf axils and at the base of the spear leaf of *R. regia, Veitchia* spp. and *D. lutescens*. In severe cases, spear leaves become necrotic and the palm dies. *P. palmarum* was found mainly on coconut in Micronesia, Hawaii and Bahamas (Williams 1981). *P. palmarum* has also been recorded in Bangladesh on leaves of coconut and palmyra palm (*Borassus flabellifer*) (Ali 1987). In India, *Palmicultor* sp. took 21.60 days to complete its lifecycle. Adult females and males lived for 18.27 and 2.8 days, resp. A female produced 37–89 offspring (Jalaluddin and Mohanasundaram 1993). Sometimes the red ant, *Oecophylla smaragdina* (Fab.) was found associated with the mealybugs.

58.1.2 *Psuedococcus longispinus*

Pseudococcus longispinus affects spindle leaves, and severe infestation results in failure of heart leaf development and finally ends up with drying up of spindle. Seedlings are highly prone to attack.

Psudococcus cocotis

Palmicultor palmarum (Ehrhorn)

58.1.3 *Dysmicoccus* spp.

They are known to infest leaves of coconut seedlings. *D. cocotis* is known to occur west of Micronesia in the north and Fiji in the south. *D. finitimus* is found colonizing the spadix of coconut to southern India, Sri Lanka, Cocos Islands and peninsular Malaysia (Williams 1994). Infesttion by *D. finitimus* was also recorded from the spathe of coconut palms from Kerala (CPCRI 2012). *Dysmicoccus carens* was observed on coconuts at Dindigul, Tamil Nadu, India on the undersurface of the leaflets, desapping the plant heavily causing severe yellowing. *D. carens* excreted honeydew on which the sooty mould (*Capnodium* sp.) developed, resulting in the reduction of the effective photosynthetic area of the leaflets (Razak and Jayaraj 2002). In Vellayani, Kerala, India, *Dysmicoccus brevipes* was reported from the perianth of immature nuts in coconut (Radhakrishnan et al. 2003).

58.1.4 *Rhizoecus* sp.

A species of the genus *Rhizoecus* infesting roots of coconut was reported for the first time from Trivandrum, Kerala (Nair et al. 1980). It infests roots of coconut palms in sandy areas. Infested seedlings turn yellowish and loose vigour.

58.1.5 *Pseudococcus microadonidam* and *Planococcus lilacinus*

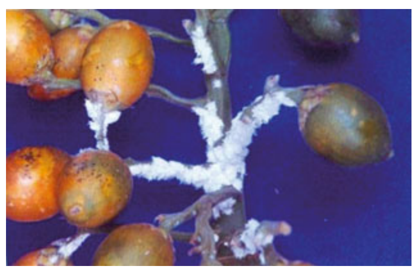
Pseudococcus microadonidam was found causing damage to coconut in Seychelles (Williams 1981). *Planococcus lilacinus* (Ckll.) was reported from Guyana (Williams 1981). *P. microadonidam* and *P. lilacinus* are known to infest coconut in India (Mohandas and Remamony 1993).

58.1.6 *Nipaecoccus nipae*

Nipaecoccus nipae was reported on coconut in Demerara, Guyana (Maskell 1893). In Florida, Howard et al. (2001) gave an account of *N. nipae* feeding on the roots of coconut palm. It was recoded on coconut in Philippines (Lit et al. 2006). The occurrence of *N. nipae* was reported from Bengal, East India (Green 1908). Re-emergence of the pest was reported in India after a time gap of 100 years. It was recorded on tender feeder roots of coconut seedling at Kayamkulam, Kerala, India. *N. nipae* was not located on any other arboreal parts of palm (Josephrajkumar et al. 2012). Adult females and immatures feed on the sap of the host plant. Ants are often found feeding on mealybug honeydew secretions and may also defend the mealybugs from predators or parasitoids (Ben-Dov 1994; Williams and Granara de Willink 1992).

Mealybug damage to coconut

Nipaecoccus nipae



Infestation of *Nipaecoccus nipae* on a palm species (Photocredit: Lyle J. Buss)

58.1.7 *Pseudococcus cryptus* and *Formicococcus cocotis*

The leaf mealybug, *Pseudococcus cryptus*, was found colonizing at moderate level on the leaves. Infested colonies were foraged by ants. *P. cryptus* was reported from Colachel, Tamil Nadu, India (CPCRI 2012). *Formicococcus cocotis* sp. nov. was reported on coconut from Zanzibar (Williams and Matile-Ferrero 2005).

58.1.8 Management

Chemical Control Management of mealybugs begins with detection and identification of the pest. Regular monitoring will allow detection of these pests before damage is obvious and will also allow improved control. All plant parts need to be searched, including the undersides of leaves and stems. Pruning or washing infested plant parts can be helpful in reducing populations, particularly in cases of small infestations. A brisk wash spray of water can also be helpful in reducing the population. Systemic insecticides can provide excellent options for mealybug control. Soil application of thiodemeton [disulfoton] at 0.5 g/plant and spraying with methyl demeton 0.05 % were both highly effective against a severe attack of *P. longispinus* on 6-month-old coconut seedlings in India (Murthy and Giridharan 1976). Application of 0.1 % malathion, 0.025 % methomyl, 0.025 % demeton-O-methyl, 0.03 % dimethoate and 0.05 % phosphamidon caused 100 % mortality within 7 days, and 0. 05 % parathion-methyl caused 70 % mortality of *Palmicultor* sp. on coconut leaves (Jalaluddin et al. 1991). Regular monitoring and spot application twice with dimethoate 0.05 % at 20 days interval during summer to avoid further spread of mealy bugs from infested coconut and cocoa plantations (Nair 1983).

58.1.9 Biological Control

Mealybugs are commonly attacked by predators, parasitoids and diseases which can help manage populations, particularly for long-term control. It is important to recognize the presence of beneficial insects and to take steps to conserve them in the environment so they are available to control the pest insects. The most important natural enemies on coconut mealybugs are *Pullus* sp., *Scymnus* sp. (Coccinellidae), *Spalgis epeus* (Lycaenidae), *Bergineus maindroni* (Mycetophazidae), *Dicrodiplosis* sp. (Cecidomyiidae), *Homalotylus oculatus* (Encyrtidae). These natural enemies exert good control of the pest in nature. In case of severe infestation only, insecticides are to be applied. *C. montrouzieri* was imported from California for the control of coconut mealybug *Nipaecoccus nipae* in Bermuda. The numbers released were not probably adequate to provide reasonable opportunity for establishment (Bennett and Hughes 1959). In Seychelles, *C. montrouzieri* was introduced in 1959 and 1961 for the control of *Pseudococcus* (=*Planococcus*) *longispinus* but not recovered (Bartlett 1977). The use of *Pseudaphycus utilis* Timberlake, a parasitic wasp, as a biological control agent successfully controlled coconut mealybug *Nipaecoccus nipae* in Hawaii and Puerto Rico (http://entnemdept.ufl.edu/creatures/orn/mealybug/coconut mealybug.htm).

58.2 Arecanut

Pseudococcus cryptus, *Dysmicoccus brevipes* and *Dysmicoccus sp.* are the mealybug species found feeding on developing fruit bunches, spadices, outer surface of leaf sheath, inflorescence, spindle leaves and occasionally on leaves. Severe infestation during tender nut stage causes immature nut fall.

58.2.1 *Pseudococcus cryptus*

It was found to infest leaves, inflorescence and developing fruit bunches (Daniel 2003).

Pseudococcus cryptus

Paracoccus marginatus

58.2.2 *Dysmicoccus* spp.

Dysmicoccus brevipes and *Dysmicoccus sp.* were reported on arecanut. They were found colonizing mainly the spindle leaf of the arecanut palm and the inner basal portion of the inflorescence. Rao and Bavappa (1961) reported *D. brevipes* on areca nut infesting the lamina and collar regions of the seedling causing yellowish patches. Ants associated with *D. brevipes* protect them by mud nests (Daniel 2003).

Colony of *Dysmicoccus*

Dysmicoccus damage to arecanut

58.2.3 Management

Basavaraju et al. (2013) reported that neem oil at 3 % significantly reduced the population of *D. brevipes* (1.07 no./nut) which is at par with pongamia oil at 3 % (1.13 no./nut) when compared to untreated check (4.53 no./nut). Natural enemies of arecanut mealybug *D. brevipes* include maggots of cecidomyiid, *Tryphlodromus* sp., coccinellid predators and ichneumonid parasitoid, *Oricoruna arcotensis* (Mani and Kurian), which keep the pest under check in nature (Daniel 2003).

58.3 Cocoa

Planococcus lilacinus, *Planococcus citri*, *Rastrococcus iceryoides* and *Paracoccus marginatus* were reported infesting cocoa from India (Nair 1981; Daniel 1994; TNAU 2015). Pest attack is more in July to October. It colonizes on the tender parts of the plant such as growing tips of the shoots, the terminal buds, the flower cushions, the young cherelles and mature pods. *Planococcoides njalensis* (Laing) occurs throughout West Africa, and is the most important mealy bug on cocoa being the vector of cocoa swollen shoot caused by badnavirus, resulting in heavy crop loss (Padi 1997; Roivainen 1976; Campbell 1983; Owusu and Bonney 1984). *Planococcus citri* (Risso), *Planococcoides njalensis* (Laing) and *Phenacoccus hargreavesi* (Laing) are the most common mealybugs on cacao at Tafo, Ghana (Campbell 1974). At Tafo, Ghana, *Planococcoides njalensis* (Laing) and *Planococcus citri* (Risso) are the main vector species of cocoa swollen shoot disease (Bigger 1977) (Table 58.2).

Table 58.2 List of mealybugs recorded on cocoa in different countries

Mealybug species	Region/country	References
Crinticoccus tectus Williams	Solomon islands	Ben-Dov (1994)
Crinticoccus theobromae Williams	Solomon islands	Ben-Dov (1994)
Crisicoccus theobromae Williams &Watson	Papua New Guinea	Ben-Dov (1994)
Deltococcus tafaensis (Strickland)	Ghana	Ben-Dov (1994)
Dysmicoccus brevipes (Cockrell)	–	Ben-Dov (1994)
Dysmicoccus debregeasiae (Green)	Malaysia	Williams (2004)
Dysmicoccus grassii (Leonardi)	Malaysia	Williams (2004)
Dysmicoccus lepelleyi (Betrem)	Malaysia	Williams (2004)
Dysmicoccus neobreipes Beardsley	–	Ben-Dov (1994)
Exallomochlus camur sp.n.	Malaysia	Williams (2004)
Exallomochlus hispidus (Morrison)	Malaysia & Singapore	Williams (2004)
Ferrisia virgata (Cockerell)	India	Ben-Dov (1994), Williams (2004)
	Malaysia	Williams (2004)
Geococcus coffeae Green	–	Ben-Dov (1994)
Hordeolicoccus nephalii (Takahashi)	Malaysia	Williams (2004)
Laingiococcus painei (Laing)	Papua New Guinea	Ben-Dov (1994)
Maconellicoccus hirsutus (Green)	Sri Lanka	Williams (2004)
	India	Anand and Ayub Khan (2006)
Maconellicoccus multipori (Takahashi)	Malaysia	Williams (2004)
Mutabilicoccus vanheurni (Reyne)	Papua New Guinea	Ben-Dov (1994)
Neochavesia trinidadiensis (Beardsley)	Trinidad	Ben-Dov (1994)
Nipaecoccus guazumae (Balachowsky)	Columbia	Ben-Dov (1994)

(continued)

Table 58.2 (continued)

Mealybug species	Region/country	References
Nipaecoccus kuduyaricus Williams & Granara de Willink	Columbia	Ben-Dov (1994)
Nipaecoccus neogaeus Williams & Granara de Willink	Columbia	Ben-Dov (1994)
Nipaecoccus nipae (Makell)	Hawaii	Ben-Dov (1994)
Nipaecoccus pikini Williams & Granara de Willink	Trinidad	Ben-Dov (1994)
Phenacoccus hargreavesi (Laing)	Ethiopian region	Ben-Dov (1994)
Planococcus citri (Risso)	Sri Lanka	Williams (2004)
Planococcus kenyae (Le Pelley)	Ethiopian	Ben-Dov (1994)
Planococcus lilacinus (Cockrell)	India, Malaysia, Philippines, Sri Lanka	Williams (2004)
Planococcus minor (Maskell)	Malaysia, Philippines, Singapore, Thailand	Ben-Dov (1994), Williams (2004)
	Trinidad	Francis et al. (2012)
Planococcus principe Cox	Principe island	Williams (2004)
Planococcoides lmbokensis (Balachowsky & Ferrero)	Central Africa	Ben-Dov (1994)
Planococcoides njalensis (Laing)	Africa	Ben-Dov (1994)
Plotococcus neotropicus Williams de Granara	Neotropical region	Ben-Dov (1994)
Promyrmococcus wayi Williams	Malaysia	Williams (2004)
Pseudococcus calceolarieae (Maskell)	–	Ben-Dov (1994)
Pseudococcus jackbeardsley Gimpel and Miller	Malaysia	Williams (2004)
Pseudococcus landoi (Balachowsky)	Neotropical	Ben-Dov (1994)
Pseudococcus longispinus (Targioni Tozzetti)	–	Ben-Dov (1994)
Pseudorhizoecus proximus Green	Columbia	Ben-Dov (1994)
Pseudococcus solomonensis Williams	Solomon islands	Ben-Dov (1994)
Pseudococcus theobromae (Douglas)	England	Ben-Dov (1994)
Rastrococcus iceryoides (Green)	Malaysia	Williams (2004)
Rhizoecus falcifer Kunckel d Herculais	–	Ben-Dov (1994)
Rhizoecus globoculus (Hambleton)	Trinidad	Ben-Dov (1994)
Rhizoecus ornatus (Hambleton)	Trinidad	Ben-Dov (1994)
Rhizoecus spelaea (Strickland)	Ghana	Ben-Dov (1994)
Rhizoecus theobromae Hambleton	Ecuador	Ben-Dov (1994)

58.3.1 *Planococcus lilacinus*

The cocoa mealybug *P. lilacinus* (Ckll.) occurs in most of the cocoa growing tracts of South East Asia viz., India, Sri Lanka and Papua New Guinea. In India, it is reported as a serious pest causing damage to cocoa and is present in all cocoa tracts of the country. It is present throughout the year colonizing the tender parts of the plants such as the growing tips of the shoots, the terminal buds, the flower cushions, the young cherelles and the mature pods. Mealybugs feeding on the tender apical shoots result in reduced growth causing deformity of the shoots which grow as brush-like structures. Infestation of the flower cushion results in cushion abortion and continuous attack results in withering and drying of the flower cushions. The feeding on the bark of pods by mealybugs results in irregular cracks and pitting and feeding on cherelles result in cherelle wilt. Peak population is reported in April-May and low level of activity is recorded during rainy and post monsoon seasons (Nair 1981).

Planococcus lilacinus

58.3.2 *Planococcus citri*

Ayyar (1940) first reported *P. citri* (Risso) on cocoa in Nilgiris and later in Kerala (Abraham and Padmanbhan 1967). This species infests shoot tips, flower stalks, foliage, stem tissues, cherelles and pods. Severe infestation of cherelles results in drying up. Infestation on mature pods results in irregular sunken necrotic lesions. Population peak occurs in July-October (Abraham and Remamony 1979). *P. citri* has also been reported on cocoa in Sri Lanka (Williams 2004). In Ghana, regression lines of log numbers per tree of *P. citri* against canopy size of the two progenies were parallel, indicating that for a given canopy size *P. citri* was 2.3 times more prevalent in trees of Series IIB (E1:C43/291XT63/967) than in T85/799XT17/359. A similar analysis with the combined numbers per tree of seven mealybug species showed that they were 1.9 times more prevalent in Series IIB than in T85/799XT17/359 trees of the same size (Bigger 1975). Resistance studies on *Planococcoides njalensis* (Laing) and *P. citri* (Risso) in cocoa indicated that progenies 85D/176A X M7/537 and T12/116 X T62/977 were judged the most resistant (Firempong 1984). In Ghana, crosses with Amelonado or T63/971 were generally more densely infested with mealybugs than those for example of NA34 and T63/967. Trees of T17/524 parentage were sparsely infested with mealybugs (Campbell 1990).

58.3.3 *Planococcus minor*

It was widely distributed throughout Trinidad but at low level. Twelve species of predators including *Diodiplosis coccidivorum* and two parasitoids, *Leptomastix dactylopii* and *Coccidoxynoides perminutus*, were able to keep the mealybug to minor status in all the locations in Trinidad (Francis et al. 2012).

58.3.4 Ant Association

Ants are always found attending mealybug colonies. Some construct tents over mealy bug colonies while some others make covered nest over colonies with mud particles. Though about seven species of ants are found associated with mealy bug colonies of cocoa in India, the Asian weaver ant, *Oecophylla smaragdina* (Fab.) and *Technomyrmex* sp. are seen attending the mealy bug colonies infesting cocoa in Southern Karnataka. Colonies of *Technomyrmex* are more prevalent on mealy bug colonies of flower cushions. The black ant *Dolichoderus bituberculatus* also attend to *P. lilacinus* (Daniel 2002). In West Africa, Crematogasterine ants attending the colonies of *P. njalensis* (Bigger (1981) indicate that incidence of West African mealybug is strongly influenced by the nature of ant fauna and the presence of planted shade trees that provide nesting sites to the associated species of *Crematogaster.*

Neochavesia caldasiae (Pseudococcidae, Rhizoecinae) and its host ant *Acropyga fuhrmanni* live in symbiosis on the cocoa tree roots at Bahia, Brazil. The mealybug antennae are used as a communication organ between the two organisms, aiming to recruit the ant to be sheltered or carried to another gallery of the nest. It is described as the "appeasement boxing": the mealybug boxes the ant with its abdominal apex when it is hustled by the ant, aiming this one far from its safe place on the root (Delabie et al 2008).

58.3.5 Management

The control of mealy bug by insecticide is usually difficult because of its habits, water repellent nature of their body covering and the protection provided by the ant-constructed nests. Hence destruction of initial foci of infestation before attaining severe proportion is very important. Destruction of highly infested plant parts and removal of alternate weed hosts in the immediate vicinity aid in reducing the mealybug population. Locate ant colonies during summer ploughing and destroy. Conservation of coccinellid lady beetles in the ecosystem. Proper pruning of cocoa branches helps some way in preventing colony build up of *O. smaragdina* (Daniel 2002). Nair (1981) indicated that foliar spraying of 0.05 % fenthion, quinalphos or dimethoate was effective against *P. lilacinus*. This could even be applied as spot spray whenever the mealy bug population was over 15 % for maintianing the population at a lower level.

When the infestation is lesser, Spraying of neem oil 3 % or fish oil rosin soap 25 g/litre was recommended. In case of severe incidence, spraying of any one of the following chemicals is recommended: Dimethoate (2 ml/litre), Profenophos (2 ml/litre), Chlorpyriphos (5 ml/litre), Buprofezin (2 ml/litre), Imidacloprid (0.6 ml/litre), Thiamethoxam (0.6 g/litre). The insecticide must be applied only after collecting the pods which are ready for harvesting (Jayaraj and Ananthan 2008). The possibility of exploiting the use of natural enemies, semiochemicals, tolerant or cocoa varieties unattractive to pseudococcids, and the sterile male technique for effective vector control are to be considered (Padi 1997).

58.3.6 Biological Control

Indigenous natural enemies, though present in all situations, are not in sufficient numbers to lower the population of mealy bugs in cocoa plantations (Daniel 2002). In India, the predators observed with mealy bugs infesting cocoa are coccinellid beetles, *Scymnus* sp., the lycaenid *Spalgis epeus* Westwood. Trials with introduced predatory beetles *Cryptolaemus montrousieri* did not give positive results (CPCRI 1986) probably due to activity of the associating attendant ant, mainly *Oecophylla smargdina*, in cocoa ecosystem. Ackonor and Mordjifa (1999) have listed the natural enemies of *Planococcoides njalensis* in Ghana. Natural enemies include two species of coccinellid predators *Hyperaspis sgregia* Mader and *Scymnus* sp., the cecidomyiid *Coccodiplosis coffeae* Barnes and six hymenopteran parasitoids including *Aenasius abengouroui* (Risbec). Cecidomyiids predating on both species of *Planococcus* infesting cocoa was reported in Southern Karnataka (Daniel 2002). Exotic parasitoid *Acerophagous papayae* was released to control *Paracoccus marginatus* infesting cocoa inter-cropped in coconut garden at Kondikulam and Alivalam villages of Pattukottai taluk in Thanjavur district in Tamil Nadu, India (http://www.thehindu.com/todays-paper/tp-national/tp-tamilnadu/parasitoids-to-control-mealy-bug--infesting-cocoa-released/article1157926.ece). In the area where *P. marginatus* alone occurs, field release of *Acerophagus papayae*, the encyrtid parasitoid @ 100 per hamlet is recommended as the best management strategy (Jayaraj and Ananthan 2008). After the complete control of ants, release predatory ladybird beetle particularly *C. montrouzieri* is to be considered to check the mealybugs on cocoa in general.

58.4 Tea

The predator *Cryptolaemus montrouzieri* was released against the mealybugs on tea (Dzhiviladze 1979). *Cryptolaemus montrouzieri* was found colonizing on sucking insects in tea gardens in China (Xuan Dai 1996). A new genus and species *Assamencyrtus jorhatensis* Singh from Assam, India, is described. This species is recorded as a primary parasitoid of coconut-mealy-bug, which has been observed as a serious

Table 58.3 List of mealybugs recorded on tea

Mealybug species	Region/country	References
Crisicoccus matsumotoi (Siraiwa)	India	Williams (2004)
Dysmicoccus impararlis sp.n.	India	Williams (2004)
Lankacoccus ornatus (Green)	Sri Lanka	Williams (2004)
Nipaecoccus viridis (Newstead)	India	Williams (2004)
	Sri Lanka	Williams (1999)
Planococcus minor (Maskell)	–	Ben-Dov (1994)
Paraputo theaecola (Green)	India	Williams (2004)
Pseudococcus theae (Rutherford)	Sri Lanka	Williams (2004)
Pseudococcus viburni (Signoret)	Iran	Abbasipour and Taghavi (2007)
Rasrococcus iceryoides (Green)	India	Ben-Dov (1994), Williams (2004)
Rhizoecus theae Kawai & Takai	Japan	Ben-Dov (1994)

pest of young coconut nuts in Assam (Singh 2006). *Rhizoecus theae* sp.n. was found infesting on the roots of tea in Japan (Kawai and Takagi 1971). In tea gardens of north of Iran, obscure mealybug *Pseudococcus viburni* (*Ps. affinis)* (Signoret) was recorded as dominant species from tea gardens. Tea mealybug density increased rapidly to an early peak in April, followed by a decline and then a low, but steady density for remainder of the season until there was another decline in November. Across the tea gardens monitored, four generations per year are indicated by peaks in crawler density (Abbasipour and Taghavi 2007). *Nipaecoccus viridis* (Newstead) was found mainly on the axils of leaves and the growth of the affected shoots in Assam (Das and Ganguli 1961). Two mealybugs, *Planococcus citri* (Risso) *Pseudococcus viburni* (Obscure mealybug), have been recorded in tea gardens of north of Iran (Table 58.3). Tea mealybug density increased rapidly to an early peak in April, followed by a decline and then a low, but steady density for remainder of the season until there was another decline in November. Across the tea gardens monitored, four generations per year are indicated by peaks in crawler density. Changes in the tea mealybug within tea tree distribution showed greater seasonal variation than its density. The most notable aspect of the within-tree distribution is that some tea mealybugs were found on the roots on all sample dates. The proportion was smallest during the June-July period, when the mealybug density was peaking (during the spring flush of growth and the harvest period). As tea mealybug population entered the warmest summer months the proportion of the population found under ground and on the lower portion of the tea trunk increased. The tea mealybug was seeking protection (probably from heat) underground (Abbasipour and Taghavi 2007).

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59 Rubber

Mani Chellappan

59.1 Species

Mealybugs are injurious to rubber (*Hevea brasiliensis*) in Sri Lanka, India, Indonesia, Egypt, Malaysia, Nigeria, Tanzania, etc. (Table 59.1). Mealybug infestation had not been a major problem on rubber until the recent introduction of the mealybug *Paracoccus marginatus* in India. Among the mealybugs infesting rubber, except *P. marginatus*, all are considered to be minor. *Ferrisia virgata* were found attached to the roots hanging down from an African rubber tree (http://bugguide.net/node/view/148641/bgpage).

59.2 Damage

Both crawlers and adult female mealybugs feed on the sap of rubber plants by inserting their stylets into the epidermis of the leaf, tender shoots, main stem, inflorescence, as well as the fruit. Due to the feeding, the leaves showed chlorosis, plant stunting, leaf deformation, early leaf and fruit drop, heavy buildup of honeydew and consequent sooty mould development on all plant parts, and drying of worst affected branches (Mani Chellappan 2010).

Mealybug *P. marginatus* infestation on rubber plants

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Table 59.1 List of mealybugs recorded on rubber in different countries

Mealybug species	Country	Reference
Dysmicoccus sp.	Sri Lanka	Jayasinghe (1999)
Ferrisia virgata (Cockerell)	India	–
	Florida	http://bugguide.net/node/view/148641
	Sri Lanka	Jayasinghe (1999)
Leptorhizoecus deharvengi (Williams)	Indonesia	Williams (2004)
Maconellicoccus hirsutus (Green)	Egypt	Hall (1921)
Paracoccus marginatus (Williams and Granera de Willink)	Sri Lanka	Galanihe et al.(2010)
	India	Mani Chellappan (2010): Lyla and Philip (2010) Jacob Mathew (2011)
Phenacoccus manihoti (Matile-Ferrero)	Nigeria	Iheagwam (1981)
Planococcus citri (Rosso)	Sri Lanka	Jayasinghe (1999), Hill (2008)
Planococcus minor (Maskell)	Malaysia	Williams (2004)
	Minnesota	Venette and Davis (2004)
Planococcus tanzaniensis (Cox)	Tanzania	Ben-Dov (1994)
Planococcus tanzaniensis sp. (nov.)	–	Cox (1989)
Pseudococcus cryptus (Hempel)	Malaysia	Williams (2004)
Pseudococcus maritimus (Ehrhorn)	Sri Lanka	Jayasinghe (1999)
Rastrococcus iceryoides (Green)	Sri Lanka	Jayasinghe (1999)
Rasrococcus spinosus (Robinson)	Malaysia	Williams (2004)

In Gampaha and Colombo districts of Sri Lanka, *P. marginatus* has spread to rubber nurseries, immature and mature rubber plantations in rubber-growing districts. Especially, the papaya mealybug disease infected only the rubber plants or trees which are around the infected papaya trees. The main reason for this unfortunate incidence is that proper steps have not been taken timely to control. Papaya mealybug infections are typically observed as clusters of cotton-like masses on the rubber leaf blades, leaf stems, and immature apex. The damage symptoms can be clearly seen on the lower surface of the leaf. The premature leaf fall, deformation of apex, and leaf curling may occur due to the sap-sucking by the mealybug. In addition, it can be observed that a fungus called sooty mould grows on the excreta of this insect. The severely infected trees eventually died (http://www.plantationindustries.gov.lk/ dwnlds/ plantation/8.pdf).

59.3 Natural Enemies

In southeastern Nigeria, *Phenacoccus manihoti* on Cerea rubber tree (*Manihot glaziovii*) was found to be attacked by *Spalgis lemolea* (Druce) and *Chrysopa* sp. (Iheagwam 1981).

59.4 Spread

Newly emerged nymphs of *P. marginatus* were greenish yellow, with oval-shaped body. Crawlers dispersed after emergence from the ovisac and started feeding. Active crawling of the early nymphal instars, wind-aided dispersion, through phoretic ants, bursting rubber seeds which reach 15–18 m away from the parent tree, infested fallen leaves and cover crops. All vegetation in and around the rubber plantation, viz., *Eupatorium odoratum* (*Chromolena oderata*), *Berrari sp., Lantana aculeata, Mimosa pudica, lmpertala cylindrica*, and a variety of other plants had papaya mealybug infestation, including glyricidia. Mulching with dry leaves, grass cuttings, and cover crop looping around the plant, is recommended as a cultural operation for rubber nurseries, and young seedlings also aggravated the problem. Also, the abnormal leaf fall in rubber caused by the fungi *Phytophthora palnivora* during wet weather coupled with humid condition and powdery mildew disease caused by fungus *Oidium heveae steinm* on newly formed tender flush during the refoliation period of January to March (symptoms including tender leaves with ashy coating curl, crinkle, edges roll inward and fall, leaving the petit. Die-back of twigs also follows. On older leaves, white patches appear causing necrotic spots affecting flower and tender fruits, which are shed affecting seed production) suppressed the actual symptom of the mealybug on rubber (Mani Chellappan 2010).

59.5 Management

Cultural management includes inspecting all papaya, temple trees, and other susceptible hosts in and around rubber plantations; burning and destroying the severely infected trees/parts of trees immediately; avoiding transportation of infested plant material; avoiding pruned, infested plant parts being left unattended or being placed in garbage bins or vehicles; washing the insects off the plants with a powerful water jet; wrapping polythene/spongy tapes impregnated with insecticides around tree trunks to exclude ants from the canopy; and unsettling the crawlers with a jet of water.

59.6 Chemical

Spraying soap solution (5 %) to dissolve the wax and expose the mealybug body to various methods of management and use of tobacco decoction (2 %) or neem oil emulsion (1–2 %) as spray were recommended to control the mealybugs. Application of thiamethoxam 25 %WG (@ 1 g/L, imidacloprid 480 SL (@ 1 mL/L), acetamiprid 20 % (1 *g* in 1 L of water), and mineral oil (@ 5 mL/L) was recommended to control *P. marginatus* (Galanihe et al. 2010). Acephate, carbaryl, chlorpyrifos, diazinon, dimethoate, malathion, and white mineral oils (Mani Chellappan 2010), dimethoate EC 40 % (1 mL in 1 L of water) / imidacloprid 20 % (1 mL in 1 L of water)/thiamethoxam 25 % (1–2 g in 1 L of water)/ acetamprid 20 % (1 g in 1 L of water) (http:// www.plantationindustries.gov.lk/ dwnlds/ plantation/8.pdf) were recommended to control *P.marginatus* on rubber.

59.7 Biological Control

Biological control includes spraying entomopathogenic fungus, viz., *Verticilium leccanii* (10 g/L) in 5 % soap solution, encouraging the lepidopteran predator, *Spalgis epeus* and release of aphelinid *Acerophagus papayae* (Noyes and Schauff). The parasitoid was found highly successful in suppressing *P. marginatus* on rubber. Kerala accounts for 92 % of the total area in India under rubber cultivation, that is, 5.17lakhs ha. Average production is 1949 kg/ha. Average price is Rs. 16–19/kg; Yield reduction – 10 %; Total infested area–49,500 ha; Saving Rs. 17.85 lakhs (Mani Chellappan 2010).

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Cashew

60

V. Ambethgar

Mealybugs are injurious to cashew plantations in India, West Africa, Tanzania, Thailand, etc. (Table 60.1).

In India, severe incidence of mealybugs was observed on cashew in Maharashtra (Godse et al. 2003), Tamil Nadu (Ambethgar et al. 2000), Kerala, Karnataka, and Andhra Pradesh (Ambethgar 2011). In South India, the first outbreak of *F. virgata* on cashew was discovered during February–March 1998 in Cuddalore district of Tamil Nadu. *Ferrisia virgata* is largely dominant across the cashew-growing areas (Ambethgar et al. 2000).

Cashew infested with *Ferrisia virgata*

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Table 60.1 List of mealybugs recorded on cashew in different countries

Mealybug species	Region/country	References
Crisicoccus hirsutus (Newstead)	Zanzibar and Pemba Islands	Williams (2004)
Crisicoccus longispilosus (De Lotto)	Zanzibar and Pemba Islands	Williams and Matile-Ferrero (2005)
Dysmicoccus brevipes (Cockerell)	Africa	De Lotto (1964)
Ferrisia virgata (Cockerell)	India	Ambethgar et al. (2000);Williams (2004); Maruthadurai et al. (2012)
	Africa	De Lotto (1964)
	Tanzania	Williams (1996)
Formicoccus nijalensis(Laing)	West Africa	Strickland (1947); Ben-Dov (1994)
Maconellicoccus hirsutus (Green)	India	Lad et al.(2013)
Paracoccus marginatus (Williams and Granara de Willink)	India	Chellappan et al. (2013)
Phenacoccus solenopsis (Tinsley)	India	Maruthadurai et al.(2012)
Planococcoides nijalensis (Laing)	–	Ben-Dov (1994)
Planococcus citri (Risso)	India	Rai (1984); Maruthadurai et al. (2012)
Planococcus flagellates (DeLotto)	Africa	De Lotto (1964)
Planococcus lilacinus (Cockerell)	India	Rai (1984); Maruthadurai et al. (2012); Ambethgar et al. (2000)
Planococcus minor (Maskell)	India	Williams (2004)
	The United States	Venette and Davis (2004)
Plotococcus neotropicus (Williams de Granara)	Neotropical region	Ben-Dov (1994)
Pseudococcus longispinus (Targioni -Tozzetti)	Tanzania	Maniania (2011)
	Mozambique	Topper (2002)
Rasrococcus spinosus (Robinson)	Thailand	Williams (2004)

Around the same period in 2001, there was another major outbreak of mealybug species *Planococcus citri* in the cashew-growing regions of Villupuram district of Tamil Nadu. These mealybugs were widespread and recorded in eight other cashew-growing locations in Tamil Nadu. In Africa, *Pseudococcus longispinus* is a potential pest of cashew in parts of Tanzania and Mozambique (Topper 2002).

60.1 Damage

All the commercially available graftedcashew varieties are susceptible to the mealybug infestations at varying extent. Mealybugs have syringe-like sucking mouthparts that feed on

Planococcus citri damage

P. marginatus damage

F.virgata damage

The plant's phloem, which contains the nutrients needed for mealybug development. As mealybugs digest their food, they excrete sugar-rich fluid called 'honeydew'. Mealybugs also exude fibrous, white waxy beard that hangs from the tree trunk and branches. In cashew, mealybug infestations are more often confined to short periods, synchronizing with flushing through the fruiting season (February-May) rather than the remaining periods of the dormant season. Both nymphs and adults prefer to feed on the tender shoots, nodes, petioles, leaves, inflorescence, flower panicles, or developing fruit clusters which are soft and succulent. Mealybugs, while desapping the plants, inject salivary toxins, which resulted in malformed leaves, reduced plant vigor, stunted growth, and occasional death of branches. Severely infested cashew trees could be easily sighted even from a distance by their sickly appearance. On susceptible trees, affected leaves showed a characteristic curling/premature senescence (yellowing), similar to the damage caused by viruses. If flower blossoms were attacked, the fruits could set poorly. When fruits are infested, they could be entirely covered with the waxy white coating of the mealybug. Heavy infestation could lead to fruit rot drop, or fruits remained on the bunch in a shriveled and dry condition. Sometimes, the whole plants may wilt and become stunted. New growth may become distorted.

More importantly, the direct sap feeding on developing fruit clusters results in ill-filled nut meal/kernel formation, improper shell-split, and reduced shelling outturn, which ultimately impair the market value of cashewnuts. Besides, mealybug causes indirect physical damage as they excrete the carbohydrate-rich clear sticky honeydew which can accumulate on the foliage and fruit clusters, and supports the growth of black sooty mold fungus. Though honeydew can be dissolved even by a slight rain, they readily dry in warm temperatures. When mealybug populations are severe, honeydew can accumulate to form a hard, wax-like layer that covers the infested plant, which clog stomatal openings and impede gas exchange and respiration. Undoubtedly, honeydew serves as a substrate for the development of black sooty mold fungi (*Capnodium* species) that can result in further plant damage, because it hastens the germination of sooty molds, which block light from the leaves and impede photosynthetic efficiency of plants. The honeydew and sooty mold contamination may also impair the quality of the cashewnut (Ambethgar et al. 2000). Additionally, the feeding punctures resulting from mealybug infestation facilitate secondary infection of twig-blight disease caused by *Pestalotia microspora* (Ambethgar 2011).

Severe outbreaks of mealybug have been reported on cashew, adversely affecting the yield of cashewnut over 80 % in extreme cases in the state of Tamil Nadu, India. Aapparent yield losses in terms of raw cashewnut have been reported to be varying from 7 to 16 % and 23–50 % during 1998–1999 and 2003–2004, respectively (Ambethgar 2011). Such a massive yield losses occur when mealybugs infest fruit clusters or excrete honeydew that covers fruit and foliage.

60.2 Seasonal Occurrence of Mealybugs

Temperature is the driving force for mealybug upsurge. The maximum mealybug population was found when dry and humid conditions prevail from March to May. There has been positive correlation between temperature and mealybug population, and also significant negative correlation with relative humidity and total number of rainy days on mealybugs. The population of *F. virgata* is abundant during January–May, coinciding with active new flushing, flowering, and fruit development periods of cashew in cashew orchards. Four to five generations are completed. The rapid population increase in summer is followed by an equally rapid decline after harvest. Low precipitation of Northeast seasonal monsoon (October–December) is found to be favorable for the early buildup of mealybugs under the climatic conditions of Tamil Nadu. Once Southwest monsoon (May–June) sets in due to heavy downpour of rain, mealybugs are washed out. Due to increase in humidity and decrease in the temperature, the mealybug population declines and becomes almost negligible. Continuous monsoon, low temperature, and humidity are detrimental for mealybug development (Abdul Rahiman et al. 1995).

60.3 Association of Ants with Mealybugs

Four ant species, viz., *Anoplolepis longipes* (Jerdon), *A. gracilipes* (Smith), *Tapinoma indicum* (Ingar), *T. melanocephalum* (Fabricius) (Rickson and Rickson 1998), and seven species, namely *Camponotus compressus* (Fabricius), *C. sericeus* (Fabricius), *Crematogaster* sp., *Diacamma rugosum* (Le Guill), *Monomorium latinode* (Forel), *Oecophylla smaragdina* (Fabricius), and *Technomyrmex* sp. (Ambethgar 2002b) were found to be associated with mealybugs in cashew ecosystem. Mealybugs are known to bribe ants with their sugary secretion called honeydew, and in return, ants help in the spreading of mealybugs and provide them protection from predators, parasitoids, and other natural enemies (Bentley 1977). Most often, colonies of *M. hirsutus* are attended by red weaver ant *Oecophylla smaragdina.* These ants are known to attack the natural enemies of mealybugs while attending the pests. Thus, ants can exacerbate mealybug pest problems by disrupting the natural enemy activity in cashew.

M. hirsutus attended by *O.samaragdina*

F.virgata attended by *C.compressus*

60.4 Management

Prevention is better than cure. This principle is highly applicable in the management of cashew mealybugs. Mealybugs are best treated if detected early, when populations are low. Once they become established, mealybugs are very difficult to achieve effective control. Hence, a concomitant use of pest monitoring, cultural, mechanical, biological, and chemical methods of control at appropriate time have to be integrated for long-term management of mealybugs and to reduce the yield loss.

60.5 Mealybug Monitoring

Farm-level regular monitoring, early detection, and isolation of infested plants are important to avoid outbreaks. Visual plant inspection is an efficient way to detect early mealybug infestations. Early infestations can be easily overlooked due to the mealybugs' tendency to hide in protected locations. Presence of white flecks or waxy residues along the leaf midribs, on leaf or stem axils, and on the underside of leaves is an indication of mealybug infestation. Honeydew, sooty mold, and the presence of ants may also be indications of mealybug infestation.

60.6 Cultural Management

In orchards, individual cashew trees should be maintained in a healthy condition, avoiding water stress by providing proper mulches around the perimeter zone of trees. Clean orchard maintenance and proper fertility are important components of plant health management. If only a few plants are infested, selective removal and elimination of mealybug colonies at the initial pest infestation (January–February) can reduce the pest load and prevent further attack (Ambethgar et al. 2000). Collection and destruction of the mealybug-borne plant residues and dry foliage amidst infested trees during nut harvest (March–April) is beneficial to prevent further spread of the pest. Postharvest sanitation pruning of cashew trees by judicial shearing of lanky and unthrifty twigs during dormant periods during June–July, and their prompt clearing may help to improve the overall health of orchards. Removal of alternate weed hosts and destruction of ant colonies within the orchards are desirable to prevent mealybug invasion. Water-stressed plants may also be more susceptible to mealybugs. If feasible, a forceful or high-pressure water spray, at least twice per week, is effective in dislodging or removing all life stages of mealybugs (eggs, crawlers, and adults) quickly, thus preventing the occurrence of outbreaks. On the other hand, certain environmental conditions (e.g., temperature) and luxuriant plant growth may increase the mealybug population. For example, cashew plants irrigated frequently and that receive high concentrations of a nitrogen-based fertilizer tend to be more susceptible to mealybugs.

60.7 Biological Control

The current thrust in mealybug management is to promote the biocontrol agents. Natural enemies such as parasitoids, predators, and pathogens occasionally exert significant control of mealybugs on cashew (Ambethgar et al. 2000). In cashew orchards, natural biological control is often restricted by the frequent use of insecticides that kill these natural enemies. In cashew orchards, *F. virgata* was found parasitized by *Blepyrus insularis* (Cameron) with 15 % parasitism. Release of *Cryptolaemus montrouzieri* can give excellent control of *Ferrisia virgata* as in the case on guava ecosystem (Mani et al. 1990). Similarly, *P. citri* on cashew was found parasitized by *Angyrus pseudococci* under field conditions with a mean parasitism of 23.0 % on cashew in Tamil Nadu. *Planococcus citri* was also found causing very severe damage to the inflorescence in Bangalore North, India. Two parasitoids, namely, *Leptomastix dactylopii* and *Anagyrus* sp., and two predators, viz., *Cryptolaemus montrouzieri* and *Spalgis epeus* were recorded on *P. cirti* infesting cashew. The Brazilian encyrtid parasitoid *Leptomastix dactylopii* (How) can be utilized in the suppression of the mealybug *Planococcus citri* infesting cashew. Field infections of *Beauveria bassiana* (Bals.) (Vuill.), *Metarhizium anisopliae* (Metsch.) (Sorokin), and *Verticillium lecanii* (Zimm.) (Veigas) on *F. virgata* were reported on enzootic levels in cashew ecosystem (Ambethgar 2002a; Ambethgar and Bhat 2008). Topical spray of *B. bassiana* (2×10^8 conidia/mL) @ 50 g/100 mL of water produced highest mortality of 76.33 % at the end of the 21st day (Ambethgar and Bhat 2008).

60.8 Use of Botanical Pesticides

Foliar application of neem seed kernel extracts (NSKE) (10 % at weekly intervals) provided good control of *F. virgata* on cashew (Ambethgar 2011). Foliar spray of neem oil–soap emulsion (3 % at weekly intervals) is reported to control mealybugs on cashew. For organic cashew farming, neem oil and fatty acid soaps may be beneficial (Mahapatro 2008; Sunitha et al. 2009).

60.9 Chemical Control

Many organophosphates are effectively used for the control of mealybugs. Spray application of dichlorvas 75 WSC @ 1.5 mL/L in combination with fish oil resin soap @ 25 g/L was found to be effective in controlling the striped mealybug *F.*

virgata on cashew (Ambethgar et al. 2000). Sprays of malathion (0.05 %) or monocrotophos (0.05 %) or phosphamidon (0.03 %) or dimethoate (0.03 %) were recommended for the control of *F. virgata* on cashew (Ambethgar 2011). Use of chlorpyriphos 20 EC @ 2.5 mL/L offered adequate control of mealybugs in cashew. Foliar sprays of dichlorvas (0.05 %) was most effective, recording 93.5 % mealy bug reduction over control in 10 days after first spray, and contributed to a maximum nut yield (1200 kg/ha (Ambethgar 2011). Triazophos (0.05 %) and profenophos (0.05 %) were at par and recorded 91.2–92.5 % reduction of mealybug over control, and contributed to the nut yield of 1100–1125 kg/ha.

Currently, newer insecticides in the group of neonicotinoids with more novel modes of action have also gained in popularity for control of mealybugs. Thiamethoxam (0.003 %) and imidacloprid (0.005 %) were at par and recorded 91.2–92.5 % reduction of mealybug over control with nut yield of 1100–1125 kg/ha (Ambethgar 2011). Insecticides recommended for control of mealybugs in cashew production are carbaryl 50 WP (2.0 g/L), acephate 75 SP (1.0 g/L), chlorpyriphos 20 EC (2.5 mL/L), dichlorvas 76 WSC (1.5 mL/L), dimethoate 30 EC (2.0 mL/L), malathion 50 EC (2.0 mL/L), monocrotophos 36 WSC (1.5 mL/L), phosphamidon 75 EC (1.0 mL/L), profenophos 40 EC (1.5 mL/L), triazophos 40 EC (2.0 mL/L), imidacloprid 17.8 SL (0.5 mL/L), thiamethoxam 25 WG (0.5 mL/L), and azadirachtin 0.03 EC (3.0 mL/L).

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61 Oil Palm

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Mealybugs are injurious to oil palm (*Elaeis guineensis*) in Angola, India, Ecuador, Colombia, Malaysia Indonesia, Maldives, etc. (Table 61.1)

Corley and Tinker (2007) reported mealybugs as pests attacking leaves and fruits in oil palm nursery as well as on field palms. Some species live on the roots of *Elaeis*, such as *Dysmicoccus brevipes* (Cockerell) in Ecuador (Mariau 2001). *Geococcus johorensis* (Williams), when found originally in Malaysia on the roots of oil palm (*Elaeis guineensis*), was reported as causing yellowing and early dieback of the leaves. The striped mealybug (*Ferrisia virgata*) is known to infest African oil palm (*Elaeis guineensis*). *Palmicultor palmorum* (Ehrhorn) was reported on oil palm in India, infesting spear leaves (Ponnamma 1999).

61.1 Damage

Both *Pseudococcus* and *Palmicultor* species attack spindle leaves of young plants, resulting in the yellowing of unfolding leaves and stunted growth of the palm. *Dysmicoccus* spp. are known to infest the oil palm fresh fruit bunches by sucking the sap from the mesocarp. When the harvest is delayed, there will be severe loss to ripe fruit bunches. The mealybug attack leads to loosening of the fruits, which leads to premature fruit drop. *Dysmicoccus brevipes* infests inflorescences and also unripe and ripe oil palm fruits (Dhileepan and Jacob 1992; Ponnamma 1999). Mealybug infestation has been reported on irrigated oil palms of India (Kochu Babu and Kalidas 2004). The mealybug incidence is found to increase with the age of the palms.

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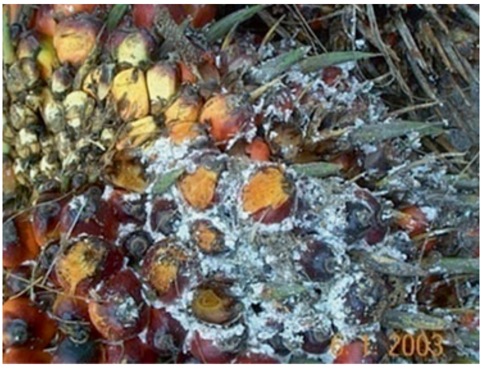

Pseudococcus citricutus on spear leaves

Dysmicoccus brevipes on Fruit Bunch

Table 61.1 List of mealybugs recorded on oil palm in different countries

Mealybug species	Country/Region	Reference
Cyperia angelica (De Lotto)	Angola	De Lotto (1969), Ben-Dov (1994)
Dysmicoccus brevipes (Cockerell)	India	Ponnamma (1999), Williams (2004)
	Ecuador	Mariau (2001), https://www.plantvillage.com/topics/oil-palm/infos
	Colombia	Orellana and Vera (1989)
	Africa	http://www.infonet-biovision.org/default/ct/94/pests
Dysmicoccus cocotis (Maskell)	Neotropical region	Williams and Granara de Willink (1992)
Ferrisia virgata (Cockerell)	Neotropical region	Williams and Granara de Willink (1992)
Geococcus johorensis (Williams)	India	Williams (1969)
Nipaecoccus nipae (Maskell)	Ecuador	Mariau (2001); https://www.plantvillage.com/topics/oil-palm/infos
Palmicultor palmorum (Ehrhorn)	India	Williams (2004)
	Ecuador	Mariau (2001); https://www.plantvillage.com/topics/oil-palm/infos
Pseudococcus citricutus (Green)	India	Dhileepan and Jacob (1992), Kochu Babu and Kalidas (2004), Kalidas (2012), Kalidas et al. (2002)
Pseudococcus cryptus (Hempel)	India, Malaysia Indonesia, Maldives	Williams (2004)
	Neotropical region	Williams and Granara de Willink (1992)
Rhizoecus nr. *americanus* (Hambleton)	Colombia	Orellana and Vera (1989)
Cyperia angolica (De Lotto)	Angola	Ben-Dov (1994)
Dysmicoccus hambletoni (Williams and Granara de Willink)	*E. guineensis*	Ecuador
Nipaecoccus nipae (Makell)	–	Ben-Dov (1994)

61.2 Management

Since mealybugs are often carried by ants, elimination of the pest can easily be done by control of ants and by keeping the garden hygienic. Poor hygienic conditions/sanitation practices are the major criteria for endemic infestation. Leaf pruning and weeding at regular intervals are found to keep the plantation free from the pest attack. Mealybug *Dysmicoccus brevipes* can potentially be controlled by natural enemies such as lady beetles, but are commonly controlled using chemicals; chemical pesticides may also decrease the populations of natural enemies, leading to mealybug outbreaks (Kalidas 2011; https://www.plantvillage.com/topics/oil-palm/infos). When the mealybugs become serious and are widespread, host-specific natural enemies can be utilized to control the mealybugs infesting oil palm.

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Spices

62

S. Devasahayam and T.K. Jacob

Mealybugs are injurious to spice crops like black pepper, cardamom, ginger, turmeric, etc. The mealybug species recorded on various spice crops in different regions are listed in Table 62.1.

62.1 Black Pepper (*Piper nigrum*)

In Indonesia, *Planococcus citri* and *Ferrisia virgata* are reported to infest the aerial parts (shoots, leaves, spikes, and berries) of black pepper vines (Kueh et al. 1993). In Sri Lanka, *P. citri* is reported to infest the roots of black pepper vines (Dharmadasa 2000), whereas in China, *Planococcus* sp. and *P. lilacinus* in Vietnam are known to infest the roots of black pepper vines (Sarma 2010). Twelve species of mealybugs are known to infest black pepper in India, and among them, the root mealybugs are the most severe (Devasahayam et al. 2009). According to these authors, the mealybugs *Planococcus* sp., *Planococcus citri*, *Planococcus lilacinus, Ferrisia virgata*, and *Dysmicoccus brevipes* are known to infest the roots and basal regions of black pepper vines in India and were confined to certain parts of Kerala and Karnataka states. In Kerala, root mealybug infestations on black pepper were observed in all the taluks surveyed in Wayanad (Kerala). The pest infestation was also observed in Udumbanchola (Idukki district), Kozhikode (Kozhikode district), and Taliparamba (Kannur district) taluks in Kerala. The pest infestation was higher in Wayanad (8.0–21.1 %) and lower in Idukki (0–3 %). Stray infestations of the pest were also observed in Kozhikode and Kannur districts in Kerala. Among the taluks in Kerala, the percentage of vines infested by root mealybugs was higher in Vythiri (21.1 %) taluk. In Karnataka state, mealybug infestation was confined to Kodagu and Hasan districts (Alur and Saklespur). Mealybug infestation was higher in Kodagu (1.7–15.1 %) district and lower in Hassan (0–4.4 %) district. Among the taluks in Kodugu district, the percentage of vines infested by root mealybugs was higher in Virajpet (15.1 %) taluk. Based on the distribution pattern, it was concluded that a highly significant and positive correlation (r=0.451**) was observed between the pest infestation and altitude of the location. A mean of 0.1 % of vines were infested at lower altitudes (0–250 m above MSL) when compared to 8.9 % at higher altitudes (751–1000 m above MSL).

62.1.1 Damage

In India, the incidence of mealybugs infesting the aerial parts of the vine (all species combined) was highest in Kasargod district (Kerala),

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Table 62.1 List of mealybug species recorded on different spice crops

Mealybug species	Country	Reference
Black pepper (*Piper nigrum*)		
Dysmicoccus brevipes (Cockerell)	India	Devasahayam et al. (2009)
Ferrisia virgata (Cockerell)	India	Rao (1926)
	Indonesia	Kueh et al. (1993)
	Singapore	Williams (2004)
Formicoccus polyspheres sp.n.	India	Ramanujam et al. (2013)
Planococcus sp.	India	Koya et al. (1996)
	China	Sarma (2010)
	Vietnam	Sarma (2010)
Planococcus citri (Risso)	India	Nayar et al. (1976)
	Indonesia	Kueh et al. (1993)
	Sri Lanka	Dharmadasa (2000)
Planococcus lilacinus (Cockerell)	China	Sarma (2010)
Planococcus lilacinus (Cockerell)	India	Devasahayam et al. (2009)
Planococcus minor (Maskell)	India	Koya et al. (1996)
	Indoneasia, Maldives, Malaysia	Williams (2004)
Pseudococcus sp.	India	Koya et al. (1996)
Pseudococcus longispinus (Targioni-Tozzetti)	India	Koya et al. (1996)
Pseudococcus orchidicola (Takahashi)	India	Koya et al. (1996)
Cardamom (*Elettaria cardamomum*)		
Planococcus sp.	India	Narasimham (1987)
Planococcus citri (Risso)	India	David and Ananthakrishnan (2004)
Phenacoccus solenopsis (Tinsley)	Pakistan	Arif et al. (2009)
Dysmicoccus debregeasiae (Green)	India and Sri Lanka	Williams (2004)
Dysmicoccus subterreus sp.n.	India	Williams (2004)
Ginger (*Zingiber officinale*)		
Pseudococcus sp.	Fiji	Ernhorn and Whitney (1926)
Dysmicoccus brevipes (Cockerell)	Africa	Anonymous (2012)
	Indonesia	Williams (2004)
Ferrisia virgata (Cockerell)	India	Williams (2004)
Formicoccus polyspheres sp.n.	India	Williams (2004)
Niapecoccus nipae (Maskell)	–	Ben-Dov (1994)
Pseudococcus cryptus (Hempel)	Thailand	Williams (2004)
Rhizoecus amorphophalli (Betrem)	India, Java, and Hawaii	Williams (2004)
Phenacoccus parvus (Morrison)	Ethiopian, Neotropical, and Pacific region	Ben-Dov (1994)
Turmeric (*Curcuma longa*)		
Planococcus sp.	India	Devasahayam (2006)
Planococcus citri (Risso)	Sri Lanka	Williams (2004)
Paracoccus marginatus (Williams and Granara de Willink)	India	Chellappan et al. (2013)
Maconellicoccus hirsutus (Green)	India	Bhatt (2010)
Rastrococcus iceryoides (Green)	India	Williams (2004)

(continued)

Table 62.1 (continued)

Mealybug species	Country	Reference
Betel vine (*Piper betle*)		
Dysmicoccus brevipes (Cockerell)	India	Williams (2004)
Formicoccus polyspheres sp.n.	India	Williams (2004)
Geococcus citrinus (Kuawna)	India	Williams (2004)
Coriander (*Coriandrum sativum*)		
Paracoccus ferrisi (Ezzat and McConnel)	Mexico	Ben-Dov (1994)
Cinnamon (*Cinnamomum verum*)		
Rastrococcus lamingtoniensis (Williams)	Australia	Ben-Dov (1994)

followed by Idukki district (Kerala), wherein 2.7 and 2.3 % of leaves of affected vines (5.4 %) were infested (Koya et al. 1996). The aerial infestation of mealybugs such as *F. virgata* and *P. citri* is mainly seen on tender shoots, leaves and spikes, especially in the nursery. *Planococcus minor*, *P. longispinus*, and *P. orchidicola* are generally encountered within old leaf galls induced by leaf gall thrips (*Liothrips karnyi* Bagn.), probably due to the conducive microclimatic conditions within them (Devasahayam 2000). In nursery plants, infestations by *F. virgata* and *P. citri* result in wilting of the affected parts.

Ferissia virgata on black pepper

Colonies of root mealybugs are distributed on the main, secondary, and tertiary roots, basal region of stems on rooted cuttings in the nursery, and also on the vines of all age groups in the field. The mealybug colonies are observed even up to a depth of 2 ft below the soil in severely affected vines. The infestation on the basal regions of the stem is seen under the soil and also when they were covered with mulch. The pest infestation results in defoliation, yellowing and wilting of leaves and lateral branches, and also mortality of vines in severe cases of infestation (Devasahayam et al. 2009). Various intercrops (coconut, arecanut, coffee, banana, colocasia, cardamom, and turmeric) grown in black pepper gardens were found infested with root mealybugs. Root mealybug infestations were observed on black pepper vines trailed on all standards (support trees like silver oak, *Erythrina* spp., and jackfruit) (Devasahayam et al. 2009). Continuous infestation without proper management leads to gradual decline and death of the vine. The infestation is generally greater during the post-monsoon season and lesser during summer months.

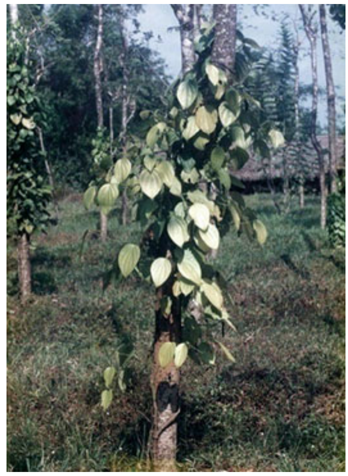
62.1.2 Associated Organisms

62.1.2.1 Pathogens

The fungus *Phytophthora capsici* (Leonian) and nematodes such as *Meloidogyne incognita* (Kofoid and White) (Chitwood), and *Radopholus similis* (Cobb) were commonly associated with root mealybug infested vines. At Wayanad and Kozhikode districts, all the root mealybug infested vines examined ($n = 104$) were also infested with either *Phytophthora* and nematodes or both. The infested vines exhibited symptoms such as rotting of roots, absence of feeder roots, yellowing and wilting of leaves, defoliation, and mortality of vines that are characteristically associated with *P. capsici* and nematode infections. At a few locations in Wayanad district, the root mealybug colonies were covered with a fungus (unidentified) which formed a soil-encrusted globular covering lined with mycelium. The mealybug associated with the fungus was identified as an undetermined species of *Planococcus* sp. The other species of root mealybugs were not covered with the fungus (Devasahayam et al. 2009).

Root mealybug infestation on the basal region of the stem

Root mealybug infestation on rooted cuttings in the nursery



Phytophthora and nematode association with root mealybug infestations in the field

The fungus *Diacanthodes philippinensis* (Pat.) (Singer) is reported to be associated with *P. lilacinus* on coffee in India, and whenever both occurred together, the plants wilted and died. Infestation by the mealybug alone did not cause the death of coffee plants (Sekhar 1964; Chacko and Sreedharan 1981). In Africa, the coffee root mealybug, which was earlier identified as *P. citri* and associated with the fungus *D. novoguineesis* (Hennings) Fidalgo, has been later described as a new species, *P. fungicola* (Watson and Cox 1990). The fungus is considered as a symbiont providing protected cavities on the root surface in which the mealybugs live in return for the sugars in the honeydew excreted by them and in the sap that escapes from the insects feeding punctures in the roots (Fidalgo 1962).

Ferrisia virgata and *P. citri* were identified to transmit Piper Yellow Mottle Virus (PYMoV), the badnavirus, causing stunt disease which is increasingly becoming serious, especially at higher altitudes in Wayanad and Kodagu districts in Kerala and Karnataka (Bhat et al. 2003a, b, 2005)

62.1.3 Ants

Three species of ants, namely, *Anaplolepis* sp., *Crematogaster* sp., and *Technomyrmex* sp., and two unidentified species were associated with root mealybug colonies. In many cases, it was easier to identify infested vines based on the activity of the ants (Devasahayam et al. 2009).

62.1.4 Natural Enemies

On black pepper, *Leptacis* sp. (Platygasteridae) and *Blepyrus insularis* (Cam.) (Encyrtidae) were found parasitizing *Pseudococcus* sp. and *F. virgata*, respectively, infesting on the aerial parts of the vine (Devasahayam and Koya 1998). Larvae of *Spalgis sp.* (Spaligidae) were observed to predate on root mealybug colonies, especially those at the base of the stems (Devasahayam et al. 2009).

62.1.5 Management

Microbial Pathogens The fungal pathogen *Metarhizium anisopliae* (Metsch.) (Sorokin) was found to cause 79.6 % reduction in mealybug population, 30 days after treatment under laboratory conditions (Devasahayam and Koya 2000).

Natural Products Alcoholic extracts (3 %) of *Azadirachta indica* and *Vitex negundo*; tobacco extract (3 %); custard apple seed extract (2 %); and agro spray oil (3 %) are known to cause up to 75 % reduction in root mealybug population, 30 days after treatment. Among the neem products, Nimbicidine (0.5 %) was the most effective, resulting in 60 % reduction in the population of root mealybugs, 30 days after treatment (Devasahayam 2006).

Insecticides In India, imidacloprid (0.0125 %), acetamaprid (0.0125 %), and carbosulfan (0.075 %) were more promising, resulting in over 90 % reduction in the population of root mealybugs, 30 days after treatment under laboratory conditions (Devasahayam 2006). Dimethoate, parathion-methyl, and quinalphos were the most effective against the pepper mealybug *F. virgata* in Karnataka, India (Prasad Kumar et al. 1998). In Sri Lanka, cleaning the base of the vine, adopting control measures against ants, drenching the base of the plant with fipronil 50 G-SC (5 mL in 10 L of water) and applying carbofuran 3G (10–15 g per vine) (Dharmadasa 2000), or drenching the base of the vine with chlorpyriphos (28 mL in 12 L water) (Sarma 2010) have been recommended for the management of root mealybug *P. citri*. In Malaysia, spraying deltamethrin (0.1 %) at biweekly intervals, five to six times, has been suggested for the control of mealybugs such as *P. citri* and *F. virgata* affecting the aerial parts of the vine. Alternatively, spraying of albolineum (white oil) – 72 % (16.5 mL/L), not more than three times a season, has been recommended. Use of *Erythirna variegata* (L.) and *E. orientalis* (Murr.) as live supports is not advocated (Sarma 2010). In Indonesia, spraying albolineum (200–250 mL in 18 L water) or dimethoate (35–40 mL in 18 L water) or malathion (45 mL in 18 L water) has been suggested for controlling *P. citri* and *F. virgata* (Kueh et al. 1993).

62.1.5.1 Integrated Management

In India, an integrated pest management strategy for the management of root mealybugs was developed based on field trials conducted with promising insecticides and plant products. The strategy involves planting root mealybug-free rooted cuttings in the field, removal of weeds in the interspaces of black pepper vines during summer, drenching tobacco extract (3 %) or custard apple seed extract (2 %) on mildly affected vines, or drenching imidacloprid (0.0125 %) or acetamaprid (0.0125 %) or carbosulfan (0.075 %) or chlorpyriphos (0.075 %) on the affected vines, and adoption of control measures against *Phytophthora* and nematode infections (Devasahayam 2006). Adequate care should be taken to ensure that the insecticide solution percolates down to the roots while drenching the vines.

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63 Mulberry

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Mealybugs are injurious to mulberry (*Morus* spp.) in several countries (Table 63.1). Mulberry is the sole food plant of the silkworm, *Bombyx mori* L., the producer of fabulous silk which derives all the nutrients for its growth from the mulberry leaf. Mealybugs pose serious threat to mulberry cultivation mainly in India. Mulberry fruits are edible, and can be great for health in some countries. Production of appreciable quantity of quality mulberry leaf is hampered by the mealybugs in silk-producing states in India. Among the mealybug species, *Maconellicoccus hirsutus* and *Paracoccus marginatus* in plains and *Paraputo* sp. in the hilly regions caused drastic reduction in mulberry leaf yield thereby affecting the silk industry.

63.1 Pink Hibiscus mealybug, *Maconellicoccus hirsutus*

In India, Misra (1919) reported for the first time, the attack on mulberry by *M. hirsutus*. Though the pest is known to attack mulberry almost since a century, it has assumed the key pest status, especially in Karnataka, Tamil Nadu and Andhra Pradesh only about one and a half decade back (Sriharan et al. 1979; Baskaran et al. 1994). *Maconellicoccus hirsutus* was first detected on mainland US in August, 1999 in Imperial Valley, a low desert region in southern California on mulberry (Roltsch et al. 2006).

Seasonal Development In south India, though the pest is observed to infest mulberry throughout the year, the incidence was highest during summer (34.93 %) and least during winter (9.45 %) with an average incidence of 22.15 % (Hemalatha and Shree 2008; Sathya Prasad and Manjunath 1992). According to Narendra Kumar et al. (2006), in Bangalore rural district, the mealybug incidence reached its peak during April (18.79 %) and gradually started declining afterwards, and lowest incidence of 2.56 % was recorded during December. Pink mealybug passes through 10–15 generations in a year and was found active even during winter months without any hibernation (Rajadurai 2005b). Further, it completes its life cycle in 24–29 days on mulberry (Misra 1919). However, Dhahira Beevi (1989) reported that total life span of the mealybug was 30.6 days for female while it was 22.7 days for males on mulberry.

Damage Mealybugs cause damage to mulberry crop by sucking the sap from young leaves and buds. As mealybugs suck and feed, they inject into the plant a toxic saliva that results in malformed leaf and shoot growth, stunting and occasional death (Lavanya Latha et al. 2004; Rajadurai

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Table 63.1 List of mealybug species recorded on mulberry in different regions in the world

Species	Region/country	References
Atracoccus fuscus (Borchsenius)	Turkmenistan	Ben-Dov (1994)
Crisicoccus maricola Tang	Mongolia	Ben-Dov (1994)
Ferrisia virgata (Ckll.)	Egypt	Attia (2006)
Formicoccus lateens sp.n	India	Williams (2004)
Maconellicoccus hirsutus Green	India	Misra (1919), Raichoudhury (1958), Manjunath et al. (1996)
	China	Sánchez (2000)
	Brazil	de Almeida and Fonseca (2000)
	Egypt	Hall (1926)
	Canada	Garland (1998)
	California	Roltsch et al. (2006)
	Philippines	Mundo (1984)
	Pakistan	Zaman et al. (1996); Sahito et al. (2012)
	Bangladesh	Ali and Ahmed (1990)
	Iran	Fallahzadeh et al. (2002)
Nipaecoccus vastator (Maskell)	Iraq	El-Haidari et al. (1978)
Niapecoccus viridis (Newstead)	Pakistan	Williams (2004)
Paracoccus marginatus Williams and Granara de Willink	India	Mani Chellappan et al. (2013); Mahalingam et al. (2010); Shekhar et al. (2011); Prasad et al. (2012)
Paraputo sp.	India	Misra et al. (1996); Biswas et al. (2002)
Peliococcus mesaiaticus Borchsenius & Kozarzhevskaya	Afghanistan	Ben-Dov (1994)
Phenacoccus divericatus sp.n.	Pakistan & India	Williams (2004)
Planococcus citri (Risso)	Pakistan	Williams (2004)
Planococcus minor Maskell	–	Ben-Dov (1994)
Pseudococcus comstocki (Kuw.)	California	Bartlett and Clancy (1972)
	Central Asia	Kryachko (1978)
	Armenia	Oganesyan and Babayan (1979)
	Crimea (USSR)	Romanchenko and Bel'skaya (1981)
	Georgia	Kanchaveli and Partsvaniya (2009)
Pseudococcus longispinus (Targioni Tozzetti)	India	Sakthivel et al. (2011)
Pseudococcus maritimus (Ehrhorn)	Nearctic & neotropical	Ben-Dov (1994)
Spilococcus mari (Siraiwa)	Japan	Ben-Dov (1994)
Trionymus mori Lobdell	Mississippi	Ben-Dov (1994)

2005a). The damage by the pink mealybug gives disease like appearance called as 'tukra'. A heavy black sooty mould develops on the infested leaves and stem as a result of honey dew excretions by the mealybug. Earlier tukra in mulberry was mistaken for a viral disease and mealybugs were believed to be the vectors of the same (Rangaswamy et al. 1976). Later it was discovered that so-called tukra disease is only a deformity symptom caused due to pink mealybug infestation.

The extent of damage by the pink mealybug in mulberry is reported to be 34.24 % (Manjunath et al. 1996) leading to an estimated leaf yield loss of about 4,500 kg/ha/year with a cocoon crop loss of about 10–15 % (Manjunath et al. 2000; Rajadurai and Thyagarajan 2003). Due to this, the sericulturists are constrained to forego a rearing of about 450 layings/ha/year, thus reducing cocoon production by about 300–350 kg/ha/year (Kumar et al. 1995) which works out to be Rs. 60,000–70,000 annually. Severe incidence of the mealybug has been reported in Erode district (63.12 %) and least in Dharmapuri (12.06 %) and Thanjavur districts of Tamil Nadu, India (Baskaran et al. 1994). Mealybug infestation had resulted in 30 to 40 % loss in mulberry leaf yield (Nighat Mehmood 2004). In West Bengal, a leaf yield loss of 7.95 to 11.03 % has been reported (Anonymous 2011).

Eggs of *M. hirsutus*

Mealybug damage to mulberry

Female *M. hirsutus*

63.1.1 Varietal Tolerance/ Susceptibility

Pink mealybug incidence is varying in different mulberry varieties but there is no mulberry variety resistant to *M. hirsutus* available in India (Ganesan 1994). In Karnataka, among the ruling mulberry varieties, S36, S34, S13, K2 and V1, the mealybug damage was least in V1 (44 %) followed by K2 (66 %) and maximum incidence was observed in S36 & S34 (87 %) (Sathya Prasad et al. 2000). Under field conditions in Bangalore rural district, the pest was found to prefer S-36 variety (24.56 %) followed by V-1 (18.32 %) & RFS-175 (13.44 %) whereas M-5 (4.17 %) and local varieties (2.38 %) were least preferred (Narendra Kumar et al. 2006). Preference of mealybugs towards the newly evolved mulberry varieties may be attributed to high contents of moisture, sugar and protein compared to M-5 and local varieties (Savithramma and Dandin 2000). In West Bengal, among the mulberry genotypes namely Kajili, S-1, S-778, S-799, S-1301 and S-1531, the genotypes S-1 and S-799 were less susceptible to mealybug damage in Berhampore area, and on the contrary same varieties along with Tr-10 were severely affected with tukra in Ambari-Falkata area. In Sabour area (Bihar state), mealybug damage was recorded highest on mulberry in variety S-763 (22 %) followed by S-799 (18 %), S-1310, C-776, Tr-4 and Tr-10 (14 %). Varieties such as C-741, C-1608, C-1729 and C-1730 were not affected by tukra. Among mulberry varieties M-5, MR-2, Kosen, Ichinose, Gosoerami, BC2-59, Tr-4 and S-13, mealybug damage was more in Ichinose and least in Kosen and BC2-59 (Babu et al. 1994).

63.1.2 Management

Chemical Control Spraying 0.2 % dichlorvos in 0.5 % soap solution twice at an interval of 10 days and allowing 15 days waiting period before using the leaves as feed for silkworm was recommended (Anonymous 2010a). In California, mulberry trees infested with *M. hirsutus* were treated with imidacloprid and thiamethoxam which were found effective against the pink mealybug (Castle and Prabhaker 2011).

Botanicals Spraying of neem oil effectively controlled the infestation of *M. hirsutus* (Ravikumar et al. 2010). Both neem seed kernel extract and Pongamia seed kernel extract were found to be more effective than seed oils against mealybug (Narendra Kumar et al. 2006). Spraying with 0.03 % Azdirachtin was recommended for the mealybug control @ 5 ml/litre (safety period: 10 days) (Anonymous 2010a).

Cultural Method Kasi Reddy et al. (2004) reported that raising of maize as intercrop in mulberry plantation increased the population of predator, *Cheilomenes sexmaculata*, (Fabricius) doubly (44 %) compared to the mulberry without intercrop (21 %) resulting in the suppression of the pink mealybug population by 84 %. Growing cowpea as intercrop with mulberry enhances the population of predatory ladybird beetles such as *C. sexmaculata,* which initially feeds on cowpea aphids and slowly shifts over to mulberry mealybugs later (Jayaraj 2006). Sidde Gowda and Kumar (1995) recommended *Hibiscus cannabinus* as trap crop. Mealy bug population was significantly low in mulberry with the trap crop (3.14 %) compared to mulberry without the trap crop (11.44 %). As the trap crop facilitates better colonization of *M. hirsutus*, it can also pave way for preventing migration of the recommended predatory beetles from the release sites so that they can effectively suppress the population of *M. hirsutus* on mulberry. Manjunath et al. (2003) also indicated a significant difference in mealybug damage in mulberry with *H. cannabinus* (4.28 %) as trap crop compared to mulberry as sole crop (26.02 %).

Samuthiravelu et al. (2005) reported that mealybug infestation was minimized by reduced application of nitrogenous fertilizer blended with neem cake @60 kg/ac (3 %) followed by pongamia cake (4 %), mahua cake (4.4 %) and castor cake (7.9 %) compared to control with recommended dose of chemical fertilizer (20.8 %). Lavanya Latha et al. (2004) also reported that limited irrigation once in 10 days and 25 % reduced nitrogenous fertilizer applied in two split doses brought down the mealybug incidence to 1.60 % from 8.5 % in control with recommended dose of fertilizer. In addition, Narendra Kumar et al. (2006) found that mealybug incidence was more when nitrogenous fertilizer was applied as a single dose and irrigated once in 6 days than applying nitrogenous fertilizer as a split dose and providing irrigation either once in 6 days or 8 days.

Mechanical Method The mechanical control of mealybugs includes clipping of infested portion by sickle or secateur, collecting them in a polythene bag or bucket and destroying them by burning or dipping in 0.5 % soap solution (Rajadurai 2005a). According to Tomy Philip et al. (2002), chopping the affected portion and killing the mealybugs either by burning or dipping them in 0.5 % DDVP with 0.5 % soap solution after pruning or leaf harvest was found to be effective in reducing mealybug population in mulberry.

63.1.3 Biological Control

In West Bengal, India it is recommended to release predatory ladybird beetles, *Cryptolaemus montrouzieri* Mulsant @250 adults/ac or *Scymnus coccivora* Ayyar @500 adults/ac in two split releases during Oct-Nov and Jan-Feb to suppress the mealybugs (Santha Kumar et al. 1995; Anonymous 2010a).

Complete control of *M. hirsutus* was achieved in Egypt, by introducing *Anagyrus kamali* Moursi (Encyrtidae) from Java, and then later in Caribbean islands and Florida. *M. hirsutus* appeared on mulberry in California in 1999. Subsequently, the parasitoids *Anagyrus kamali*, *Gyranusoidea indica* Shafee, Alam & Agarwal (Encyrtidae) and *Allotropa* sp. nr. *mecrida* (Walker) (Platygastridae) were released for permanent establishment on mulberry trees. The population density of *M. hirsutus* within the first year was reduced by approximately 95 %. *Anagyrus kamali* was the predominant parasitoid of *M. hirsutus* (Roltsch et al. 2006). Such introduction of *A. kamali* to India should be tried against *M. hirsutus* in mulberry gardens.

63.1.3.1 Integrated Pest Management (IPM)

The Integrated Pest Management package against pink mealybug includes clipping and destruction of affected terminal portion, spraying of 0.2 % DDVP with 0.5 % soap solution and release of *C. montrouzieri* @250 adults/acre. The per cent reduction in mealybug damage ranged from 73.21 to 88.81 whereas the increase in leaf yield ranged from 3416.68 to 4750 kg/ha/year. Narendra Kumar et al. (2006) also recommended that the IPM practice involving the application of 5 % Neem seed kernel extract on 10th and 20th day after pruning (DAP) integrated with release of predatory ladybird beetles @ 250/acre and top clipping on 45th DAP proved better in controlling the mealybug wherein the pest suppression was recorded to an extent of 82.17 % (Manjunath and Katiyar (1995).

63.2 Papaya mealybug, *Paracoccus marginatus*

Paracoccus marginatus popularly known as papaya mealybug (PMB) has been accidentally introduced in to south India and posing serious threat to several crops including mulberry. It assumed the status of a major pest resulting in huge losses to farmers in Tamil Nadu, Karnataka, Kerala (Shekhar and Qadri 2009; Krishnakumar and Rajan 2009; Mahalingam et al. 2010).

63.2.1 Damage

In mulberry, the papaya mealybugs infest leaf buds, leaves, stem portion, stump portion after pruning, etc. They are found congregating all along the veins on the lower side of the leaves. Since they suck the plant sap continuously, affected leaves turn yellow and the plant growth retards. In addition to sucking of plant sap they also inject toxic substance through their saliva, which causes deformation of plant parts. Due to profuse honey dew secretion, black sooty mould secretion is also formed. When the mealybugs infest with heavy population, the plants will end up with drying and death. Due to large quantity of honey dew secretion, lots of ants will be attending to them which arrive to feed on the sweet honey dew (Shekhar and Qadri 2009).

P. marginatus

Papaya Mealybug damage to mulberry

Acerophagus papayae

63.2.2 Management

Chemical Insecticides were recommended until the importation of parasitoids in India. Profenophos 50 EC @ 2 ml/litre was the most effective in knocking down the pest population followed by dimethoate, imidacloprid, dichlorvos and acephate (Mahalingam et al. 2010). But profenophos was found to be toxic to silkworms even 60 days after spray and hence considered to be not safe to silkworms (Anonymous 2010b). Fish Oil Rosin Soap @ 25 g/litre recorded the lowest infestation (2.22 %) one day after treatment (Suresh et al. 2010).

Biological Control A total of 13 local natural enemies were reported attacking *P. marginatus* in India. *Spalgis epius* Westwood is seen devouring all the stages of the mealybug in several mulberry gardens (Sakthivel et al. 2010; Shekhar et al.

2011). However the indigenous predators are not so effective in managing the huge populations of papaya mealybug. Since *P. marginatus* is an exotic pest, a classical biological control programme was initiated, and the parasitoid *A. papayae* was imported by National Bureau of Agriculturally Important Insects (ICAR), Bangalore during July 2010 (Shylesha et al. 2010). The parasitoid was multiplied and released in farmers gardens through extension units of Department of Sericulture of the southern states of India (Qadri et al. 2011).

63.3 Impact Analysis of Classical Biological Control of Papaya Mealybug in Mulberry in South India

Tamil Nadu There was 60 % damage by papaya mealybug in Tamil Nadu (T.N.). A total area of 10,000 acres of mulberry gardens was found infested with *P. marginatus*. It was estimated that mulberry crop worth Rs. 135 crores was lost due the papaya mealybug infestation in T.N. According to Qadri et al. (2011), more than 33,000 adults of *A. papayae* were released (from Nov 2010 to March 2011) in the papaya mealybug infested mulberry gardens of 350 farmers in the districts of Erode, Tiruppur and Salem. After the release of the parasitoids, the mealybug infestation was reduced from 90 % to less than 5 % thereby achieving a suppression of 85–95 %. Similar control was achieved with the parasitoid in Trichy and in Coimbatore districts in Tamil Nadu.

Karnataka A total of 15,000 adults of *A. papayae* were released (from Nov 2010 to Jan 2011) in papaya mealybug infested mulberry gardens of 150 farmers covering about 300 acres mulberry in Chamarajanagar district. Further, a total of 20,000 parasitoids were released in Mysore district covering about 400 acres under seven Technical Service Centres (from Feb 2011 to May 2011). After the release of the parasitoids, 90–95 % suppression in papaya mealybug infestation was recorded (Qadri et al. 2011). Surprisingly the pest incidence was reduced to mere 1 % within 5–6 months of release. Saving the mulberry crop thereby increasing the cocoon production has resulted in savings to the tune of few crores of rupees in Karnataka.

Kerala *Paracoccus marginatus* appeared on mulberry in 2009 in Idukki, Wyanad, Palakkad, Malappuram, Thrissur districts of Kerala (Krishnakumar and Rajan 2009). Mulberry is cultivated in about 300 acres in Kerala. Due to release of *Acerophagus papayae* in 2011, mulberry crop worth few lakhs was saved. The success of classical biological control using *A. papayae* has emerged as an excellent model reviving the sericulture to normalcy in the entire Tamil Nadu, Karnataka and Kerala.

63.4 Root mealybug – *Paraputo* sp.

Mulberry plantations in hilly areas of Northern India such as Darjeeling and Kalimpong are being infested by root mealybug, *Paraputo* sp. (Pseudococcidae: Hemiptera) causing considerable damage. It is considered as most persistent and noxious pest (Biswas et al. 2002; Das et al. 2004; Mukhopadhyay et al. 2010). It occurs throughout the year with a peak during July-August, and the population decreases with fall in temperature during winter months (Biswas et al. 2002; Anonymous 2011). It is a noxious pest which remains in the root zone as well as adjacent to stump portion below the soil surface up to 20 cm or 3″ deep and causes damage to root system by sucking the sap (Biswas et al. 2002; Mukhopadhyay et al. 2010; Anonymous 2011). The affected mulberry becomes yellow and stunted in growth (Misra et al. 1996).

The mealybug causes appreciable damage to mulberry directly by sucking the sap and indirectly by making way for some fungal infection, leading to rotting of the root and ultimately death of the plants. The infested mulberry plants show vulnerability to the attack of various fungal pathogens such as *Fusarium solani, Phomopsis*

Root mealybug damage to mulberry

mori and *Colletotrichum gloeosporioides*. Due to this, decaying of bark portion of root and stem occurs with severe anthracnose disease. Finally, it results in the death of such severely affected mulberry plants (Biswas et al. 2002).

Highest density of this perennial pest is observed at 7.5–15 cm depth on the underground stem and root region of mulberry during June–September. The population diminishes with the fall in atmospheric temperature and humidity. Nymphal population is double *vis-à-vis* the adults (females) from March to August, and remains at par with adults during autumn and winter. The steadiness of the pest population (infestation) pattern suggests that the microclimate at 7.5–15 cm depth of the soil, i.e. at root stem transition zone was to the best of liking and most congenial for this persistent pest of mulberry (Das et al. 2004).

Citronella oil (5 %) performed better towards controlling root mealybug followed by 5 % neem oil and 5 % neem leaf extract, without any adverse effect on silkworm rearing (Anonymous 2011). Biswas et al. (2002) reported that carbofuran (3 % a.i.) and endosulfan (0.2 % a.i.) were effective in controlling root mealybug for longer period.

63.5 *Pseudococcus comstocki*

In California, the imported natural enemy complex consisted of three parasitoids, *Pseudaphycus malinus* Gah. *and Allotropa burrelli* Mues. and *A. convexifrons* Mues., plus native predators, mainly *Leucopis ocellaris* Mall. and *Chrysopa* spp. The population density of *P. comstocki* was reduced by a maximum of 68 % in East Porterville from 1972 to 1976, 71 % in Central Porterville and 73 % in West Porterville from 1974 to 1976 as a result of the newly established natural enemy complex. *Allotropa convexifrons*, the last to be established, was now the dominant parasite (Meyerdirk et al. 1981). In Odessa region of the Crimea (USSR), the mealybug *Pseudococcus comstocki* was reduced 76.8–96.8 % with the release of the exotic parasitoid *Pseudaphycus* sp. (Romanchenko and Bel'skaya 1981).

63.6 *Ferrisia virgata* (Ckll)

Ferrisia virgata (striped mealybug) appeared in severe form on *Morus alba* at Giza region, Egypt during 2004–2005. *Scymnus syriacus* Mars. was released for the control of the striped mealybug, *F. virgata* (Ckll) attacking *M. alba*. Percentage of reduction among the nymphs and adults of *F. virgata*, 30 days after releasing of the predator reached 94.08 and 68.99 %, respectively, and 99.76 % after 100 days for nymphs and 92.27 % for adults (Attia 2006).

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64 Tobacco

M. Mani and G.N. Rao

64.1 Species

Mealybugs are found to be injurious to tobacco (*Nicotiana tabacum*) in India, Zimbabwe, Africa, Italy, Argentina, etc. (Table 64.1). *Phenacoccous solenopsis* (Tinsley) has been reported both in the nursery and fields in India (Rao 2009; Bhatt 2010). Heavy infestation of *P. solani* has been reported to be found in Zimbabwe.

64.2 Damage

P. solenopsis appears in early sown tobacco nurseries and multiplies in large number and causes damage to young leaves by sucking sap from the succulent leaves. The affected leaves show puckering symptoms and become brittle during the later course of development. As many as 19 mealybugs were recorded in each nursery bed. In the main field, mealybug damage was also observed. The mealybugs were found on the ventral side of the lower leaves, and they were found to suck the sap. Ants were also noticed visiting the mealybugs for honeydew. This pest was noticed during the crop season when hot weather condition prevailed and rains were delayed. About 20–28 mealybugs were observed on the ventral side of 4–5 lower leaves of 10–15 % plants. Crinkling of the lower leaves and puckering in young leaves was observed (photo) due to the damage of the pest in Andhra Pradesh (Rao 2009). In Gujarat, *P.solenopsis* has been reported as the major species. At the initial stage, the mealybugs attach themselves to the lower leaves and suck the cell sap. The infested leaves of tobacco showed sickly appearance, dried out before maturity, and the quality of leaf also deteriorated (Bhatt 2010).

64.3 Management

Biological Control The Australian ladybird beetle *Cryptolaemus montrouzieri* (Mulsant) (2–3 per tobacco plant) gave good control of *F. virgata* in the glasshouse. The mealybug population declined from 16/cm^2 to 0 after 35 days of release (Gautam et al. 1988). *C. montrouzieri* can also be used to control *P. solenopsis* on tobacco (Rao 2009). In Gujarat, the encyrtid *Aenasius bambawalei* (Hayat) was found on *P.solenopsis* (up to 30 % parasitism). Parasitized mealybugs turned reddish brown, loss of white mealy powder from their mummified body (Bhatt 2010).

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Table 64.1 List of mealybugs recorded on tobacco

Mealybug Species	Country	References
Ferrisia virgata (Cockerell)	India	Gautam et al. (1988); http://www.plantwise.org/KnowledgeBank/Datasheet.aspx?dsid=23981)
Geococcus coffeae (Green)	–	Ben-Dov (1994)
Phenacoccus solani (Ferris)	Zimbabwe	springer.com/article/10.1007%2FBF02980920
Phenacoccus solenopsis (Tinsley)	India	Rao (2009); Bhatt (2010)
Planococcus citri (Risso)	Africa	http://www.infonet-biovision.org/default/ct/94/pests
Pseudococcus notobilis (Leonardi)	Italy	Ben-Dov (1994)
Trionymus nicotinicola (Williams and Granar de Willink)	Argentina	Ben-Dov (1994)

Chemical Since tobacco is a high-value crop, the leaf is used for human consumption; care is to be taken to select the chemicals for the control of mealybugs. Chloripyriphos— 0.05 % spray gave 100 % control of the mealybugs in Andhra Pradesh (Rao 2009). On tobacco, methomyl 90.80 % and profenophos had significantly reduced the mealybug population of *P.solenopsis* in Gujrat (Bhatt et al. 2009).

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65 Jatropha

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Biodiesel produced from nonfood crops like Jatropha (*Jatropha curcas*) is one of the most promising solutions for tackling the growing carbon emissions from transport. *Paracoccus marginatus* (Williams and Granara de Willink) was found to cause serious damage on jatropha in India (Regupathy, and Ayyasamy, 2009; Pretheep-Kumar et al. 2013), Malaysia (Mastoi et al. 2011), and Sri Lanka (Galanihe et al. 2010) The infestation resulted in symptoms like crinkling or twisting of leaves and shoots, bunched and unopened leaves, yellowing of leaves or leaf drop, fruit drop, appearance of honeydew on leaves, sooty mould development, stunted growth, deformation, and death of the plants in case of severe infestation. *Ferrisia virgata* (Cockerell), *Phenacoccus herreni* (Cox and Williams), *and Planococcus minor* (Maskell) are known to attack *Jatropha* sp. In California, roots of jatropha were found infested with the mealybug *Rhizoecus bicirculus* (McKenzie) (Ben-Dov 1994). A prediction model has been developed, which could act as an indicator of the severity of the mealybug *Paracoccus marginatus* damage in jatropha plantations, under tropical conditions, if no proper pest management measures had been employed (Pretheep-Kumar et al. 2013). The model for predicting the percentage of mealybug infestation in jatropha was of the form: $y = ax_1^b + cx_2^d$, where y is the percentage of mealybug infestation, x_1 is the mean monthly temperature, x_2 is the mean monthly rainfall, and a, b, c, d are the coefficients: $a = 1.172$; $b = 1.951$; $c = 3.722$; $d = 9.024$. Standard error = 7.231; Correlation coefficient = 0.966. It was apparent that the percentage of mealybug damage in jatropha decreased with increase in rainfall and vice versa (Pretheep-Kumar et al. 2013).

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Paracoccus marginatus damage to jatropha

Ten natural enemies, including parasitoids viz. *Acerophagus papayae* (Noyes and Schauff), *Anagyrus loecki* (Noyes), *Pseudleptomastix mexicana* (Noyes and Schauff), and predators like *Spalgis epeus* (Westwood), *Cryptolaemus montrouzieri* (Mulsant), *Brumoides suturalis* (Fabricius), *Cheilomenes sexmaculata* (Fabricius), *Scymnus coccivora* (Ayyar), *Chilocorus* sp., and *Chrysoperla zastrowi* (Sillemi) (Esben-Petersen) were found attacking *P. marginatus* in India. Among them, *Acerophagus papayae* was found to be highly effective in controlling the mealybug population in Bangalore North.

Mealybugs *Ferrisia virgata* and *Planococcus* sp. suck the plant's sap, resulting in yellowing, withering and drying of plants, and shedding of leaves and fruits. The foliage and fruits become covered with large quantities of sticky honeydew, which serves as a medium for the growth of black sooty moulds, resulting in the reduction of the photosynthetic area. Some ladybird beetles, including *Cryptolaemus montrouzieri*, *Olla v-nigrum*, and *Azya luteipes*, together with syrphids such as *Alloagrapta oblique*, are known predators of mealybugs. Chemicals such as diazinon, malathion, dimethoate, and parathion are effective in controlling *F. virgata*. However, they have to be sprayed repeatedly to achieve satisfactory control. The combination of parathion and malathion with white oils makes spraying more efficient. To manage the insects at the beginning of a local outbreak, severely infested branches should be cut and burnt immediately (file:///C:/Documents%20and%20Settings/user/y%20Documents/Downloads/Jatropha%20under%20attack.pdf). The systemic acephate on the plant can be used to clear up the mealybugs on jatropha. Spraying is to be done twice at 10-day intervals. Sprays can be scheduled in the early morning or evening when the temperatures are low. (http://articles.sun-sentinel.com/2000-06-23/lifestyle/0006220403_1_mealybug-toads-seeds)

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Forage Crops and Grasses

66

Narendra S. Kulkarni and M. Mani

Fodder crops and grasses harbour large number of mealybugs throughout the world (Table 66.1). Though a number of mealybugs are recorded on grasses and fodder crops, only some are known to cause economic damage.

66.1 *Rhizoecus kondonis*

The mealybug *Rhizoecus kondonis* Kuwana feeds on alfalfa roots causing severe damage to alfalfa. It sucks out plant juices, which causes stunting and yellowing of plants. The infestations generally start in small circular areas near the field borders and gradually increase in size up to an acre or so. Within the infested areas, the plant stand is sparse and existing plants yield poorly and weeds often overtake these areas. The mealybugs produce white webbing and clusters of whitish eggs, so they're often obvious in the soil. Ground mealybug is restricted to the heavier soils. The eggs, nymphs and adults all occur in the soil. Infestations in alfalfa fields generally occur in "circular" patches and spread slowly. The damage to alfalfa plants is very apparent in the summer months but less so during the winter and spring (McKenzie 1967). There are three generations per year. Mealybugs are abundant in July-August, December-January and March-April. Significantly more *R. kondonis* were found 15.2–45.7 cm deep in the soil.

Rhizoecus kondonis

Ground mealybug damage in foreground compared with undamaged field in the background

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Table 66.1 List of mealybugs attacking the grasses and fodder crops

Mealybug species	Plant species	Region	References
Antonina graminis (Maskell)	Cyprus, Cyanodon, Echinochloa	Many countries	Ben-Dov (1994)
Antonina martima Green	Cyprus, Cyanodon	India	Williams (2004)
		Sri Lanka	
Antonina purpurea Signoret	Grasses	France, Italy & Spain	Ben-Dov (1994)
Antonina graminis, A. indica Hall., *A. natalensis* Brain & *A. transvaalensis* Brain	Grasses	Africa	Williams (2001)
Antonina graminis (Maskell)	Bermuda grass,	Brazil	Culik and Gullan (2005)
Balanococcus botulus Cox	Cyprus	New Zealand	Cox (1987)
Balanococcus poae (Maskell)	Pasture grass	New Zealand	Charles et al. (2009)
Balanococcus mediterraneus Lozar	Cynodon	Greece	Kozar (1983)
Balanococcus notodanthoniae Cox	Cynodon	Italy & Korea	Ben-Dov (1994)
Brevennia cyanadontis (Bodennhemer)	Cynodon & Sorgum	Iraq	Ben-Dov (1994)
Brevennia filicus (DeLotto)	Sorgum	South Africa	De Lotto (1967)
Brevennia rehi (Lindinger)	Sorgum	India	David and Ananthakrishnan (2004)
	Cyprus & grasses	California	Miller (1973)
	Cynodon dactylon	Australia & Papua New Guinea	Williams et al. (1981)
Chaetococcus australis (Froggatt)	Cyperus	Australia	Ben-Dov (1994)
Chlorozococcus sorghi Williams	Sorgum	India	Williams (2004)
Dysmicoccus andropogonisn sp.n.	Andropogon grass	India	Williams (2004)
Dysmicoccus boninsis (Kuwana)	Sorghum & Cynodon	–	Ben-Dov (1994)

Dysmicoccus brevipes (Cockrell) & *Dysmicoccus neobrevipes* Beardsley	Maize & Cyprus	–	Ben-Dov (1994)
Dysmicoccus multivorus Koteja & Zak-Ogaza	Lucerne	Turkmenia & USSR	Myartseva and Kharchenko (1988)
Ehrhornia cupressi (Ehrhorn)	Cyprus	California & Mexico	Ben-Dov (1994)
Fonscolombia butorinae (Danzig et Gavrilov)	Grasses	Russia	Danzig (2007)
Formicoccus lingnani (Ferris)	Sorghum	Malaysia	Williams (2004)
Ferrisia virgata (Ckll.)	Su-babul *Leucaena leucocephala*	India	Pillai and Gopi (1990)
	Maize & Lucerne	–	Ben-Dov (1994)
Geococcus coffeae Green	Cyperus	Many countries	Ben-Dov (1994)
Heliococcus singularis Awasthi & Shafee	Cyperus	India	Williams (2004)
Heterococcus cyperi (Hall)	Cyperus	Egypt	Ben-Dov (1994)
Marendelleae harrisae Williams	Sorhgum	Nigeria	Ben-Dov (1994)
	Leucaena	–	http://www.plantwise.org/KnowledgeBank/Datasheet.aspx?dsid=36335
Paradoxococcus mdaniell McKenzie	Sorghum	Texas	Ben-Dov (1994)
Phenacoccus angustatus Borchsenius	Sorghum	Kazakhstan	Ben-Dov (1994)
Phenacoccus bicerarius Borchsenius	Sorghum	Kazakhstan	Ben-Dov (1994)
	Colver	Europe	
Phenacoccus hordei (Lindeman)	Grasses	England	Malumphy (2011)
Planococcoides lindingeri (Bodenheimer)	Sorghum	Egypt & Israel	Ben-Dov (1994)
Planococcus minor (Maskell)	Maize	–	Ben-Dov (1994)

(continued)

Table 66.1 (continued)

Mealybug species	Plant species	Region	References
Pseudococcus kozari sp. n.	Pasture grasses (*Poa pratensis & Loliu perenne*)	Romania	Savescu (1984)
Pseudococcus scaaharicola Takahashi	Sorghum	India, Pakistan	Williams (2004)
Pseudococcus sorghiellus (Forbes)	Sorghum & Maize	California	Ben-Dov (1994)
Rhizoecus kondonis Kawana	Lucerne	California	McKenzie (1967)
Rhodania porifera Goux	Pastures	France	Ben-Dov (1994)
Sacchariococcus sacchari (Cockrell)	Sorghum	–	Ben-Dov (1994)
Spilococcus expressus (Borchsenius)	Sorghum	Tadzhikistan	Ben-Dov (1994)
Stemmatomerinx spp.	Grasses	United States	Howell and Miller (1976)
Trionymus ceres Williams	Sorghum	India & Pakistan	Williams (2004)
Trionymus internodii (Hall)	Maize	Egypt & Israel	Ben-Dov (1980)
Trionymus polyporus Hall	Sorghum	Egypt	Ben-Dov (1994)
Trionymus radicola (Morrison)	Sorghum	Columbia & Jamaica	Ben-Dov (1994)
Trionymus townsei Beardsley	Sorghum	India	Ben-Dov (1994)
Trionymus utahensis (Cockrell)	Sorghum	California	Ben-Dov (1994)
Trionymus violascens Cockrell	Grasses	Colorado & California	Ben-Dov (1994)

The highest ground mealybug populations were generally found at intermediate soil moisture conditions; however, some individuals were found in soils as dry as 7 % moisture. Ten lucerne varieties were examined for susceptibility to this insect and found to be equally susceptible. Crop rotation with corn, wheat, or dry beans might be the best rotation option for reducing populations, perhaps coupled with a summer fallow period (Godfrey and Pickle 1998).

66.2 *Ferrisia virgata*

Infestations of *F. virgata* (Cockrell) remain clustered around the terminal shoots, leaves, sucking the sap which results in yellowing, withering and drying of plants and shedding of leaves of lucerne. The foliage also becomes covered with large quantities of sticky honeydew which serves as a medium for the growth of black sooty moulds. The sooty moulds and waxy deposits result in a reduction of photosynthetic area. Such plants are not preferred as cattle feed.

Lucerne infested with *Ferrisia virgata*

66.3 *Dysmicoccus multivorus*

In Turkmenia, USSR, *Dysmicoccus multivorus* was observed as a potential pest of Lucerne. Numbers of the mealybugs were markedly reduced by *Leptomastix flava, Anagyrus diversicornis*, *Leptomastidea rubra* and *Ericydnus robustior* (Myartseva and Kharchenko 1988).

66.4 *Antonina graminis*

Rhodesgrass mealybug (often called Rhodesgrass scale) *A. graminis* (Maskell) attacks a wide range of pasture, lawn and turf grasses. It has been recorded in several Asian countries, California, Texas, Mexico, Australia, Philippines, Africa, South and Central America. The mealybug is unique in Pseudococcidae in that the legs are not retained throughout the life (Clausen 1978). This mealybug *A. graminis* (Maskell) is of Asiatic origin infesting at least 69 species of lawn and turf grasses (Dean et al. 1979). Bermuda grass, St. Augustine grass, tall fescue, and centipede-grass are severely injured. Mealybugs typically feed under leaf sheaths, on nodes or in the crowns. They feed on plant sap with piercing-sucking mouthparts and disrupt the plant's vascular system which will interfere with water and nutrient uptake resulting in discoloration and wilt. Stunting, thinning and death may result in a heavy infestation. Masses of waxy, white secretions may be noticed along with possible honeydew and sooty mould. These mealybugs feed under leaf sheaths, on nodes or in the crowns. Damage may be most noticeable during periods of drought or if the grass is stressed. Mealybug females deposit 300–600 eggs in a cottony ovisac. Eggs hatch into crawlers within 1–3 weeks and the crawlers will begin feeding under the leaf sheath at a node. A generation may take 4–6 weeks depending upon temperature and location. There can be several generations per season.

Antonina graminis on Rhodesgrass

Neodusmetia sangwani

Rhodesgrass mealybug was an important pest of forage and lawn grasses in Texas. Cultural control includes collecting and destroying grass clippings. A classical biological control project resulted in the introduction of several species of parasitoids (Schuster et al. 1971). However, complete control was attained by encyrtid parasitoid *Neodusmetia sangwani* (Rao), imported from India after being disseminated by aircraft (Schuster et al. 1971: Dahlsten and Hall 1999). By 1976, it was estimated that the parasitoid saved ca. 17 million dollars annually in turf grass management costs (Dean et al. 1979). The exotic parasitoid *Anagyrus antoninae* Timb. established and gave good control in cooler and more humid areas of Texas, Mexico and Florida. *Antonina graminis* is resurging as an important pest of turfgrass across Texas and the South-eastern United States. This mealybug is known to feed on many warm-season turf grasses and pasture grasses. Cultivars of kikuyugrass (*Pennisetum clandestinum* Hochst) and bermudagrass (*Cynodon* spp.) were significantly more susceptible than cultivars of seven other genera of turfgrass. Cultivars of St. Augustinegrass, buffalograss and zoysiagrass each exhibited susceptibility of >2 mealybugs per 7.5×7.5-cm plant. Populations did not exceed<=0.5 mealybug per plant on centipedegrass, seashore paspalum, bahiagrass, or tall fescue (Reinert and Vinson 2010). A survey conducted in south-eastern United States indicated that *N. sangwani* was uncommon overall, occurring at only 20 % of survey sites. In addition, *N. sangwani* exhibited a patchy geographic distribution. Possible causes for these results are that *N. sangwani* has not dispersed widely since its introduction, or that the imported fire ant, *Solenopsis invicta* Buren, is interfering with biological control. Two other encyrtid wasps *Acerophagus* sp. and *Pseudectroma* sp. are utilizing *A. graminis* as a host (Chantos et al. 2009.

66.5 *Dysmicoccus brevipes*

Dysmicoccus brevipes (Cockerell) is a polyphagous mealybug; it was only found in moderate densities on Rhodesgrass, *Chloris gayana*, and wire grass, *Eleusine indica*, both of which were found in mowed and unmowed weedy areas with the former species being more common in Hawaii. All phenological stages of Rhodesgrass were infested with pink pineapple mealybugs, but only mature wire grass plants were infested (Gahan) (Pandey and Johnson 2006).

66.6 *Brevennia rehi*

Many grass species are grown as lawns or used in golf courses and other recreational settings especially turf grasses are susceptible to numerous species of pest insects, and annually millions of dollars are spent to prevent or eliminate infestations. The Tuttle mealybug, *Brevennia rehi* (Lindinger), is a pest of many grass species and occurs nearly worldwide, especially where rice and sugarcane are grown. Officially recorded in the United States only from Arizona, California, Florida and Texas (Ben-Dov 2012), but is probably more widespread in south-eastern states that produce turf grasses for the sod market. Tuttle mealybug is known from other regions of the world (e.g., Palearctic region – Afghanistan, Iraq, Iran; Ben-Dov 2012) where there is a distinct cold season, which suggests the mealybug may be capable of surviving in much of the United States. Tuttle mealybug was described in the United States as *Heterococcus tuttlei* Miller and its taxonomy status is now amended to junior synonym of *Brevennia rehi.* Healthy turfgrass will have lower mealybug populations, so proper fertilization and watering is needed. Keep beneficial insects in the area to reduce the number of mealybugs, such as big-eyed bugs and lady beetles. After mowing, collect and destroy all infested grass clippings. *Brevennia rehi* is also recorded from Israel, Iraq, Azerbaijan, and Tajikistan and from Brazil. The rice mealybug is recorded from Israel as a pest to lawn grasses, *Dactyloctenium australe* (Poaceae) (Ben-Dov 2008). Mealybugs hide between the grass blade and the stem where they can be difficult to see. They are destructive infestations in South Asia (e.g., India, Bangladesh). There was a correlation between drought stress and degree of infestation, possibly due to an increase in the availability of amino acids in the vascular fluid (Dale 1994). It was discovered infesting bermudagrass (*Cynodon dactylon*) seed production crops in Arizona to such an extent that the sticky exudates produced by the mealybugs fouled the harvesting equipment (Miller and McKenzie 1970). Tuttle mealybug is a recorded host of the parasitoids *Rhopus nigroclavatus* Ashmead and *Apoleptomastix bicoloricornis* Girault (Hymenoptera: Encyrtidae) (Noyes 1988). *Rhopus nigroclavatus* does not occur in Florida, but is recorded from several other states, and *A. bicoloricornis* is not recorded from the United States. Because Bermuda and zoysia are important lawn grasses, especially in the southern United States, infestation by Tuttle mealybug should be considered whenever dieback is noticed, especially if the grass blades show white wax or are sticky from honeydew secretion. Both Bermuda and zoysia lawns are commonly installed as sod or plugs, which provide a ready route for the spread of infestations should the pest control practices of the grower fail to maintain a pest-free production environment.

66.7 *Trionymus winnemucae* & *Saccharicoccus sacchari*

Trionymus winnemucae McKenzie (Winnemuca grass mealybug) lives within the sheath, but may also be found below the crown at the crown–soil interface. *Saccharicoccus sacchari* (Comstock) (pink sugarcane mealybug) is also an elongated pinkish mealybug that will occasionally infest ornamental grasses. Both *T. winnemucae* and *Sa. sacchari* are slightly larger, with a more elongate body form.

66.8 *Balanococcus poae*

The pasture mealybug *Balanococcus poae* (Maskell) can be a serious pasture pest in Canterbury areas, and is known to occur in Manawatu and Nelson region of New Zealand. Adult mealybugs are small, growing to about 2 mm in size, pink in colour. There are white, waxy secretions in the plant crown and upper roots. These will appear as cotton-wool–like globules. Damage becomes apparent in autumn during extended dry periods. Symptoms of infestation resemble those of drought, with pastures browning off. The mealybug damage tends to affect a whole paddock, rather than isolated patches. It causes widespread ryegrass death, leading to poor pasture persistence. At Hawke's Bay, adult females of *Balanococcus poae* were found throughout the year, typically in wax cells ca.

1–2 cm below the soil surface, with a peak density of ca. 1,300/m^2 during winter and early spring (June-October). Winter eggs were followed by neonate nymphs from spring through summer. The timing of life-stages indicates that there was a single generation each year, but a partial second generation may also have occurred in late summer. No males were found (Charles et al. 2009).

Brevennia rehi on a stem of zoysia grass

Pasture mealybug

Pasture mealybug (*Balanococcus poae*) was found infesting native grasses, tussocks in Poaceae and several introduced pastoral grass species particularly ryegrass (*Lolium* spp.) in Canterbury, New Zealand. Pasture mealybug are capable of inflicting severe damage to endophyte-free ryegrass (Pennell et al. 2005). The use of pure stands of endophyte-infected grasses or a mixed stand of infected and non-infected plants may increase the persistence and durability of turf and forage grass species in the presence of foliar damaging mealybugs (Sabzalian et al. 2004).

66.9 *Miscanthicoccus miscanthi*

Miscanthus is a genus of about 15 species of perennial grasses native to subtropical and tropical regions of Africa and southern Asia. The dispersal of the Miscanthus mealybug, *Miscanthicoccus miscanthi* (Takahashi), has actually been unsuspectingly rapid, by means of selling as well as exchanging the plants infested with this insect. It only becomes conspicuous when the population of this bug reaches a very high number on any individual plant and the symptoms of infestation on the surface become easily visible. Usually, the mealybug is capable of growing to a maximum length of 4 mm (3/16 in.) and it thrives in the narrow gap between stem and the enfolding leaf sheath. Initially, this pest generally forms colonies near the base of the plant and gradually ascends upward with the amplification of their population. In general, the initial surface symptoms of a plant being infested by Miscanthus mealybug include slowing down of the plant's growth and an abnormal entwining of the flowering head. In addition, the colour of the sheath tissue as well as the stem becomes deep red in parts where the mealy bugs are drawing their food from the plant, particularly in the later part of the growing season. Even when a plant is severely plagued, it is not eliminated, but is decreased to ugly, distorted masses as the white powdery wax swathes its stems, particularly in the lower parts. Plants that are infested by this bug usually become incapable of flowering in any way. In some cases, the flowering stalks may possibly be underdeveloped resulting in the flowers to open droopingly among the foliage, instead of blossoming elegantly above.

66.10 *Geococcus coffeae* and *Rhizoecus hibisci*

Geococcus coffeae and *Rhizoecus hibisci* Kawai & Takagi are the root mealybugs infest grasses, cyperus etc. Mealybugs secrete lots of white waxy material that cover their bodies. Because the root mealybug is very difficult to control, efforts should be made to prevent spread and establishment: inspect roots of newly purchased plants; do not allow water from infested areas to drain in to clean areas, as crawlers can be transported in water; hot water dips alone or with insecticides work as insecticides such as Dursban WP and Marathon G.; watering plants prior to drench application will significantly reduce problems with phytotoxicity.

66.11 *Phenacoccus hordei*

It is a root-feeding species that occurs throughout Europe, and is oligophagous on Poaceae, and occasionally plants in other families. Its hosts include several important crops, such as alfalfa (Malumphy 2011).

66.12 *Antonina pretiosa*

Antonina pretiosa Signoret is known to infest the arundinaria, mocker grass. They tend to cluster in masses on protected parts of the bamboo and move slowly, if at all. Adult females lay yellow eggs in a mass with white wax. Nymphs are white, yellowish or reddish and oblong, and several generations of mealybugs can occur each year. *Antonina purpurea* is known to occur on the roots of the grasses (Ben-Dov 1994).

66.13 *Phenacoccus dearnessi*

Phenacoccus dearnessi Whitney has been found infesting several hawthorns in Minneapolis and northeast Illinois (Hann 2012). This insect colonizes the bark of twigs and small branches using its piercing sucking mouthparts to feed on the sap. Hawthorn mealybugs also produce a lot of honeydew, a sugary waste material as a result of feeding on the sap. Honeydew is shiny, clear or whitish in appearance and sticky. Honeydew can also lead to sooty mould, a black fungus that colonizes the honeydew. Hawthorn mealybug has the potential to weaken branches and cause dieback, although that has not been noticed on infested trees here so far. Hawthorn mealybugs

Hawthorn mealybug, *Phenacoccus dearnessi*

appear to have one generation per year. They mature in the late spring. Eggs hatch and nymphs are active by early summer. After feeding on leaves briefly, the nymphs move to twigs and feed in protected sites. Because of the white waxy material that is present and the habit of the nymphs to feed in protected places, direct insecticide control can be challenging. However, if management is necessary, an application of a systemic insecticide, like imidacloprid and dinotefuran should be effective.

66.14 *Tridiscus sporoboli* and *Trionymus* sp.

Two grass-feeding mealybugs, *Tridiscus sporoboli* (Cockerell) and *Trionymus* sp., were found heavily damaging buffalograss (*Buchloe dactyloides*) stands near Mead, Nebraska. They were most commonly found feeding within leaf sheaths just below the collar or behind leaf axils enclosing the pistillate spikelets. Injury appeared as foliar yellowing with the most severely injured plants turning straw-brown and dying (Baxendale et al. 1994). Pubescent leaves increase buffalograss susceptibility to mealybugs *Tridiscus sporoboli* and *Trionymus* sp. (Johnson-Cicalese et al. 1998, 2011). Parasitism on these mealybugs by *Rhopus nigroclavatus* in Nebraska went up to 78.5 % indicating its potential in the population regulation of these mealybugs (Heng-Moss et al. 1999).

66.15 *Pseudococcus saccharicola* Takahashi

It was found infesting *Chloris barbata* Sw. (swollen fingergrass), *C. radiata* (L.) (radiate fingergrass) and *Cynodon dactylon* L. (bermudagrass) in Guana Island, and nearby Beef Island and Tortola, in the British Virgin Islands (BVI). The coccinellid predator *Hyperaspis scutifera* (Mulsant) was commonly witnessed with colonies of *P. saccharicola* on all three islands (Wheeler et al. 2010).

66.16 *Dysmicoccus dennoi & Trionymus clandestinus*

The coccinellid predator *Hyperaspidius venustulus* (Mulsant) was reported on *Dysmicoccus dennoi* Kosztarab from South Carolina on big cordgrass (*Spartina cynosuroides)*, in or near brackish marshes and along tidal waterways and on the mealybug *Trionymus clandestinus* McConnell infesting beardgrass, *Andropogon tenuispatheus.*

66.17 *Heliococcus summervillei*

It was a very severe pest on grasses in pastures in New Caledonia. In Australia, similar populations of *H. summervillei* Brookes were observed on Paspalum grass in a pasture. Like in Australia, a natural reduction of populations was observed, so pronounced that the species is supposed to be extinct locally (Brinon et al. 2004).

66.18 Sorghum

Pink sugarcane mealybug *Saccharicoccus sacchari* (Cockerell) sucks the sap and reduces cane vigour, besides causing sooty mould. The mealybugs are usually attended by ants. Severe attack results in stunted growth, yellowing of leaves, deposition of sticky honeydew, and development of sooty mould on the mealybug infested plants.

66.19 Maize

Infestations of *Ferrisia viragata* remain clustered around the terminal shoots and leaves, sucking the sap which results in yellowing, withering and drying of plants and shedding of leaves. The sooty moulds and waxy deposits result in a reduction of photosynthetic area.

66.20 Forage Trees

Gliricidia, *Gliricidia sepium and* subabul *Leucaena leucocephala*, multipurpose fodder trees are frequently attacked by the striped mealybug *Ferrisia virgata.* A severe outbreak of *Ferrisia virgata* was found in a 25-ha plantation of *Leucaena leucocephala* in Tamil Nadu, India in May 1988. The coccinellid predator *Scymnus coccivora* Ayyar (Coleoptera) and the encyrtid parasitoid *Aenasius advena* (Hymenoptera) were the biological control agents in the field (Pillai and Gopi 1990).

66.21 General Management Practices

It's important to always monitor the forage crops, pasture or turf grasses for the presence of mealybugs and their damaging symptoms before initiating any management options. Yellow sticky cards can be used to trap the flying adult males, preventing them from mating. Insecticidal soaps and horticultural oils work great in controlling the mealybugs. The tricky part is mealybugs tend to hide very well where leaves attach to the stem, so make sure you get coverage there. Horticultural soaps and oils don't have systemic properties, which means when spraying, the product must come in contact with the pest. Burn leaves with horticultural soaps and oils. These products need to be applied when the air temperature is cool. Make sure your plants were watered well the day before applying any control measures. Following labelled rates also reduces the risk of leaf damage. More is not better. Also, make sure beneficial insects are not affected while spraying insecticides. There are a few beneficial insects that can help in mealybug treatment, too. Green lacewings feed on the crawler stage of almost any mealybug, where some others are more specialized – like the mealybug destroyer (*Cryptolaemus montrouzieri*). This beneficial insect is a type of ladybug that loves to feed on most mealybug species. Mealybugs can be controlled if the timing of the initiation of the treatment is planned correctly at the crawler stage.

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Forest Plants

67

R. Sundararaj and M. Mani

Mealybugs often cause serious damage to the growth of forest tree species particularly in nurseries and plantations. The damage is caused by sap sucking resulting in dieback symptoms and secreting copious amount of honeydew on which black sooty mould fungus develops. Often the infestation results in drying of branches causing dieback of branches and ultimately death in seedlings and trees. The affected flowers wither and fruits dry up, fall off prematurely. The seedlings and trees affected severely by mealybugs shed their leaves and look like sickly appearance and in some cases drying of branches in trees and death of seedlings. Most of the mealybugs are highly polyphagous and have many collateral hosts and hence, they can spread very rapidly to the neighbouring plants.

67.1 *Ferrisia virgata*

The striped mealybug *Ferrisia virgata* (Cockerell) is covered with powdery white wax and has a pair of purplish dorsal stripes along the back. It is reported to breed on leaves, stem and fruits of large number of tree plants including *Azadirachta, Anacardium, Annona, Artocarpus, Caesalpinia, Casuarina, Cassia*, etc. in India (Ali 1970). On a

Ferrisia virgata on *S. album*

Ferrisia virgata on *P. pinnata*

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variety of host plants, it was most active during August-November and March-April but very much reduced during December-January (Rawat and Modi 1968). *Ferrisia virgata* was found infesting *Santalum album* in India (Sundararaj et al. 2006).

It is emerging as an important pest on *Pongamia pinnata.* Nymphs and adults were found sucking the sap from both the surfaces of leaves as well as tender shoots and flowers of *P. pinnata* at the time of formation of new foliage and flowering. During this period, it infests almost all parts of tree. The affected flowers wither and fruits dry and fall off prematurely. Its infestation starts from February reaching peak during March and April and then it declines in Karnataka (Mangala et al. 2012). An infestation by *F. virgata* was reported on four tree species (*Albizia lebbeck, Gliricidia sepium, Leucaena leucocephala* and *Cassia siamea*) in a screen house at IITA main station, Ibadan, Nigeria (Kadiata et al. 1992).

Ferrisia virgata on white leadtree

Nipaecoccus viridus on *S. album*

67.2 *Nipaecoccus* spp.

The spherical mealybug *Nipaecoccus viridis* (Newstead) occurs on foliage, stem, branches and root of sandal (Chatterjee and Bose 1933). It is also known to infest *Acacia karroo, Ficus carica, Grevillea robusta, Spathodea campanulata* and *Tamarindus indica* (http://www.plantwise.org/KnowledgeBank/Datasheet.aspx?dsid=36335. On *Santalum album*, the mealybug infestation was found throughout the year with two peaks of population the first during April-May and the *other* during February-March. Besides, it was found parasitized by ten species of hymenopteran and two species of dipteran parasitoids (Sundararaj et al. 2006; Sundararaj 2008). *N. viridis* has been reported on *Dalbergia sisso* in India. In Egypt, the lebbeck mealybug was particularly destructive to the lebbeck tree, *Albizia lebbeck*. Releases of *C. montrouzieri* has resulted in establishment but were of limited effectiveness (Hall 1927). Two encyrtid parasitoids, *Anagyrus aegyptiacus* Moursi and *Leptomastix phenacocci* Compere were introduced from Java and established. Parasitization levels soared to 98 %, providing complete biological control, so that it was difficult to find the host (Clausen 1978; Dahlsten and Hall 1999). Population of *N. viridis* was significantly higher on branches of the woody legume *Leucaena leucocephala* in northern Guam, Mariana Is. *Cryptolaemus* was found feeding on *N. viridis* (= *N. vastator*) infesting several plants in Guam but the predator was not feeding preying *N. viridis* when it occurred on woody legume *L. leucocephala.* It might be due to the presence of amino acid mimosin derivative which might have acted as feeding deterrent through the host (Muniappan et al. 1980). The presence of the ants *Technomyrmex albipes* (Fr. Smith) decreased the percentage of *N. viridis* parasitized by the encyrtid *Anagyrus indicus* Shafee et al. and the mortality of mealybugs was attributed due to parasitism by *A. indicus* and predation by other arthropods. Natural enemies play an important role in maintaining *N. viridis* populations at low levels (Nechols and Seibert 1985).

67.3 *Nipaecoccus filamentosus*

Nipaecoccus filamentosus (Cockerell) (*Pseudococcus filamentosus*) has been recorded on limes, *Tamarix stricta*, *Ficus carica* [figs], *Vitis* sp. and Nerium oleander in Iran. There were four generations annually in the Fars region. The coccinellid *Cryptolaemus montrouzieri* has been imported from northern Iran and has proved to be effective as a biological control agent of *N. filamentosus* (Khalaf and Aberoomand 1989).

Rastrococcus iceryoides on *P. pinnata*

Paracoccus marginatus on teak leaf

67.4 *Nipaecoccus nipae*

Nipaecoccus nipae (Maskell) (*Pseudococcus nipae*) completely defoliated *Erythrina glauca* each year but since the introduction of *C. montrouzieri*, there is no economic importance of this pest on the above tree in Puerto Rico (Martorell 1940).

67.5 *Rastrococcus iceryoides*

The mango mealybug *Rastrococcus iceryoides* (Green) has been reported on several tree plants including *Ficus indicus, Mangifera indica, Pithecellobium saman, Samanea saman*, *S. album*, *Wendlandia notoniana*, *Zizyphus mauritiana, Tephrosia candida, Vitex* sp. (Varshney 1992). It is reported to infest on *Pongamia pinnata* in and around Bangalore. Both the nymphs and adults suck the plant sap from leaves and sooty mould develops on the honey dew excreted. The extent of infestation was more (23 %) in younger plantations and lower (8.0 %) in older plantations. In some cases, due to severity of infestation, the leaves gradually dried resulting in defoliation of trees (Mangala et al. 2012; Sundararaj and Devaraj 2010). *Rastrococcus invadens* was also recorded on *Ficus* sp. in Sri Lanka (Galanihe and Watson, 2012).

67.6 *Maconellicoccus hirsutus*

M. hirsutus (Green) (PHMB) was known to infest *Acacia arabica* and *Albizzia lebbak* in Egypt. *Maconelicoccus hirsutus* was detected in teak plantations in 2004 in the Banderas valley in Mexico. A biological control programme was initiated in May 2004 to release 210,000 of the predator *Cryptolaemus montrouzieri* on 150 ha. Damage to trees was reduced by 92 %. In India, it has been reported on *Samanea saman*, *Tectona grandis*, *Tabeubuia rosea, Delonix regia* (Anand Persad and Khan 2006), *Ficus cunia, F. religiosa, F. indica* (Ayyar 1930; Varshney 1992). In Bahia de Banderas, Nayarit, Mexico, the parasitoid *Anagyrus kamali* Moursi regulated the population growth of *Maconellicoccus hirsutus* on teak. The average reduction of the pest was 96.5 % in 30 days after release (Garcia-Valente et al. 2009). *M. hirsutus* was found infesting *Casuarina equisetifolia* in Andhra Pradesh (Murthy et al. 1997) and Ficus trees in Gujarat, India (Muralidharan and Badaya 2000).

Saman tree killed by heavy PHM B infestation

67.7 *Humococcus resinophilus*

Humococcus resinophilus (Green) in northern India is a pest of *Pinus roxburghii* regeneration. As a result of heavy infestations, branches apparently turn black and die (Ben-Dov 1994).

67.8 *Paracoccus marginatus*

In multi-tier agroforestry ecosystems of Kerala, India, the invasive mealybug *Paracoccus marginatus* Williams and Granara de Willink infestation was reported from teak, rubber, and other such plantations of Kerala even though the incidences were highly localized. In the case of young teak plantations, the immediate action taken was to chop off the infested branches and burn them. Subsequently the exotic parasitoid *Acerophagus papayae* was released in the forest ecosystem to control *Pa. marginatus.*

67.9 *Planococcus vovae*

Planococcus vovae (Nasonov) was known to infest cypress trees in Shiraz, Iran. A total of 15 species of natural enemies was found attacking cypress tree mealybug *Pl. vovae*. These included two parasitoids, *Anagyrus pseudococci* (Girault) and *Dusmetia fascipennis* (Noys & Hayat). The most common predators included *Exochomus quadripustulatus* (L.) *Hyperaspis polita* Weise, *Nephus bipunctatus* (Kugelann), *Chrysoperla carnea* (Stephens), *Suarius fedtschenkoi* (McLachlan in Fedchenko), *Dicrodiplosis manihoti* Harris and *Geocoris quercicola* Linnavuor (Lotfalizadeh and Ahmadi 2000) and *Coccidoxenoides perminutus* Girault (Talebi et al. 2008). *P. vovae* is a common pest of cypress trees in Greece (Milonas and Kozar 2008). *C. montrouzieri* adults and larvae were detected in Turkey during May and June on cypress trees (*Cupressus sempervirens* L.) heavily infested with *P. vovae* (Yigit and Canhilal 1998). *It* was found attacking the conifers, e.g., Chamaecyparis, Cupressocyparis, Cupressus, Libocedrus and Thuja in Poland. Insecticides Actellic [pirimiphos-methyl] 500 EC and Ultracid [methidathion] 40 EC for its control were recommended (Golan and Jaskiewicz 2002).

Planococcus vovae

Oracella acuta on slash pine

Close up of the mealybug

67.10 *Phenacoccus azaleae*

The Bunge Prickly-Ash tree plant (*Zanthoxylum bungeanum*) damaged by the mealybug *Phenacoccus azaleae* Kuwana which attracts its natural enemy, the ladybug *Harmonia axyridis* (Pallas), was studied in Tainhang Mountain Area of Shanxi Province, China, during 1999–2001 (Xie et al. 2004).

67.10.1 *Oracella acuta*

The mealybug *Oracella acuta* (Lobdell) is native to the south-eastern United States. Hosts of this mealybug include loblolly (*Pinus taeda* L.), slash (*Pinus elliottii* Engelm.), Virginia (*Pinus virginiana* Miller), shortleaf (*Pinus echinata* Miller), and longleaf (*Pinus palustris* Miller) pine (http://forestpests.org/vd/7047.html). *O. acuta* was accidentally introduced into Guangdong, southern China, in 1988 on scions of slash pine (*Pinus elliottii*) and found damaged pine trees (Sun Jiang Hua et al. 1996). Mealybugs either settle on the shoot or occasionally between the needles near the fascicle. Females secrete a characteristic white resin cell that covers their body. The tips of new shoots are the preferred settling site, though the entire shoot may be colonized when populations are high. The resin cells, shoots, and needles may become covered with black, sooty mould growing on honeydew produced by the mealybug. Infestations rarely cause tree mortality, but they may severely retard growth (http://forestpests.org/vd/7047.html). Three native parasitoids, *Zarhopalus debarri* Sun, *Acerophagus coccois* Smith and *Allotropa oracellae* Masner help regulate this mealybug's population size in the southeast United States. All three parasitoids were imported to China and released in heavily infested slash pine plantations (Clarke et al. 2010).

67.10.2 *Pseudococcus viburni* (=*Pseudococcus obscurus*)

Judas tree, *Cercis siliquastrum*, is a small deciduous tree from Southern Europe and Western Asia which is noted for its prolific display of deep pink flowers in spring. Heavy predation by *Cryptolaemus montrouzieri* was observed on *Ps. viburni* (Signoret) infesting Judas trees in avenues of Turin resulting in small mealybug population in subsequent years (Arzone 1983).

67.11 *Peliococcus serratus*

American Beech *Fagus grandifolia* is an important tree in forestry. *Peliococcus serratus* (Ferris) was known to attack *F. grandifolia* in Maryland, USA. The mealybug had two generations in a year. The eggs were laid in an ovisac on the bark in June-August (hatching in 7–10 days) and in October-November (these overwintering, hatching in late April or early May). Limiting factors included adverse weather conditions, parasitoids and predators (Russell 1987).

67.12 *Pseudococcus aurilanatus*

In South Australia, *C. montrouzieri* played a key role in controlling the golden mealybug, *Pseudococcus aurilanatus* (Maskell) – a serious pest of Norfolk Islands pines, *Araucaria excelsa* (Vosler 1920).

67.13 *Plotococcus* spp.

Plotococcus capixaba Kondo was found infesting the leaves of the jaboticaba tree, *Myrciaria jaboticaba* at Espirito Santo and *Leandra erinacea* at Sao Paulo. *Plotococcus hambletoni* Kondo was collected in Sao Paulo on a myrtaceous plant (Kondo et al. 2005).

67.14 *Antonina* spp.

Bamboo node mealybugs, *Antonina* sp., in the absence of attending ants, produced long waxy filaments both in the greenhouse and in the field conducted in the Philippines. In contrast, ant-attended mealybugs had only very short filaments or none at all. Ant exclusion experiments using potted *Bambusa tuldoides* and *B. vulgaris* var. *vitatta* confirmed the field observations. The available data suggest that the long filaments are an adaptation for the dispersal of honeydew in the absence of solicitous ants to avoid drowning in the accumulating honeydew or suffocation due to development of sooty moulds (Lit et al. 1999). Eleven species of Antonina were reported on bamboos from Taiwan, China, Japan, and the U.S. (California) (Williams and Miller 2002).

67.15 *Palmicultor lumpurensis* and *Chaetococcus bambusae*

Palmicultor lumpurensis (Takahashi) and *Chaetococcus bambusae* (Maskell) had established in Florida, USA. The potential economic impact of these invasive species for Florida's bamboo is not yet known. Monitoring of populations from each of these invasive species will be important for the native bamboo species, *Arundinaria gigantea*, and for ornamental bamboo stands (Hodges and Hodges 2004). The bamboo mealybug *Palmicultor lumpurensis* causes considerable damage to the host plant. New shoots are more susceptible to damage and heavy populations can cause abortion of new shoots. Severe infestations could potentially kill stands of bamboo.

Palmicultor lumpurensis

67.16 *Dysmicoccus obesus*

Dysmicoccus obesus (Lobdell) was found in Arkansas living in crevices under bark scales of loblolly pine trees (*Pinus taeda*). Most individuals (77 %) were found on the bole between 0 and 90 cm of the ground, and they showed slight preferences for the northern and southern bole exposures. Individuals of the formicid *Crematogaster* were observed tending the mealybug. Three broods per year were detected, with adults produced in May, July and September. It is suggested that *D. obesus* probably overwinters off the tree as immatures. The documented occurrence of *D. obesus* from ten southern and south-eastern states in the USA suggests that its distribution is probably throughout the range of its host, *P. taeda*. Records from Maryland indicated that the pseudococcid also feeds on Virginia pine (*P. virginiana*) (Thompson and Colvin 1990).

67.17 *Chaetococcus* sp.

On the bamboo *Gigantochloa scortechinii* in Malaysia, the ant *Tetraponera* sp. was found to be always associated with the pseudococcid *Chaetococcus* sp. (Klein et al. 1992).

67.18 *Pseudococcus baliteus*

In Philippines, *Pseudococcus baliteus* Lit was recorded on prop roots of *Ficus elastica* (Lit and Calilung 1994).

67.19 *Acaciacoccus* spp.

Acaciacoccus hockingi Williams and Matile was recorded in swollen thorns of *Acacia drepanolobium* in Tanzania. The species was tended by *Crematogaster nigriceps prelli*. It was not found without this formicid in attendance and appeared to be reliant on *C. n. prelli* to remove honeydew from the thorns (Williams and Matile-Ferrero 1994)

67.20 *Dysmicoccus* spp.

Serianthes nelsonii is a large tree endemic to Guam and Rota of the Mariana Islands. Three species of mealybugs, *Dysmicoccus neobrevipes* Beardsley, *D. brevipes* (Cockerell), and *Planococcus citri* (Risso), feed on the leaves, leaf buds, branch tips, and roots of trees and seedlings. On the cultivated tree in Yona, up to 40 % of the branch tips were killed every two weeks by a combination of *D. neobrevipes* and *P. citri*. Most mealybug colonies were removed by predators, including the lady beetle *Nephus roepkei* (Fluiter) (Coccinellidae). Seedlings may remain vulnerable to mealybugs for longer periods of time; malathion effectively killed the mealybugs on the seedlings (Gary et al. 1996).

67.21 Management

Inspecting seedlings and young trees regularly is essential for early detection. The branches, heavily infested by these coccid bugs, should be lopped and burnt. Eggs of the mealybugs, protected by waxy filamentous secretions of ovisacs, are almost impossible to reach with insecticides. Late instar nymphs and adult female mealybugs are not affected by foliar application of insecticides since they are covered with waxy coating. Besides, spraying with suitable insecticides may not be economically and environmentally viable. Hence, biological control particularly the third type that involves the supplemental release of natural enemies is the best control option in forestry. Among the predators, coccinellids commonly known as ladybird beetles are mainly free-living species that consume a large number of preys during their lifetime. They feed on mealy bugs, and other injurious insect and mites and keep the insect populations under control. Proven natural enemies of the respective mealybug species can be used for their suppression on forest plants. Hence, it is vital to exploit natural enemies to develop ecologically and environmentally sound insect pest management in forestry (Table 67.1).

Table 67.1 List of mealybug species infesting different forest plants

Mealybug species	Vegetables	Region/country	Reference
Anaparaputo liui Borchsenius	Ficus	China	Ben-Dov (1994)
Antonina banbusae Khalid & Shafee	Bamboo	India	Williams (2004)
Antonina meghalayaensis Khalid & Shafee	Bamboo	India	Khalid and Shafee (1988b)
Antonina pretiosa Ferris	Bamboo	USA, China, Cuba	Ben-Dov (1994)
Antonina thiensis Takahashi	Bamboo	Thailand	Takahashi (1951b)
Antonina zonata Green	Bamboo	Thailand	Takahashi (1951b)
Apodrastacoccus onar Williama	Acacia	Australia	Williams (1985a)
Astraputa eucalypti Williams	Eucalyptus	Australia	Williams (1985b)
Cataencoccus barbatus (De Lotto)	Acacia	Tanzania	Ben-Dov (1994)
Cataencoccus hispidus (Morrision)	Ficus	Java, Malaysia	Williams (2004)
Cataencoccus mazoensis (Hall)	Acacia	Zimbabwe	Ben-Dov (1994)
Cataencoccus olivaceus (Cockerell)	Ficus	California	Ben-Dov (1994)
Cataencoccus villosus (De Lotto)	Acacia	South Africa	Ben-Dov (1994)
Chaetococcus bambusae (Maskell)	Bamboos	Uganda, Brazil, Hawaii, Sri Lanka & China	Ben-Dov (1994)
Cirnecococcus policis (Mamet)	Eugenia	Mauritius	Ben-Dov (1994)
Conlicoccus Beardsley Williams	Eucalyptus	Australia	Ben-Dov (1994)
Crinticoccus ficus Williams	Ficus	Solomon Islands	Ben-Dov (1994)
Crisicoccus acaciae Williams	Acacia	Solomon Islands	Ben-Dov (1994)
Crisicoccus chalpus (Williams)	Ficus	Solomon Islands	Ben-Dov (1994)
Crisicoccus matsumotoi (Siraiwa)	Ficus	Japan, Korea	Ben-Dov (1994)
Crisicoccus pini (Kuwana)	Pines	California & Japan	Ben-Dov (1994)
Deltococcus tafaensis (Strickland)	Casurina	Ghana	Ben-Dov (1994)
Dysmicoccus acaciarum Williams	Acacia	Australia	Ben-Dov (1994)
Dysmicoccus aciculus Ferris	Pines	California	Ben-Dov (1994)
Dysmicoccus angustus (Ezzat & McConnel)	Bamboo	New Jersey & China	Ben-Dov (1994)
Dysmicoccus anicus Williams	Acacia & Eucalyptus	Australia	Ben-Dov (1994)
*Dysmicoccus banks*i Williams	Acacia	Australia	Ben-Dov (1994)
Dysmicoccus bispinosus Beardsley	Acacia	Neotropical region	Ben-Dov (1994)
Dysmicoccus brevipes (Cockrell)	Date palm	–	Ben-Dov (1994)
Dysmicoccus casuarinas Williams	Casurina	Australia	Ben-Dov (1994)
Dysmicoccus grassii (Leonardi)	Acacia	Neotropical region	Ben-Dov (1994)
Dysmicoccus hawrahicus Williams	Casurina	Tasmania	Ben-Dov (1994)
Dysmicoccus kaiensis (Kanda)	Bambusa	Japan	Ben-Dov (1994)

(continued)

Table 67.1 (continued)

Mealybug species	Vegetables	Region/country	Reference
Dysmicoccus nesophilus Williams & Watson	Pines, Erithrina	Austroriental & Pacific region	Ben-Dov (1994)
Dysmicoccus neobrevipes Beardsley	*Tectona grandis*, Tamarind	–	Ben-Dov (1994)
Dysmicoccus periius Williams	Acacia	Australia	Ben-Dov (1994)
Dysmicoccus pinecolus McKenzie	Pines	Mexico	Ben-Dov (1994)
Dysmicoccus senegalensis Balachowsky	Casurina	Senegal	Ben-Dov (1994)
Dysmicoccus texensis (Tinsley)	Acacia	Mexico	Ben-Dov (1994)
Epicoccus acacia (Maskell)	Acacia	Australia	Ben-Dov (1994)
Erium globosum (Maskell)	Acacia	Australia	Ben-Dov (1994)
Eucalyptococcus brookesae Williams	Eucalyptus	Australia	Ben-Dov (1994)
Eucalyptococcus gisleni (Ossiannilsson)	Eucalyptus	Australia	Ben-Dov (1994)
Eurycoccus monody Balachosky & Ferrero	Acacia	Kenya	Ben-Dov (1994)
Eurycoccus saudiensis Matile Ferrero	Acacia	Saudi Arabia	Ben-Dov (1994)
Ferrisia consobrina Williams & Watson	*Tectoma grandis*	Australian, Ethiopian, Neotropical & Pacific region	Ben-Dov (1994)
Ferrisia virgata (Cockerell)	Acacia, Ficus	India	Williams (2004)
Fijicoccus casurainae Williams & Watson	Casurina	Fiji	Ben-Dov (1994)
Formicoccus erythrinae sp.n.	Erythrina	India	Williams (2004)
Geococcus coffeae Green	Ficus	–	Ben-Dov (1994)
Heliococcus bambusae (Takahashi)	Bambusa	China &Taiwan	Ben-Dov (1994)
Heliococcus takae (Kuwana)	Bambusa	China & Japan	Ben-Dov (1994)
Idiococcus bambusa Takshashi & Kanda	Bambusa	Japan	Ben-Dov (1994)
Indococcus pipalae Ali	Ficus	India	Williams (2004)
Itycoccus beardsleyi Williams	Acacia	Australia	Ben-Dov (1994)
Itycoccus milprinkae Williams	Acacia	Australia	Ben-Dov (1994)
Laingiococcus painei (Laing)	Ficus	Papua New Guinea	Ben-Dov (1994)
Maconellicoccus auatraliensis (Green & Lidgett)	Acacia	Australia	Ben-Dov (1994)
Maconellicoccus hirsutus (Green)	*Aegle marmelos*, *Albizia* spp., *Bauhinia* spp. *Caesalpinia* spp., *Casuarina* spp., *Cordia*, *Syzygium*, *Tabebuia*, *Erthrina* spp., *Haldina. agerstroemia*, *Melia*, *Cassia* spp.	Many countries	*manatee.ifas.ufl.edu/comm-hort/pdf/pest-topics/InsectPHMHosts.pdf*
	Parkinsonia, *a*, *Tamarindusia* & *Terminalia* spp.		
	Ficus, *Tectona grandis* & Tamarind	–	Ben-Dov (1994)

(continued)

Table 67.1 (continued)

Mealybug species	Vegetables	Region/country	Reference
Maconellicoccus ugandae (Laing)	Acacia	Ghana	Ben-Dov (1994)
Melanococcus albizziae (Maskell)	Acacia, Albizia	Australia	Ben-Dov (1994)
Niapecoccus brasilicus Williams & Granara de Willink	Ficus	Brazil	Ben-Dov (1994)
Niapecoccus gilli Williams & Granara de Willink	Acacia	Mexico	Ben-Dov (1994)
Niapecoccus guazumae (Balachowsky)	Acacia & Ficus	Columbia	Ben-Dov (1994)
Niapecoccus nipae (Makell)	Ficus	–	Ben-Dov (1994)
Nipaecoccus viridis (Newstead)	Acacia, Ficus	Many countries	Ben-Dov (1994)
	Albizia & Tamarind		
Paracoccus barymelus Williams & Watson	Casurina	Papua New Guinea	Ben-Dov (1994)
Paraputo anomala (Newstead)	Acacia	Tanzania	Ben-Dov (1994)
Phenacoccus eugeniae Takahashi	Eugenia	Mongolia	Ben-Dov (1994)
Phenacoccus hystrix (Baerensprung)	Pines	Germany	Ben-Dov (1994)
Paraputo leveri (Green)	Ficus	Papua New Guinea	Ben-Dov (1994)
Peliococcus subcoticola Williams	Casurina & Eucalyptus	Australia	Ben-Dov (1994)
Peridiococcus ethtelae (Fuller)	Casurina	Australia	Ben-Dov (1994)
Phenacoccus aceris (Signoret)	Ficus	Nearctic & Palaearctic region	Ben-Dov (1994)
Phenacoccus hargreavesi (Laing)	Ficus	Ethiopian region	
Phenacoccus madeirensis Green	Ficus	Pakistan	Williams (2004)
Phenacoccus pratti Takahashi	Eucalyptus	Malaysia	Ben-Dov (1994)
Planococcoides robustus (Ezzat & McConnel)	Ficus & date palm	Bangladesh, India & Pakistan	Williams (2004)
Planococcus citri (Risso)	Cassia & *Delonix regia*	–	Ben-Dov (1994)
	Teakwood	India	Williams (2004)
Planococcus ficus (Signoret)	Date palm	Many countries	Ben-Dov (1994)
Planococcus dorsopinosus Ezzat & McConnel	Ficus	Philippine, India & Thailand	Williams (2004)
Planococcus kraunhiae (Kuwana)	Casurina	Taiwan, China, Japan	Ben-Dov (1994)
Planococcus lilacinus (Cockrell)	Acacia, Ficus & Eugenia	–	Ben-Dov (1994)
Planococcus minor (Maskell)	Casurina, Ficus, Eucalyptus, *Tectona grandis*	–	Ben-Dov (1994)
Planococcus nigritulus De Lotto	Ficus, date palm	Tanzania	Ben-Dov (1994)
Plotococcus subterraneus De Lotto	Ficus	South Africa	Ben-Dov (1994)

(continued)

Table 67.1 (continued)

Mealybug species	Vegetables	Region/country	Reference
Pseudococcus cryptus Hempel	Date palm	Maldives	Williams (2004)
Pseudococcus viburni P = affinis	Eucalyptus	–	Ben-Dov (1994)
Pseudococcus bombusicola Takahashi	Bamboos	–	Ben-Dov (1994)
Pseudococcus calceolarieae (Maskell)	Ficus	–	Ben-Dov (1994)
Pseudococcus comsocki (Kuwana)	Ficus	–	Ben-Dov (1994)
Pseudococcus eucalypticus Williams	Eucalyptus	Australia	Ben-Dov (1994)
Pseudococcus kikuyensis James	Ficus	Sudan & Kenya	Ben-Dov (1994)
Pseudococcus longispinus (Targioni-Tozzetti)	Acacia, ficus, date palm, Carambola & pines	–	Ben-Dov (1994)
Pseudococcus moribensis Takahashi	Casurina	Malaysia	Williams (2004)
Pseudococcus occiduus DeLotto	Ficus	Ethiopian	Ben-Dov (1994)
Rasrococcus iceryoides (Green)	Caesalpinia & ficus	Many countries	Ben-Dov (1994)
	Ficus & teak	India	Williams (2004)
Rasrococcus invadens Williams	Ficus	Indonesia	Williams (2004)
Rasrococcus spinosus (Robinson)	Ficus	Malaysia	Williams (2004)
Rhizoecus americanus (Hambleton)	Ficus	Nearctic, neotropical. Palaearctic region	Ben-Dov (1994)
Trionymus bambusa (Green)	Bambusa	Bangladesh, India, Sri Lanka	Williams (2004)
Trionymus internodii (Hall)	Bambusa	Egypt & Israel	Ben-Dov (1980)
Xenococcus annandalei Silvestri	Ficus	Malaysia & India	Williams (2004)

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68 Glasshouse, Greenhouse and Polyhouse Crops

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Protected environments such as glasshouse/greenhouse/net house/polyhouse are those that maintain plants year round. They provide optimal conditions for insect and mite pests to survive, develop, and reproduce. Mealybugs are serious pests of various crops in greenhouses and probably the most difficult-to-control pests in greenhouses. Mealybugs are not particular about their hosts, and probably all species of crops are susceptible to mealybugs, especially when cultivated in protected environments.

68.1 Mealybug Species

There are a number of different mealybugs of concern to greenhouse growers. In greenhouses of California, the most frequently found mealybugs are the long-tailed mealybug, *Pseudococcus longispinus* (Targioni-Tozzetti) and the citrus mealybug, *Planococcus citri* (Risso) (Laflin and Parrella 2004). *Planococcus citri* is the most common and damaging insect pest in greenhouse and protected cultures. With the exception of roses, *P. citri* feeds on many short-term crops such as coleus, whereas *P. longispinus* often feeds upon perennial crops such as cycad and *Phormium tenax. Ferrisia virgata* (Ckll.) appears in a very severe form on poinsettia in the polyhouse. In glasshouse, the obscure mealybug, *Pseudococcus viburni* (Signoret), and *Phenacoccus gossypii* (Townsend and Cockerell) are found on chrysanthemum. *Maconellicoccus hirsutus* (Green), *Paracoccus marginatus* (Williams and Granara de Willink), and *Phenacoccus solenopsis* (Tinsley) are also found on several crops in greenhouses. *Phenacoccus madeirensis* (Green) has become an increasingly damaging pest in greenhouse ornamental production. *Maconellicoccus hirsutus* is known to attack many species of ornamental plants including *Allamanda, Angelica, Anthurium, Bougainvillea*, *Croton*, ginger lily, *Heliconia, Ixora*, hibiscus, palm, and oleander. The lily bulb mealybug *Vryburgia amaryllidis* (Bouché) and the obscure mealybug *Pseudococcus viburni* were commonly found as well. *Vryburgia amaryllidis* is limited to a few plant families (especially Liliaceae and Iridaceae). It occurs on the bulb and on the basal portion of the leaves. *Pseudococcus viburni* was found both on the roots and the aerial portion of the plants, most commonly on short-term crops. Root mealybugs (*Rhizoecus* spp.) feed on the root systems of plants; so, they can be undetected for long periods of time. *Phenacoccus solenopsis* occurs more commonly on the roots, stems, and foliage close to the soil line in dry climates, compared to settling on the upper foliage of the plant.

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68.2 Damage

The most common species of mealybugs that infest crops are immediately recognized in the adult stage by the white, yellowish-white, whitish-gray, or pale pink to pale blue color coating. Mealybugs can be found on all plant parts, especially roots, rhizomes, pseudobulbs, and the underside of leaves. They are adept at hiding on roots and rhizomes deep in the potting media, in crevices, and under sheaths. Mealybugs are active and crawl from one plant to another, pot to pot, and across benches. Mealybugs hide under rims of pots and trays, in bench crevices, and even drop from overhead plants. The mealybugs species have the ability to increase rapidly in population size in a relatively short period of time. With their piercing–sucking mouthparts, they feed on leaf and stem axils, and even on the roots of some plants. The mealybugs damage the plant by extracting the sap, which stresses the plant, resulting in the leaves becoming chlorotic and shedding over time, as well as fruit bodies being aborted. Flowers often take on an abnormal shape, reducing yield. Infested leaves become curled and crinkled, acquiring a rosette pattern, with the plant appearing bushy and stunted. In addition, the high numbers of developing mealybugs produce large amounts of honeydew that fall onto the lower leaves, producing a substrate for the development of sooty mould, which inhibits photosynthesis within the plant.

Mealybugs can be serious and persistent pests in the greenhouse. Host plant range depends on the particular mealybug species, and includes herbaceous annuals or perennials, foliage plants, orchids, vegetables, and herbs. Some of the greenhouse crops prone to mealybug infestations include coleus, croton, dracaena, hoya, English ivy, ficus, fuchsia, stephanotis, schefflera, hibiscus, mandevilla, strawberry plant (houseplant), jade plants, palms, prayer plants, gardenia, and orchids as well as many other foliage plants. The mealybugs have been found feeding on marigolds, gerbera, daisies, poinsettias, begonias, and chrysanthemums.

68.3 Monitoring

Monitoring of immature and adult mealybugs is to be carried out on the stems, leaves, and flowers. The mealybugs survive several millimeters below the soil surface. Observations should be directed to all plant tissues for the white waxy specimens. Sticky traps set out in the greenhouse can be used to detect the presence of mealybug. Once mealybugs become established, it is difficult to achieve effective control. Incoming plants should be inspected for signs of mealybugs. Roots of newly purchased plants should be inspected for the root mealybug. Greenhouses should be kept as weed-free as possible. Operational parameters of traps baited with the pheromones of three mealybug species were optimized in nurseries producing ornamental plants. All pheromone doses (1–320 μg) attracted *P. longispinus* and *P. viburni* males, with the lowest dose (1 μg) attracting the fewest males for both species. Doses of 3.2–100 μg were as attractive to male *P. longispinus* as the highest dose (320 μg); doses from 10 to 320 μg were equally attractive for *P. viburni* males. Lures containing 25-μg doses of either pheromone had effective field lifetimes of at least 12 weeks. When pheromone-baited traps for *P. longispinus* were compared with manual sampling, trap counts of male mealybugs were significantly correlated with mealybugs counted on plants in the vicinity of the traps (Waterworth et al. 2011).

68.4 Management

Mealybug management in greenhouses is difficult because of their propensity to move into the potting medium and feeding on roots, or for the crawlers to work their way into tight places. Repeated application of any treatment is required to kill the immature, and treatments are at their greatest effectiveness against the small crawlers. All control efforts must begin immediately following discovery. Even light infestations restricted to one or a few plants can explode rapidly and necessitate chemical methods. When required, infested plants should be isolated immediately from others to prevent the mealybugs from moving among them. Also, the lips and cracks of pots, trays, and benches should be checked, because females will wander and leave the plant to find hiding places. The physical conditions in greenhouses approach an optimum environment for the uncontrolled increase in populations of phytophagous insects. Once the insect is introduced, the greenhouse structure affords warm temperature, high humidity, and a physical barrier, isolating the pest from the naturally occurring predators and parasites. Effective chemical control of insects in greenhouse conditions when plant diversity is high is difficult. Compact growth habit, certain structural plant forms such as leaf sheaths, and dense foliage, all prevent adequate application of the chemical to the entire plant. Failure to treat all surfaces, along with sublethal dosages due to improper application rates and pest diversity contribute to a serious problem encountered by greenhouses today—resistance and resurgence. The phenomenon of pesticide resistance followed by a rapid resurgence of the surviving insects can cause an actual increase in the pest population following chemical application.

68.5 Cultural/Physical/mechanical control and sanitary measures

Prevention is the most important element of mealybug control. Careful selection of clean cutting materials before propagation is critical. If needed, the cutting materials could be treated with pesticides before rooting. Planting material should not be taken from infested fields. It should be made sure that transplants are clean and healthy before introducing into fields. Sanitation is the second most important element of control. Fields should be scouted regularly, checking entire plants, paying attention to ants and other crawling insects that move mealybugs. Aggressive control programs, if present, could be implemented immediately. Sanitation in greenhouses and shade houses is critical. The female can live up to 6 weeks and can continue to reproduce after crop harvest. Severe pruning of infected plants can be considered to allow for better spray coverage, followed by an aggressive control program. As soon as an infestation is detected, infested plants should be isolated and treated. It is important to prune or cut infested stems or branches from plants and destroy the infested plant material. Also, stalks and crop residue in infested sites should be removed and destroyed, as such residue left in the greenhouse can harbor mealybugs, which can survive to invade the new crop. It is necessary to sanitize equipments and check clothing items to prevent the transfer of the pest into new locations. Small populations of mealybugs can be controlled by inspection of plants, removing, and handpicking the specimens from newly infested plants. Soap applications are often effective against targeted small populations of the mealybug.

68.6 Chemical Control

The conventional management tactics for mealybugs in greenhouse ornamental production include regular application of insecticides. Persistent populations of mealybugs or infestation in many plants may demand the need for use of synthetic insecticides. Well-established infestations are difficult to control, because their waxy secretions help to protect the young nymphs and eggs from penetration with chemical sprays. The crawler stage, which does not possess a waxy covering, is most susceptible to insecticides, including insect growth regulators (e.g., azadirachtin, buprofezin, and kinoprene), insecticidal soaps (potassium salts of fatty acids), horticultural oils (petroleum-based), and possibly insect-killing fungi (*Beauveria bassiana*).

The types of insecticide applications include foliar sprays and those directed toward the growing medium (drench or granule). Adult mealybugs are difficult to manage, because they form a white, waxy protective covering that is nearly impervious to most insecticides. And, because most insecticides have no activity on eggs (with the possible exception of petroleum-based or neem oils), at least 2–3 weekly applications usually are required to achieve satisfactory suppression, especially when dealing with overlapping generations. Although very few (if any) insecticides are able to penetrate the waxy covering of mealybugs, those containing ethyl alcohol (ethanol), such as some oil-based insecticides, may allow the material to penetrate through the waxy covering, killing mealybugs. When applying high-volume sprays, thorough coverage is imperative, especially when using contact insecticides, because mealybugs are commonly located in areas that are not easily accessible, such as the base of leaf petioles, leaf sheaths, and leaf undersides. Adding a spreader-sticker to a spray solution may be helpful in improving coverage and penetration. For highly susceptible plants, it may be prudent to routinely spray with either an insecticidal soap or horticultural oil to prevent mealybug populations from reaching outbreak proportions. Also, it is essential to make multiple applications when crawlers are present, because eggs will hatch (with the exception of the long-tailed mealybug) over an extended time period. Insecticides classified as reduced-risk include insecticidal soaps, horticultural oils, insect growth regulators, and systemic insecticides.

Insecticidal soaps are usually solutions of a synthetic pyrethrin and a plant-safe detergent. As with oils, the detergent acts as a surfactant and spreader for dispersing the pyrethrin evenly, and as a mild caustic against the insects. Pyrethrins are synthetic analogs of pyrethrum, the natural extract from certain Asteraceae. Caution should be urged with the so-called "safe" insecticidal soaps, as some plants are sensitive, particularly tender new tissues.

Horticultural oil, neem oil, and mineral oil are effective for mealybug suppression. Horticultural, mineral, or neem oil solutions smother the insects; so, complete coverage of all sprayed plants is essential. These oils are mixed with water and usually a plant-safe detergent for enhancing the spreading and sticking of the oil. The main caution with these oil solutions is that they should never be applied to plants on hot days or in direct sunlight, as to prevent burning of tissues. Also, to prevent sun-burning, the chemical should be applied and allowed to dry in shade.

Growth Regulators and Chitin Inhibitors are classes of insecticides that have some potential for mealybug management. The insect growth regulator (IGR) buprofezin was not decisive; however, the IGR pyriproxyfen and the insecticide flonicamid were not directly or indirectly harmful to the predator *C. montrouzieri* and parasitoid *L. dactylopii*, indicating that these insecticides are compatible with both the natural enemies when used together for the control of citrus mealybug in greenhouses and conservatories (Cloyd and Dickinson 2006).

Systemic insecticides, those that move throughout plant parts, may also be used to protect plants from mealybug infestations. Applications should be initiated early in the cropping cycle or before introducing the plants into interiors. Systemic insecticides may be applied as either a growing medium drench or granule. It is important to avoid overwatering plants afterward, so that the roots can absorb the active ingredient. Systemic insecticides, depending on the type, may be less effective on mealybugs than on aphids or whiteflies. This may be associated with mealybugs not ingesting lethal concentrations of the active ingredient, because they feed within the mesophyll tissues or on plant stems.

The use of insecticides is the most effective control against the mealybug when applications are timed to coincide with the crawler stage. In greenhouse tests, acephate, oxydemeton methyl, and kinoprene suppressed populations of both mealybug species and prevented crop damage. Overall reductions of *Rhizoecus floridanus* (Hambleton) by kinoprene and Ro 10–3108 were comparable to the insecticides acephate and oxamyl (Hamlen 1977). In greenhouse against *P.solenenopsis* on coleus *Solenstemon scutellarioides*, soil drenching with thiamethoxam, a neonicotinoid-based insecticide, provided the highest mealybug control (Willmott 2012).

When using pesticides, nymphs are easier to control than mature mealybugs. Insecticides used for mealybug control should be rotated to minimize resistance buildup. Insecticides should be applied using a sprayer that provides complete spray coverage of plant. Particularly for mealybugs, it is important to totally wet the entire plant, including the basal portion. All pesticide labels should always be read and followed.

The following insecticides are registered for use against mealybugs in greenhouses:

Acephate, Acetamiprid, Azadirachtin, *Beauveria assiana*, Bifenthrin, Buprofezin, Chlorpyrifos, Cyfluthrin, Dinotefuran, Fenoxycarb, Fenpropathrin, Flonicamid, Imidacloprid, Kinoprene, Paraffinic oil, Petroleum oil, Potassium salts of fatty acids, Spirotetramat, Thiamethoxam.

68.7 Biological control

With some of these chemicals facing phase-out, and with the rising environmental and economic concerns surrounding chemical control tactics, biological control presents a promising alternative to chemical control for greenhouse ornamental growers. The waxy covering may be the reason for the rare occurrence of pathogens and nematodes as major infesting agents of the mealybug (Franco et al. 2009). Still, biological control of greenhouse pests through introduction of natural enemies offers a viable alternative to chemical controls. The use of biological control agents such as parasitoids and predators has been successful in managing mealybugs, primarily citrus mealybugs, under specific crop production systems and interiorscapes. Biological control of mealybug in greenhouse production relies on augmentative releases of parasitoids and predators. Biological control agents that are available commercially include a variety of tiny parasitic wasps, brown lacewings, green lacewings, and lady beetles. Some of the commercially available mealybug natural enemies are the parasitoids *Anagyrus pseudococci* (Girault), *Leptomastidea abnormis* (Girault) and *L. dactylopii* (Howard) (all Hymenoptera: Encyrtidae) for *P.citri*, and the predator *Cryptolaemus montrouzieri* (Mulsant) (Coleoptera: Coccinellidae) for many mealybug species (Chong and Oetting 2007).

Biological control in greenhouse ornamental production is characterized by the diversity of plants and pests. A biological control program for one pest must be compatible with the production practices and the management program against another pest. The nontarget effects of a biological control agent on other beneficial or nonpest organisms have to be investigated. The most suitable host stages may achieve higher rates of parasitism, survival and development, and produce a higher number of progeny consisting of mainly female parasitoids. The mean temperature of the greenhouse should be maintained at 15 to 30 °C for the parasitoids to achieve the highest developmental rate. Choosing the appropriate release time and environmental conditions can enhance the establishment and effectiveness of the parasitoid population. The parasitoids can be released as an inundative or seasonal inoculative biological control agent when the mealybug population level is low. When the mealybug population is high, chemical control may be required to reduce the mealybug population below the damaging level, before the parasitoids can be released. Insecticides of choice may include insect growth regulators and other compatible chemicals.

68.7.1 *Planococcus citri*

Biological control agents currently available for suppression of citrus mealybug populations include the predatory ladybird beetle, *Cryptolaemus montrouzieri*, commonly referred to as the "mealybug destroyer," and the parasitoid, *Leptomastix dactylopii*. The larval stages of the mealybug destroyer resemble mealybug adults. *L. dactylopii* females only attack the third instar and young adult female life stages. Both the natural enemies are effective in suppressing or regulating citrus mealybug populations, and they can be used together under certain systems and situations. Doutt (1952) demonstrated that the mealybug *P. citri* could be successfully controlled on gardenias by two encyrtid parasites (*Leptomastix dactytopii* and *Leptomasiidea abnormis*) and the ladybird *Cryptolaemus montrouzieri* Mulsant. One of the difficulties encountered in the use of a predatory insect as an agent of pest control is that the near eradication of the host, in this case mealybugs, is followed by the disappearance of the predator. This necessitates reintroduction of the natural enemy.

The parasitic wasps *Leptomastix dactylopii* and *Anagyrus pseudococci* are commercially available for the control of citrus mealybugs. Generalist predators, such as green lacewings *Chrysoperla* spp., and a mealybug predator *Cryptolaemus montrouzieri* are also marketed as biological control agents of mealybugs. *Cryptolaemus montrouzieri* is highly effective in the control of mealybugs in greenhouses. *Cryptolaemus* has also been often used to control the mealybugs in glasshouses. The temperature has to be above 20 °C in the glasshouse, and the mealybug infestation should be great enough to provide adequate food for the predator (Panis and Brun 1971). *Planococcus citri* on gardenias and *Phenacoccus gossypii* on chrysanthemum were controlled effectively by the release of *C. montrouzieri*. One adult per plant of gardenia and one for each two chrysanthemum plants were released. *C. montrouzieri* was recommended to compliment *L. dactylopii* for the control of ornamentals in the glasshouse. Good control of *P. citri* on Clivia and crotons, and reasonable control on Pelargonii, Saintpaulia, Cattleya, and Pilea were observed (Copland et al. 1985). *C. montrouzieri* was used to control *P. citri* on the crops grown in glasshouses (Lagowska 1995). In the green net house, *Cryptolaemus*, when released at 20 larvae/plant, was found highly effective in clearing the mealybugs *P. citri* on the ornamentals red ginger, *Heliconia*, etc. within 2 months of its release in India. In Canada, *C. montrouzieri was* found in greenhouses on *P. citri* and *P. gossypii* (McLeod 1939). *P. citri* is the major pest of ornamental citrus plants in greenhouses. A predator:prey ratio of 1:15, in most cases, resulted in lower populations of *P. citri*. When compared with *Nephus reunioni* (Fursch), *C. montrouzieri* caused a significant reduction in the mealybug population. In most cases, significant differences in pest reductions were not detected between *C. montrouzieri* and methidathion on potted orange plants (Hamid and Michelakis 1994; 1997).

In a commercial greenhouse in Leiden, Netherlands, biological control of the pseudococcid *P. citri* on *Stephanotis* plants was carried out with the coccinellid predators *Cryptolaemus montrouzieri* and *Nephus reunioni*, and with the encyrtid parasitoids *Leptomastix dactylopii* and *Leptomastidea abnormis.* Successful control was obtained during summer and autumn, but not in winter when the temperature was 13-17 °C. *Leptomastix dactylopii* was more successful in summer and *Leptomastidea abnormis* in autumn. Aggregation of adults of *Leptomastix dactylopii* occurred at the level of sample areas, but no spatial relationship was found between host density and percentage of parasitism.

Introduction of parasitoids gave improved biological control of *P. citri* in a large glasshouse stocked with a variety of ornamental plants in the United Kingdom, supplementing that achieved by the coccinellid predator *Cryptolaemus montrouzieri.* Following the release of parasitoids *Leptomastix dactylopii* and *Leptomastidea abnormis*, there was evidence of mealybug population regulation on guava and coffee bushes with reduced and stabilized mealybug numbers and stable percentage parasitism. The encyrtid *Leptomastidea abnormis* was responsible for about 90 % of the parasitism observed; the remainder was by another encyrtid, *Leptomastix dactylopii.* The combinations of *L. dactylopii* and other parasitoids (e.g., *L. abnormis*) and predators (e.g., *C. montrouzieri*) are most effective against *P. citri* in greenhouses (Copland et al. 1985; Chong and Oetting 2007). Inoculative release of five encyrtid parasitoids, *Leptomastidea abnormis*, *Anagyrus pseudococci*, *L. dactylopii*, *Chrysoplatycerus splendens* (Howard), and *Coccidoxinoides perminutus* (Timberlake), resulted in the rapid suppression of citrus mealybug, *P. citri*, on greenhouse citrus. Several parasites, *L. abnormis*, *A. pseudococci*, and *L. dactylopii*, persisted for periods >20 weeks and maintained the host at reduced densities through delayed density-dependent regulation (Summy et al. 1986; Van Lenteren and Woets 1988).

68.7.2 ***Pseudococcus viburni*** **syn.** ***P. affinis and P. obscurus***

Good control of *Pseudococcus obscurus* (Essig) on cacti and Clivia were achieved by using *C. montrouzieri* (Copland et al. 1985). The Australian ladybird beetle *Cryptolaemus montrouzieri* is used to control the mealybugs in glasshouses. A minimum temperature of 21 °C was needed for the predator to feed and lay eggs. The time between the introduction of adults into a house and the next generation of adults was 6 weeks during summer. It is suggested that under greenhouse conditions, predators could maintain their populations and provide continuous control of mealybugs for at least 4 months in the year (Codling 1977).

Biological control of mealybugs on various kinds of ornamental plants in greenhouses at Antibes in southern France was attempted by means of the release of *Cryptolaemus montrouzieri* and the encyrtid *Hungariella pretiosa* (Timb.), either alone or together, and of *H. pretiosa* with another encyrtid, *Pseudaphycus maculipennis* (Merc). *P. maculipennis* gave good control of *Pseudococcus obscurus* at temperatures of 20-25 °C, even when the mealybugs were attended by *Iridomyrmex humilis* (Mayr). *C. montrouzieri* controlled the mealybugs at over 20 °C, but were ineffective at lower temperatures or in the presence of ant attendants. *C. montrouzieri* gave good control of *Pseudococcus affinis* (Maskell) on *Streptocarpus hybridus*, citrus, Passiflora, potato, and coffee in glasshouses (Copland 1983). *C. montrouzieri* was used to control the coccid pests in the glasshouses of the botanic garden in Lublin, Poland (Golan and Górska-Drabik 2004). In glasshouses, good control was achieved against the obscure mealybug *P. viburni* by *C. montrouzieri*, irrespective of the hairiness of the plant species. The plants used include *Citrus limon*, *Coffeae arabica*, *Lycopersicon esculentum*, *Passiflora caerulea*, *Solanum tuberosum*, and *Streptocarpus* sp. (Heidari 1999).

68.7.3 *Phenacoccus madeirensis*

Anagyrus loecki (Noyes and Menezes) (Hymenoptera: Encyrtidae) is a parasitoid of the Madeira mealybug *P.madeirensis* in the greenhouse ornamental production in Georgia (Chong 2005). *Anagyrus sinope* sp. nr is a highly host-specific parasitoid that develops only in *P. madeirensis* (Chong and Oetting 2007).

68.7.4 *Phenacoccus solenopsis*

Several parasitoids and predators have been identified that attack *P. solenopsis*. The incorporation of parasitoids into the management system provides the opportunity to control pest populations at low densities. *Aenasius bambawalei* (Hayat 2009) can be exploited for the control of *P. solenopsis* infesting plants in the greenhouses.

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69 Root Mealybugs

Maicykutty Mathew and M. Mani

Root mealybugs are several small species of mealybugs found below the soil surface, and feed on root and root hairs in numerous plants. They are also called soil mealybugs and subterranean mealybugs. Infestations frequently are not detected as the pests occur in the soil, and populations are quite slow to develop, with 3–6 months occurring before infestations are easily visible. Careful examination of infested roots will reveal white, cotton-like masses. These white masses contain both mature females and eggs. Infected plants become wilted and stunted with foliar yellowing or chlorosis. They are oval shaped (1/16 to 3/16 of an inch long) that look like they have been covered by flour. Because they are white or light grey in colour, they often resemble small grains of rice. These mealybugs have a thin, uniform waxy coating and lack the terminal wax filaments typical of their foliar-feeding relatives. Root mealybugs are slow moving, sac-like mealybugs with pronounced crosswise grooves. They do not have filaments surrounding their body like many of the foliar feeding mealybugs. Root mealybugs pose serious problem to potted and greenhouse plants and also field crops. The species belonging to genera *Geococcus, Rhizoecus, Xenococcus*, *Chorizococcus*, *Spilococcus*, *Spinococcus* and *Chnaurococcus* are known to roots of the plants (Table 69.1).

69.1 Important Root Mealybug Species

69.1.1 *Gonococcus coffeae*

Geococcus coffeae Green can be easily be distinguished by the pair of stout dorsal spines situated on the head (Green 1933). *Geococcus coffeae* was known to infest sweet potato *Ipomoea batatas* in Tamil Nadu, India (Williams 1985) and also several other plants such as *Theobroma cacao, Coffea* spp., ornamentals, pine apple, and palms (Ben-Dov 1994).

69.1.2 *Geococcus citrinus*

Geococcus citrinus is a ground mealybug that lives in the soil and damages the root of citrus in

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Table 69.1 List of other root mealybugs on different host plants in different countries

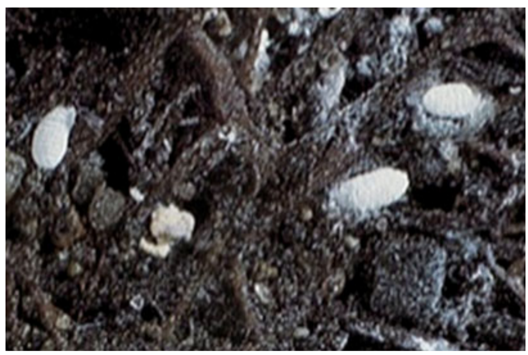
Mealybug species	Plants	Country
Dysmicoccus brevipes (Cockerell)	Pigeon pea & groundnut	South India
	Pineapple	Many countries
Dysmicoccus texensis (Tinsley)	Coffee	Espirito Santo
	Cassava	Paraguay, Bolivia & Brazil
Dysmicoccus vaccinii sp. n.	Blueberries	USA
Ferrisia virgata (Ckll.)	*Parthenium hysterophorus*	India
Geococcus johorensis Williams	Oil palm	Johore & Malaya
Geococcus lawrencei Williams	*Asplenium nidus*	Solomon Islands
Geococcus oryzae Kuwana	*Oryza sativa*	Japan & Ceylon
Phenacoccus salviacus Moghaddam	*Salvia bracteata*	Iran
Phenacoccus hordei (Lindeman)	Grasses, alfalfa, barley, clover, rye & wheat	European countries
Planococcoides robustus Ezzat & McConnell	Mango	India
Planococcus citri (Risso)	Coffee	Kenya/East Africa
	Citrus	Crete
Planococcus cryptus Hempel	Coffee	Brazil
Planococcus ficus Signoret	Grapevine	South Africa
Planococcus fungicola sp. nov.	Coffee	Kenya
Pseudococcus eriocerei Williams	Cacti	Argentina
Pseudococcus viburni (Signoret)	Plum	Chile
Pseudococcus cryptus Hempel	Coffee	Espirito Santo
Polystomophora arakensis Moghaddam	*Atraphaxis* sp.	Iran
Rhizoecus maasbachi Jansen	*Segeretia theezans*	Netherlands
	Michelis sp.	China
	Segeretia sp.	England
Rhizoecus amorphophalli Betrem	*Amorphophallus variabilis*	Java
	Amorphophallus sp.	India
	Gingiber officinale	
	Diosorea elephantipes	
	Curcuma domestica	
	Amorphophallus variabilis	Caroline Islands
	Colocasia esculenta, *Curcuma longa* and *Kaempferia galangal*	Philippines
Rhizoecus theae sp.n.	Tea	Japan

(continued)

Table 69.1 (continued)

Mealybug species	Plants	Country
Rhizoecus hibisci Kawai & Takagi	*Hibiscus rosasinensis*	Japan
	Coffee	Hawaii
	Tea, bonsai plant *Serissa foetida*, ornamentals: *Cuphea*, *Hibiscus rosa-sinensis,* Nerium*, Oleander largonium*, *Rhododendron*, bonsais like, *Ligustrum ovalifolium, Punica granatum, Segeretia theezans, Ulmus parviflora, Zelkova serrata*, foliage plants *Calathea, Diffenbachia, ficus,* and various members of Araceae and dwarf Bermuda grass	East and southeast Asia, Puerto Rico, Florida and Hawaii, Italy and the Netherlands
Rhizoecus kondonis Kuw.	Citrus	Japan
Rhizoecus cynodontis Green	*Cynodon dactylon*	India
Rhizoecus arabicus Hambleton	Coffee, *Gasteranthus atratus* & other ornamental plants	Colombia, Costa Rica & Florida
Rhizoecus kondonis Kuw.	Citrus	China
Rhizoecus aloes sp. Nov	*Aloe glauca*	UK
Ripersia speciosa De Lotto	*Coreopsis* sp.	Congo
Xenococcus annandalei Silvestri	Grapes	India

China and orange in Izu peninsula, Shizuoka-ken and Japan. It has been reported on the roots of betel vine from Tamil Nadu (India) (Muthukrishnan et al. 1958). This species became an important pest of Nendran variety of banana in Kerala. A total of 28 collateral hosts were recorded for *Geococcus citrinus* in banana ecosystem (Abraham et al. 2000; Smitha et al. 2005).



Adult females on the roots

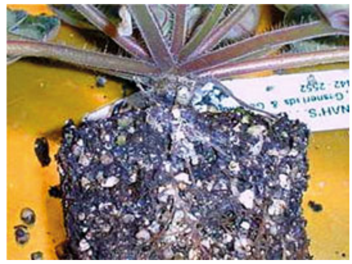
69.1.3 *Rhizoecus hibisci*

Potted palms and other slow-growing plants are more susceptible to infestation by root mealybug *Rhizoecus hibisci* Kawai & Takagi because they require lengthy bench time to attain marketable size. *Rhizoecus hibisci* have been found on palms, calathea, and *Serrisa* spp.

69.1.4 *Rhizoecus americanus*

Rhizoecus americanus Ferris is a *soft-bodied, sucking insect that attacks the tips of roots*. It is very common in Florida and other southern states. However, if shipped in plants, it continues to thrive indoors and in greenhouses. These creatures are dangerous to the plants and are often ignored as insignificant or misidentified as mycorrhiza.

Roots of *Euphorbia squarrosa* infested with mealybugs



Rhizoecus americanus on African Violets

69.1.5 *Rhizoecus falciper*

The ground mealybug *R. falciper* Kunckel d' Herculais was described in France, and occurs in scattered locations across the United States. The ground mealybug feeds on the roots of anemone, chrysanthemum, gladiolus, iris, and numerous other flowers, shrubs, and ornamental grasses. At times, the ground mealybug becomes abundant enough to damage its host.

Rhizoecus falcifer

69.1.6 *Rhizoecus pritchardi*

Pritchard's mealybug *Rhizoecus pritchardi* Mckenzie is found across the United States. Pritchard's mealybug has become a serious pest of African violet, although it is also known to infest Achillea, Arctostaphylos, Geum, and Polygala. Pritchard's mealybug causes devitalization, foliage deterioration, and even death of its host plant. When infested African violets are irrigated, Pritchard's mealybugs crawl out of the drainage holes and spread throughout the greenhouse. Eggs are laid in a loose ovisac in clusters of at least six eggs. All stages can be found on the roots.

69.1.7 *Rhizoecus maasbachi*

Rhizoecus maasbachi Jansen is known to infest bonsai plants of *Sageretia* spp. in China. This species lives hidden on root hairs and detection of small population is difficult. *Rhizoecus hibisci* and *R. maasbachi* are the only two species regularly detected on Chinese bonsai and could be confused with one another. In *R. maasbachi*, eyes are present and the antennae are 6-segmented. In *R. hibisci*, the eyes are absent and antennae are 5-segmented (Jansen 2003).

69.1.8 *Rhizoecus amorphophalli*

Rhizoecus amorphophalli Betrem was recorded on roots of elephant foot yam, *Amorphophallus* sp. from Trivandrum, Kerala (India) and roots of ginger *Zingiber officinale* from Calicut, *Dioscorea elephantipes* from Goa, and rhizomes of *Curcuma domestica Zingiberaceae)* from Kohlapur, Maharashtra stored for seed purpose.

69.1.9 *Rhizoecus cocois*

Rhizoecus cocois Williams was reported from Kazhakkoottam, Kerala infesting coconut palms. Infested young palms show yellowing and loss of vigour and discolouration of the roots at the point of feeding resulting in the drying up of such roots. The adult female is subglobular, cream coloured and enclosed within a loose jacket of pure white cottony felt (Nair et al. 1980).

69.1.10 *Rhizoecus kondonis*

Rhizoecus kondonis Kuwana is a subterranean pest of alfalfa (lucerne), prunes (plums, Prunus domestica) and other crops primarily in the Sacramento Valley of California. Root feeding by the mealybug results in chlorotic, stunted lucerne plants. *Rhizoecus kondonis* has three generations per year with peaks in abundance in July-August, December-January and March-April. Significantly more *R. kondonis* were found 15.2–45.7 cm deep in the soil (averaging 8.3/1240 cm superscript three soil core samples) compared with depths of 0–15.2 cm (averaging 2.2/sample). All ten lucerne varieties were examined for susceptibility to this insect and found to be equally susceptible (Godfrey and Pickel 1998).

69.1.11 *Dysmicoccus brevipes*

Dysmicoccus brevipes Cockerell is common on the roots of pineapple, and large colonies develop on the stems just above ground level. It is associated with pineapple wilt. It was also found on the roots of the groundnut. It lives in colonies underground, and few may be seen on foliage. They feed on nodules and cut off the nutrient supply to plants (Singh et al. 1986).

69.1.12 Pepper Root Mealybugs

Mealybugs are major insect pests of black pepper plantations in southern parts of India. Five mealybugs species namely *Planococcus* sp., *Planococcus citri* (Risso), *P. lilacinus* Cockerell, *Dysmicoccus brevipes* (Cockerell) and *Ferrisia virgata* (Cockerell) are known to infest the roots and basal region of stem of black pepper vines (*Piper nigrum*) (Ventataramaiah and Rehman 1989; Devasahayam et al. 2010).

69.1.13 *Planococcoides robustus*

Planococcoides robustus sp.nr. was found infesting roots of mango, grapes and the weed plant *Coniza ambigua* in the Kolar district of Karnataka, India. Ants were observed to carry the mealybugs. The affected plants showing desiccation and leaf fall survived (Puttarudriah and Eswaramurthy 1976).

69.1.14 *Xenococcus annandalei*

The grape root mealybug *Xenococcus annandalei* Silvestri in India also known to cause damage occasionally by sucking the sap from roots, and the affected vines show reduced vigour, shortening of fruit bearing canes and reduction in size of fruit bunches and yield.

69.1.15 *Paraputo* sp.

Mulberry plantations in hilly areas of Northern parts of India such as Darjeeling and Kalimpong are being infested by root mealybug, *Paraputo* sp. (Pseudococcidae: Homoptera) causing considerable damage (Mukhopadhyay et al. 2010).

69.1.16 *Phenacoccus parvus*

Phenacoccus parvus Morrison was recorded feeding mainly on collar region and subterranean plant parts of the ornamental China aster in India. About 25 % of the plants were infested making the plant stunted without bearing flowers (Sridhar et al. 2012).

69.1.17 *Chryseococcus arecae*

The golden root mealybug, *Chryseococcus arecae* Maskell is a native of New Zealand. It was found in Britain and can be witnessed on the roots of outdoor plants all year round. Golden root mealybug is a sap feeding insect that feeds on the roots of a wide variety of plants, although it has only been found on *Meconopsis* and *Primula* in UK. Mealybug infestations have been noticed on plants lacking vigour.

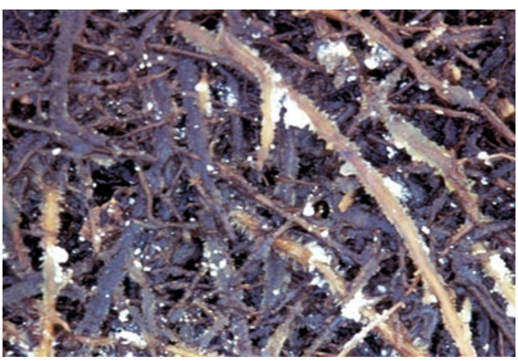
Chryseococcus arecae

69.1.18 The Enset Root Mealybug *Cataenococcus ensete*

Enset (*Ensete ventricosum*) was domesticated in Ethiopia several hundred years ago, and is now the staple food crop for over 15 million Ethiopians living in the highlands of southern Ethiopia. The enset root mealybug *Cataenococcus ensete* Williams and Matile-Ferrero is a major pest in the enset growing regions of southern Ethiopia. Infestation was high in Amaro, Gedeo, Sidama and Bench districts with 100, 67, 61 and 57 % incidence respectively. Low mealybug incidence was recorded in Gurage, Kembata Tembaro, Hadyia zones and Yem districts. More than 30 % of the enset farms were infested with the mealybugs. The highest infestation of 81 mealybugs per plant was recorded in Gedeo zone while the lowest infestation of three mealybugs per plant was recorded in Yem district. Knowledge about the biology and distribution of this species has paramount importance in devising proper management. Enset plants infested with mealybugs have a retarded growth and dried lateral leaves. The insects attack all plant age groups but symptoms are more severe on 2 to 4 years old enset plants. Enset root mealybugs are found on roots and corms. However, during periods of extreme drought the mealybugs tend to move towards the corm when some of the roots drought. The dispersal mechanism of enset root mealybugs is facilitated by movement of infested suckers, farm implements during cultivation, repeated transplanting operations and association with ants. The population density of the mealybugs was significantly ($P<0.05$) higher on the roots than the corms. Enset root mealybugs were found up to a soil depth of 60 cm and up to 80 cm from the corm. However, root density as well as mealybug population numbers decreased with increasing soil depth. About 99 % of the mealybugs and 96 % of the roots were collected within the upper 40 cm soil layer. In addition, about 90 % of the mealybugs were found within a 60-cm radius from the plant (Addis et al. 2008, 2010).

69.2 Damage

There can be several generations of the root mealybugs throughout the year and numbers can multiply under favourable conditions. With severe infestations, root mealybugs can be found on the soil surface at the stem base. It is very difficult to detect symptoms of root mealybugs on the plant. White, cottony-like masses containing egg-laying females and/or eggs are normally visible on the outside of the root mass when an infested plant is lifted. Slow plant growth and leaf deterioration may be signs of the presence of the pest. Root-bound or under environmental or nutritional stress, the plants are more susceptible to attack. Once established in the greenhouse, root mealybugs may spread as crawlers from plant to plant as the water moves out of the drainage holes to nearby plants and in plant debris. It is mainly potted plants (especially bonsai plants) that are concerned during import inspections. The pot should be removed and roots examined for waxy secretions. In case of heavy infestations, crawlers may be observed on the soil surface. The mealybugs may be found particularly in the new feeder roots in the upper layer of the soil. The resulting damage stifles the ability of roots to absorb water and nutrients. The only outward sign of root mealybug feeding may be a decline in the health of infested plants. When plants are removed from the pot, the whitish mealybugs feeding on the roots are then observed. If the plant seems to be declining in health because it has yellow foliage or slow growth or is stunted for what seems to be no particular reason, then it is to be looked for something that could be lurking below feeding on the plant's root system. In case there are mealybugs on bonsai trees, leaves may be pale (sometimes greyish) or wilted, despite regular fertilizer and watering. Maybe the plant growth has slowed down and/or flowering has ceased. In severe cases, the leaves may be misshapen. Although they occur throughout the roots, they are most obvious along the edges.



Mealybugs on the roots

The adults and nymphs of *Geococcus* suck sap from the lateral roots of banana colonizing at the junction of laterals with main root resulting in drying up of such roots. Yellowing and narrowing of leaves, general weakening of the plant, reduction in bunch weight, etc. were the observed symptoms. *Geococcus citrinus* occurs seriously on banana roots in reclaimed paddy fields. *G. coffeae* was also associated with banana grown in uplands.

The adults and immature stages of *Rhizoecus hibisci* feed on plant roots particularly new roots in the upper layer of soil reducing water and nutrient uptake by host. Feeding reduces plant growth resulting in shrivelling and crinkling. Leaves wilt, become pale and turn yellow or grey; alternatively they can become soft, translucent and brown. Flowers may not be produced.

Mealy bugs (*Planococcus* sp., *P. citri*, *P. lilacinus*, *Dysmicoccus brevipes* and *Ferrisia virgata*) were found infesting the roots and basal region of stem of black pepper vines (*Piper nigrum*). Infested plants show slow or poor growth. Leaves wilt, become pale or turn yellow or grey. Wax deposit is seen around the roots, on the soil or on the side of the pots. The infestation is generally severe during the post monsoon. The root mealy bug affects the aerial parts of the black pepper vines such as the tender shoots, leaves and berries (Devasahayam et al. 2010).

Parputo sp. cause appreciable damage to mulberry directly by sucking the sap and indirectly by making way for some fungal infection, leading to rotting of the root and ultimately death of the plants. The infested mulberry plants show vulnerability to the attack of various fungal pathogens such as *Fusarium solani, Phomopsis mori* and *Colletotrichum gloeosporioides.* Due to this, decaying of bark portion of root and stem occurs with severe anthracnose disease. Finally, it results in the death of such severely affected mulberry plants (Biswas et al. 2002).

Symptoms of banana root mealy bug infestation on banana

Roots of banana infested with mealybugs

Banana plants infested with root mealybugs

69.2.1 Mode of Spread

Under moist conditions, young root mealybugs or nymphs are active. They move short distances to adjacent plants. They may crawl from pot to pot via drainage holes. They are slow moving in irrigation water thereby facilitating the spread. However their dispersal potential is usually limited. Infestations often begin with the purchase of infested plant material.

69.2.2 Seasonal Development

Banana root mealybugs: The maximum population of *Geococcus* spp. was observed within 20–40 cm radius followed by 40–60 cm. In the case of vertical distribution, more mealybugs were collected within 20 cm depth. The population increased with the commencement of southwest monsoon in June and reached a peak in July, followed by a decline in September, reaching a lower level in January and remained low up to May (Smitha and Mathew 2010a).

Mulberry root mealybugs: Plantations in hill are being infested by root mealybug *Paraputo* sp. causing considerable damage. It remains in the root-zone and adjacent to stump portion below the soil surface up to 20 cm deep, sucks sap and secrets honey dew, thus inviting the occurrence of several fungi on the plants. Due to sucking root becomes stunted, normal growth ceases and leaves become yellow and appear to be wilting (Das et al. 2004).

69.2.3 Natural Enemies

There is poor natural enemy complex, particularly natural predators or parasites on root mealybugs. Two predators namely *Scymnus* sp. (Coccinellidae: Coleoptera) were found feeding on *G. citrinus* (Smitha and Mathew 2010a). Mathew et al. (2010) reported the fungal pathogen, *Paecilomyces lilacinus* on *Geococcus* spp. It was pathogenic to both *Geococcus coffeae* and *G. citrinus* (Smitha and Mathew 2011) and also isolated *Hirsutella* sp. infecting *G. citrinus*. The larvae of *Spalgis* sp. were observed to predate on pepper root mealybug colonies (*Planococcus* sp., *P. citri*, *P. lilacinus*, *Dysmicoccus brevipes* and *Ferrisia virgata*) (Devasahayam et al. 2010; Ventataramaiah and Rehman 1989).

Larva of *Scymnus* sp.

Adult *Scymnus*

69.3 Management

It is very difficult to detect and control root mealybugs. Every effort should be made to prevent their spread and establishment. Pesticides applied as dips, drenches, or granules are more effective for root mealybug control than are foliar sprays.

69.3.1 Pot Culture Plants

- Infestations usually begin with new plant material. Inspect roots of newly purchased plants by removing them from their pots.
- Inspect roots of suspected plants, especially slow growing ones.
- Avoid pot-bound plants by re-potting when necessary.
- Use pots with inner coatings of copper hydroxide which prevents root matting and thereby minimizes root mealybug infestations. Separate pots from the ground on raised benches or with plastic film over the soil. Palm roots in the pot not treated with copper hydroxide (right) are more compacted and infested with mealybugs (Hara et al. 2001).
- Do not allow water from infested areas to run onto clean areas.
- Remove alternate host plants from around the greenhouse, or control mealybugs on them.
- Use clean pots and soil; if infested, wash pots with soap and water.
- Keep the growing area clean of plant debris.
- First, isolate the affected plants, especially if they share a common watering tray with other, healthy plants. Although soil mealy bugs do not spread easily, they will travel over moist surfaces.
- Root mealybugs can be spread by irrigation water, re-use of previously infested pots, re-use of contaminated media, and crawlers moving from infested plants to other plants.
- Infestation of greenhouse bench plants by root mealybugs can occur by introducing nursery stock that was already infested when purchased or from crawlers that move in from host plants near the greenhouse.
- For root mealybug in pots, remove all soil and destroy it. Wash the roots thoroughly and treat (eventually immersing the whole plant) with the above mentioned insecticide, letting the roots dry after treatment and before replanting in completely fresh, sterilized soil. Always cleanse and sterilize frames and all other items

used when replanting. Regular applications (weekly for several weeks) of insecticide watered into the soil are also effective; it is also possible to immerse the plant pot up to the top of the soil in a bucket of insecticide.

- A promising alternative to chemical treatments has been found in the use of Diatomaceous Earth, a fully inert, non-volatile substance that has proven effective in eradicating certain insect pests. Strictly speaking, Diatomaceous Earth is not an insecticide. It is made from the skeletal remains of diatoms, a microscopic form of algae. When processed into Diatomaceous Earth, these skeletal remains form razor-sharp particles which cut into the bodies of small insects. While eradicating the insects, Diatomaceous Earth does not harm African Violets. To treat for soil mealy bugs, repot the African Violet in a soil that has been mixed with Diatomaceous Earth. Use about one tablespoon per one litre of soil. Pasteurize soil before re-potting. To make soil uninhabitable for future mealy bug infestations, mix about one fourth tablespoon of Diatomaceous Earth with every litre of soil.
- Hot-water dips are as effective as insecticides against mealybugs. Submerging the potted palms in water held at 120 °F (49 °C) until the internal root ball temperature reached 115 °F (46 °C) was 100 % effective in killing root mealybugs. Drenching potted palm roots in hot water at 120 °F for 15 min will not only control mealybugs but will also eliminate burrowing nematodes. If an infestation is found (*Rhizoecus hibisci)*, hot water treatment of root balls is very effective (Hu et al. 1996).
- Chemical control of root mealybugs requires saturation of the root ball and potting medium to a degree that allows the pesticide to penetrate the pests' white, waxy secretion. Dipping or drenching with liquid insecticide is more effective than applying a granular formulation. Chlorpyriphos, applied twice as a drench or dip at 2-week intervals controls coffee root mealybug; however, it may take 4–6 months before the cottony, waxy secretions deteriorate completely. In the dip method, submerging the plant's entire root ball without the pot in a diluted chlorpyriphos solution (1 pint per 100 gal) for about 30 s with slight agitation is nearly twice as effective as dipping the plant while still in its pot. Imidacloprid, which can be applied only as a drench and incorporated with a surfactant or wetting agent to ensure thorough distribution of solution in the potting medium, can also significantly reduce the number of individuals in an infestation (Hata et al. 1996).
- Moth ball**:** As a preventative measure, moth balls (paradichlorobenzene), added to the potting mix, seem to discourage infestation by root mealy bug, and probably discourages other insects. However, the chemicals in the moth balls can cause damage to plastic plant pots and are best used with clay pots.
- Traditionally, the only effective treatment for soil mealybugs (*R. amercanus*) has been to spray the soil with acephate (as directed on the label) or with malathion (1 teaspoon of Malathion 50 per 4 l of lukewarm water). While this treatment does work, it usually takes several applications over a period of days. Moreover, there is usually some risk to plants when using any chemical treatment.

69.3.2 Field Conditions

Application of sodium silicate and calcium oxide at the time of planting effectively reduced the population of banana root mealybug, *G. citrinus*. Drenching of the chemical insecticides, chlorpyriphos at 0.05 % at monthly intervals, reduced the root mealybug population. Among the combinations, without synthetic insecticides, sodium silicate alone and its combination with neem seed kernel extract (NSKE) and *Cephalosporium lecanii* Zimm, were effective in reducing the mealybug population at sixth and seventh month of the crop. Application of chlorpyriphos gave the highest benefit--cost ratio of 2.46 followed by sodium silicate (2.30) (Smitha and Mathew 2010b). Application of neonicotinoids, which include imidacloprid, t*hiamethoxam*, thiocloprid, by way of soil drench can also be tried against root mealybugs in general.

Drenching the affected vines with about 0.075 % chlorpyriphos is effective in controlling the pepper root mealybug infestation in India. If the infestation persists, then drenching may have to be repeated after 20–30 days, "Adequate care should be taken to ensure that the insecticide solution percolates down to the roots while drenching the vines. Farmers should not transplant infested nursery plants in the field and mild infestations should be controlled in the nursery itself. Ploughing the interspaces in black pepper gardens and removal of weeds also help in lowering the level of pest population. The mango root mealybug *Planococcoides robustus* sp.nr. was controlled by application of disulfoton granules at monthly intervals and watering weekly. The affected plants showing desiccation and leaf fall had survived (Puttarudriah and Eswaramurthy 1976).

Under green house and farmers field conditions, insecticides like diazinon 60 % EC and chlorpyriphos 48 % EC caused at least 98 % mortality of enset mealybug *Catenococcus ensete* both under field and green house conditions (Tadesse et al. 2010a). Seed water suspension of *Millettia ferruginea* at 10 % was toxic to *C. ensete*, causing 66 % mortality. However, the efficacy was inferior to diazinon application in the pot and dipping treatments (Tadesse et al. 2010b). Citronella oil at 5 % performed better towards controlling mulberry root mealybug *Paraputo* sp. followed by 5 % neem oil and 55 neem leaf extract, without any adverse effect on silkworm rearing (Anonymous 2011). Biswas et al. (2002) reported that both carbofuran and endosulfan were effective in controlling mulberry root mealybug for longer period. Diazinon, oxamyl and granules of aldicarb are recommended for control of *Rhizoecus arabicus* Hambleton (Hamon 1982). Phyrinex 48 % EC and Phostoxin tablet had provided better control of root mealybug (*Paraputo* sp.) than the other insecticides. Phostoxin tablets and Phyrinex 48 % EC resulted in mean pseudostem circumference increases of 23.23 and 32.34 cm, and in mean plant height increases of 71.09 and 58.11 cm, respectively, over the control (Bekele 2001).

69.3.3 Biological Control

Smitha and Mathew (2010b) found *Cephalosporium lecanii* Zimmerman as the best among the three fungi screened, namely, *Beauveria bassiana* Balsomo, *Hirsutella* sp. and *Cephalosporium lecanii.* Entomopathogenic nematodes (EPNs) have potential for biological pest control and have been successfully used in several countries in soil and cryptic pests control, as for example the coffee root mealybug *Dysmicoccus texensis* (Tinsley). Aqueous suspension of *Heterorhabditis* on coffee root was more efficient with 70 % control efficiency when compared with thiamethoxam (Alves et al. 2009).

69.3.4 Phytosanitary Risk

R. hibisci has spread from Asia to USA (Hawaii and Florida) and has established in some ornamental glasshouses in Europe. Though there are also European species of *Rhizoecus* with similar biology, *R. hibisci* is a potentially serious pest in the EPPO region, particularly on glasshouse pot plants. Moreover, it has significance as an indicator that pot plants (especially bonsai plants) produced in eastern Asia, and exported to the EPPO region, have not been grown under adequately controlled conditions (as defined for example in EU 2000), and may accordingly be infested by other non-European pests. *Rhizoecus hibisci* was added in 2001 to the EPPO A2 list of regulated pests. Nurseries producing pot plants for export to the EPPO region should maintain good standards of hygiene, and in particular should respect EPPO Standard PM 3/54 growing plants in growing medium prior to export (OEPP/EPPO 1994). Bonsai plants for export to the EPPO region should respect the requirements set out in EU (2000) or equivalent requirements. Consignments of containerized host species from areas where *R. hibisci* occurs should have containers removed and the roots inspected. Montanucci (2010) described a safe and inexpensive procedure for elimination of root mealybugs (genus Rhizoecus) from a small cactus collection. The procedure prevents re-infestation by taking advantage of the fact that the root mealybug females and nymphs are wingless and must crawl to potted plants to become established. The procedure is expected to permanently eradicate rather than simply control these pests.

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Coffee

70

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70.1 Species Distribution

Among the two commercially cultivated coffee varieties, *Coffea arabica* L. (arabica coffee) and *C. canephora* Pierre ex Froehner (robusta coffee), the latter is more prone to attack by mealybugs since this variety is grown in more open conditions and at lower elevations. Over 50 species of scales and mealybugs are reported to attack various parts of the coffee tree – roots, branches, leaves, flower clusters and berries where they suck the sap and are of great economic importance (Wrigley 1988). *Planococcus kenyae* (Le Pelley), popularly known as coffee mealybug, is distributed in Uganda, Tanzania and Kenya (Bigger 2009). The two most commonly encountered mealybugs on coffee in India are *Planococcus citri* Risso (Coleman and Kannan 1918; Ayyar 1940) and *P. lilacinus* Ckll. (Sekhar 1964; Bhat and Shamanna 1972). *Ferrisia virgata* Ckll. has also been recorded (Chacko and Bhat 1976). They attack both robusta and arabica but prefer the former. *Planococcus ficus* and *P. minor* have been recorded on coffee as minor pests. The mealybugs, *P. citri* and *P. lilacinus*, are distributed throughout the coffee tracts of India and can be noticed quite often during the summer months. *Planococcus lilacinus* is predominantly found in Kodagu district of Karnataka state, while *P. lilacinus* and *P. citri* are found in equal proportion in Wayanad district of Kerala state in India (Abdul Rahiman et al. 1995). In Wayanad district of Kerala, the population of *P. citri* was higher in all the zones compared to *P. lilacinus* (Abdul Rahiman and Naik 2009b). For *P. lilacinus*, several collateral hosts have been recorded, which can aid in the survival of the mealybug even if adequate measures are adopted to control them on coffee (Bhat and Shamanna 1972) (Table 70.1).

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Table 70.1 List of mealybugs recorded on coffee from different countries

Mealybug species	Region	Reference
Archeomyrmococcus dolichoderi Williams	Indonesia	Williams (2004)
Benedictycoccina ornata (Hambleton)	Trinidad & Tobago	Williams and Granara de Willink (1992)
Capitisetella migrans (Green)	Surinam	Bigger (2009)[a]
Cataenococcus sp.	India	Williams (2004)
Coccidella globocula (Hambleton)	Trinidad & Tobago	Bigger (2009)
Coccidohystrix insolita (Green)	India	Williams (2004)
Crisicoccus hirsutus (Newstead)	India	Williams (2004)
Delottococcus aberiae De Lotto	Kenya	Bigger (2009)
Dysmicoccus brevipes (Cockerell)	Brazil, El Salvador, Guatemala, Trinidad and Tobago, Venezuela, Uganda	Williams and Granara de Willink (1992)
	Colombia, Costa Rica, Federated States of Micronesia, Cuba, Guam, Hawaii, Honduras, Indonesia Madagascar, New Caledonia, Surinam, Zaire	Bigger (2009)
	Cook Is, Fiji, Tonga	Williams and Watson (1988)
	Malaysia, India	Williams (2004)
	Papua New Guinea	Williams (1986b)
Dysmicoccus debregeasiae (Green)	India	Williams (2004)
Dysmicoccus grassii (Leonardi)	Brazil	Culik et al. (2006)
	Colombia, Costa Rica	Williams and Granara de Willink (1992)
Dysmicoccus lepelleyi (Betrem)	Indonesia	Williams (2004)
Dysmicoccus neobrevipes Beardsley	Colombia, El Salvador, Guatemala	Williams and Granara de Willink (1992)
	Western Samoa	Williams and Watson (1988)
Dysmicoccus nesophilus Williams & Watson	Papua New Guinea	Williams and Watson (1988)
Dysmicoccus probrevipes (Morrison)	Guatemala	Bigger (2009)
Dysmicoccus radicis (Green)	Brazil, Surinam, Venezuela	Bigger (2009)
Dysmicoccus subterreus Williams	India	Williams (2004)
Dysmicoccus texensis (Tinsley).	Portugal	Alves et al.(2009)
	Brazil	Souza et al. (2008)
Farinococcus sp.	Ghana	Bigger (2009)
Ferrisia virgata (Cockerell)	Colombia, Ghana, Guatemala, El Salvador	Williams and Granara de Willink (1992)
	Federated States of Micronesia Caroline Is, Fiji, Hawaii, Indonesia, Kenya	Bigger (2009)
	Madagascar, Malaysia, China	
	New Caledonia, Papua New Guinea, Philippines, Sierra Leone, Solomon Is, Sudan	
	Tanzania, Uganda, Zaire, Cameroon	
	Vietnam	Williams (2004)
Ferrisia sp.	Colombia	Bigger (2009)
Formicococcus greeni (Vayssiere)	Madagascar	Bigger (2009)
Formicococcus ireneus (De Lotto)	Uganda	Bigger (2009)

(continued)

Table 70.1 (continued)

Mealybug species	Region	Reference
Formicococcus njalensis (Laing)	Ghana, Ivory Coast, Sierra Leone	Bigger (2009)
	Togo, Zaire	
Formicococcus robustus (Ezzat & Mc Connell)	China	Bigger (2009)
	India	Williams (2004)
Geococcus coffeae Green	Costa Rica	Williams and Granara de Willink (1992)
	Brazil, Colombia, Surinam	Bigger (2009)
	El Salvador, Ghana, Guatemala, Honduras	
Hypogeococcus boharti Miller	Mexico	Williams and Granara de Willink (1992)
Maconellicoccus hirsutus (Green)	Cameroon	Williams (1986a)
	India	Williams (2004)
	Belize, Indonesia, Tanzania	Bigger (2009)
Maconellicoccus ugandae (Laing)	Kenya, Uganda	Bigger (2009)
Neochavesia caldasiae (Balachowsky)	Colombia	Bigger (2009)
Neochavesia eversi (Beardsley)	Colombia	Bigger (2009)
Neochavesia trinidadensis (Beardsley)	Colombia	Williams and Granara de Willink (1992)
Nipaecoccus coffeae (Hempel)	Brazil	Bigger (2009)
Nipaecoccus filamentosus (Cockerell)	Haiti	Williams and Granara de Willink (1992)
Nipaecoccus nipae (Maskell)	Dominican Republic	Bigger (2009)
Nipaecoccus pseudofilamentosus Betrem	Indonesia	Bigger (2009)
Nipaecoccus viridis (Newstead)	Vietnam,India	Williams (2004)
	Angola, China, Indonesia	Bigger (2009)
	Kenya, Madagascar, Malaysia	
	Uganda, S. Africa, Tanzania	
Nipaecoccus sp.	Colombia	Bigger (2009)
Paracoccus burnerae (Brain)	Ethiopean region	Ben-Dove (1994)
Paracoccus cognatus Williams	India	Williams (2004)
Paraputo sp.	India	Bigger (2009)
Paraputo leveri (Green)	Papua New Guinea	Ben-Dove (1994)
Phenacoccus hargreavesi (Laing)	Ethiopean region	Ben-Dove (1994)
Planococcus angkorensis (Takahashi)	India	Williams (2004)
Planococcus angkorensis (Takahashi)	Cuba	Williams and Matile-Ferrero (2009)
Planococcus citri (Risso)	Costa Rica, Honduras	Williams and Granara de Willink (1992)
	Angola, Australia, Brazil	Bigger (2009)
	Canary Is, China, Colombia, Cuba, Dominican Republic Eritrea, Ghana, Guatemala, Hawaii	
	Indonesia, Kenya, Madagascar, Malawi, Peru, Philippines, Sao Tome & Principe, Vietnam, S. Africa, Sudan, Uganda	
	Surinam, Taiwan, Tanzania	
	Togo, Trinidad & Tobago, Zaire, Zimbabwe	

(continued)

Table 70.1 (continued)

Mealybug species	Region	Reference
Planococcus minor (Maskell)	India	Williams (2004)
Pseudococcus cryptus Hempel	India, Sri Lanka	Williams (2004)
Pl. fungicola Watson & Cox	Cuba	Williams and Matile-Ferrero (2009)
Pl. halli Ezzat & McConnell.	Cuba	Williams and Matile-Ferrero (2009)
Pl. radicum Watson & Cox	Cuba	Williams and Matile-Ferrero (2009)
Planococcus kenyae (Le Pelley)	Kenya, Sudan, Tanzania, Uganda	Bigger (2009)
	Zaire	
	Cuba	Williams and Matile-Ferrero (2009)
Pl. kraunhiae (Kuwana)	Vietnam	Nguyen Thi et al. (2011)
	Cuba	Williams and Matile-Ferrero (2009)
Planococcus lilacinus (Cockerell)	Philippines	Williams and Matile-Ferrero (2009)
	Indonesia, Reunion, India	Bigger (2009)
	Sri Lanka, Taiwan, Vietnam	
Planococcus minor (Maskell)	Argentina, Costa Rica, Brazil, Guatemala	Williams and Granara de Willink (1992)
	Fiji, Vanuatu	Williams (1982)
	Malaysia, Sri Lanka, Indonesia	Williams (2004)
	Papua, New Guinea	Williams (1986b)
	India	Reddy et al. (1990)
	Australia, Cuba, Federated States of Micronesia, Tonga, Western Samoa	Bigger (2009)
Planococcus radicum Watson &Cox	Nigeria, Tanzania	Ben-Dove (1994)
Planococcoides irenus Delotto	Uganda, Angola	Ben-Dove (1994)
Planococcoides nijalensis (Laing)	–	Ben-Dove (1994)
Pseudococcus cryptus Hempel	Sri Lanka, India	Williams (2004)
	Western Samoa	Williams and Watson (1988)
	Brazil, Honduras	Bigger (2009)
Pseudococcus landoi (Balachowsky)	Neotropical	Bendove (1994)
Pseudococcus longispinus (Targioni-Tozzetti)	Colombia, Costa Rica, Guadeloupe, Java, Madagascar	Bigger (2009)
	Martinique, New Caledonia, Papua New Guinea, Puerto Rico, Reunion	
	Sri Lanka, Vietnam	
	India, Indonesia, Sri Lanka	Williams (2004)
Paracoccus burnerae (Brain)	Angola, Kenya	Bigger (2009)
Paraputo leveri (Green)	Papua New Guinea	Williams and Watson (1988)
Paraputo podagrosus (Green)	Surinam	Bigger (2009)
Paraputo sp.	Ghana, Guatemala, Honduras	Bigger (2009)
Phenacoccus hargreavesi (Laing)	Angola, Tanzania, Uganda	Bigger (2009)
Phenacoccus madeirensis Green	Ghana	Bigger (2009)
Phenacoccus parvus Morrison	Surinam	Bigger (2009)

(continued)

Table 70.1 (continued)

Mealybug species	Region	Reference
Planococcus fungicola Watson & Cox	Kenya, Tanzania, Uganda	Watson and Cox (1990)
	Zaire, Zimbabwe	
Planococcus halli Ezzat & McConnell	Colombia	Bigger (2009)
	Guatemala	Williams and Granara de Willink (1992)
Planococcus kraunhiae (Kuwana)	Taiwan	Bigger (2009)
Planococcus radicum Watson & Cox	Nigeria, Tanzania	Watson and Cox (1990)
Planococcus sp.	Cuba	Bigger (2009)
Pseudococcus calceolariae (Maskell)	Indonesia	Bigger (2009)
Pseudococcus concavocerarii James	Kenya, Tanzania, Uganda	Bigger (2009)
Pseudococcus cryptus Hempel	Brazil, Honduras	Bigger (2009)
	Sri Lanka	Williams (2004)
	Western Samoa	Williams and Watson (1988)
Pseudococcus elisae Borchsenius	Brazil	Bigger (2009)
Pseudococcus jackbeardsleyi Gimpel & Miller	Colombia, Guatemala	Bigger (2009)
	Trinidad & Tobago	Williams and Granara de Willink (1992)
Pseudococcus kikuyuensis James	Kenya	Bigger (2009)
Pseudococcus landoi (Balachowsky)	Costa Rica, Guatemala	Williams and Granara de Willink (1992)
Pseudococcus longispinus	Brazil	Souza et al. (2008)
Pseudococcus occiduus De Lotto	Cameroon, Ethiopia, Sudan	Williams and Matile-Ferrero (1995)
	Angola, Kenya, Tanzania	Bigger (2009)
	Uganda, Zaire	
Pseudococcus pseudocitriculus (Betrem)	Indonesia Java	Bigger (2009)
Pseudococcus pseudofilamentosus Betrem	Java	Ben-Dove (1994)
Pseudococcus sociabilis Hambleton	Colombia	Bigger (2009)
Pseudococcus solomonensis Williams	Papua, New Guinea	Williams and Watson (1988)
Pseudococcus sp.	Colombia, Ethiopia, Indonesia	Bigger (2009)
	Ivory Coast, Kenya, Kenya, Sierra Leone, Zaire	
	Sri Lanka, Tanzania, Venezuela	
Pseudococcus viburni (Signoret)	St Helena	Bigger (2009)
Pseudorhizoecus proximus Green	Colombia, Ecuador, Guatemala	Williams and Granara de Willink (1992)
	Surinam	Bigger (2009)
Puto antioquensis (Murillo)	Colombia, Guatemala, Honduras	Bigger (2009)
Puto barberi (Cockerell)	Colombia, Venezuela	Williams and Granara de Willink (1992)
Puto lasiorum (Cockerell)	El Salvador	Bigger (2009)
Puto mexicanus (Cockerell)	El Salvador	Bigger (2009)
	Guatemala	Williams and Granara de Willink (1992)
Puto sp.	Costa Rica	Bigger (2009)

(continued)

Table 70.1 (continued)

Mealybug species	Region	Reference
Rastrococcus iceryoides (Green)	India	Williams (2004)
	Malaysia	Williams (1989); Miller (1941)
Rastrococcus spinosus (Robinson)	Indonesia, Philippines, Taiwan	Bigger (2009)
Rastrococcus vicorum Williams & Watson	Indonesia	Williams and Watson (1988b)
Rhizoecus americanus (Hambleton)	Colombia	Williams and Granara de Willink (1992)
	Ecuador	Bigger (2009)
Rhizoecus arabicus Hambleton	Colombia, Costa Rica	Bigger (2009)
	Guadeloupe	Williams and Granara de Willink (1992)
Rhizoecus americanus (Hambleton)	Nearctic, neotropicpalaearctic region	Bendove (1994)
Rhizoecus cacticans (Hambleton)	Guatemala	Williams and Granara de Willink (1992)
Rhizoecus caladii Green	Surinam	Bigger (2009)
Rhizoecus coffeae Laing	Brazil,Colombia, Surinam, Venezuela	Bigger (2009)
	Costa Rica	Williams and Granara de Willink (1992)
Rhizoecus compotor Williams & Granara de Willink	Colombia	Williams and Granara de Willink (1992)
Rhizoecus cyperalis (Hambleton)	El Salvador	Williams and Granara de Willink (1992)
Rhizoecus divaricatus Hambleton	Nicaragua	Bigger (2009)
Rhizoecus eloti Giard	Guadeloupe	Williams and Granara de Willink (1992)
Rhizoecus falcifer Kunckel d'Herculais	Surinam	Bigger (2009)
Rhizoecus globoculus (Hambleton)	Trinidad	Ben-Dove (1994)
Rhizoecus knodaonis Kuwana	Coffee	Ben-Dove (1994)
Rhizoecus ornatus (Hambleton)	Trinidad	Ben-Dove (1994)
Rhizoecus nemoralis (Hambleton)	El Salvador, Honduras	Bigger (2009)
Rhizoecus tropicalis Hambleton	Guatemala	Williams and Granara de Willink (1992)
	Mexico	Ben-Dove (1994)
Ripersiella andensis (Hambleton)	Colombia	Bigger (2009)
Ripersiella campestris (Hambleton)	Guatemala	Williams and Granara de Willink (1992)
Ripersiella kondonis (Kuwana)	Guatemala	Williams and Granara de Willink (1992)

[a]Original reference from the Source: Bigger (2009)

Planococcus kenyae on coffee

Planococcus citri

70.2 Damage

Heavy infestation of mealybugs (*P. citri*) around the floral buds leads to deformity of the flowers and also sometimes total arrest of the blossom process. The mealybugs can be usually seen infesting the tender twigs, fruits and leaves. They suck the sap leading to debilitation of the plant and crop loss (Ramesh 1987). Crop loss can be enormous depending upon the level of infestation. Heavy infestation leads to development of fungus, *Capnodium* sp., on the honey dew secreted by the mealybugs which forms a black coating on the surface of the leaves. This can hinder the photosynthesis process as well as raise the surface temperature of the leaves. Sometimes the infestation is on the roots leading to serious damage to young seedlings in the field. This mealybug is very destructive to the roots of young plants. In areas where replanting is taken up, the roots of the young coffee plants are usually observed to be infested by the mealybug leading to debility of the plants, with the plants exhibiting stunted growth and yellowing of leaves. The roots are sometimes encrusted with mycelia of a fungus, *Diacanthodes* sp., in association with the mealybugs. The mealybugs are visible beneath the fungus when the encrustation is peeled away (Chacko and Sreedharan 1981). When the root form is associated with fungus, it is capable of killing the plant. *Planococcus citri* is a pest on arabica and robusta coffee (young trees are occasionally killed) (Anonymous 1998). *Ferrisia virgata* was first recorded on robusta coffee during 1976; the incidence appeared to be limited but severe infested occurred on leaves, shoots and berries (Chacko and Bhat 1976). In Uganda, attack of the berry clusters by *F. virgata* interrupted normal bean development, leading to premature ripening and drying of berries on primaries. Such berries were of lower marketable quality. Mean bean size was reduced by 7.7 %. Roast colour, centre-cut appearance and liquor quality were reduced (Kucel and Ngabirano 1997).

Coffee berries affected by mealybugs

Leaf damage

70.3 Seasonal Development

Mealybug population increases if warm and humid conditions prevail. Continuous monsoon, high humidity and low temperatures are detrimental to mealybug development. The migration of mealybugs starts in September/October from the ground to the aerial parts of the coffee plant along the main stem. The attack of mealybugs becomes severe during summer and with intermittent showers/irrigation (Anonymous 1998). Excessive removal of shade in the robusta plantations often leads to flare up of mealybugs. *Planococcus citri* on arabica and robusta coffee is distributed throughout the coffee tracts of India, mostly on robusta coffee which is grown at lower elevations with lesser shade. Two peaks were in February–March and January–March; there was a positive correlation between maximum temperature and adults and nymphs and a negative correlation with relative humidity and nymphs (Gokuldas Kumar 1987). According to Vinod Kumar et al. (2007), the population of *P. citri* on coffee responded positively to maximum temperature and had no correlation with minimum temperature. More than rainfall, relative humidity was negatively correlated with the mealybug population. The hours of sunshine received had a positive correlation with mealybug population (Vinod Kumar et al. 2007).

70.4 Ant Association with Mealybugs

Mealybugs produce honeydew, a sweet excretory product, to which ants are attracted. Ants provide mealybugs' sanitation and protection from natural enemies. The ants feed on the honeydew and act as clearing agents. The common ants found in association with the mealybugs on coffee in India are *Anoplolepis longipes*, *Oecophylla smaragdina* and *Crematogaster* sp. (Venkataramaiah and Rahiman 1989). Sometimes, ants of the genus *Camponotus* are also observed. Some of the aggressive ants like the red ant, *O. smaragdina*, and the cock tailed ant, *Crematogaster* sp., actually chase away the bigger predators while their constant presence over the mealybug colony is a hindrance for the parasitoids. This is evident in the case of the lepidopteran predator *Spalgis epeus* Westwood wherein the aggressiveness of the ants and *S. epeus* population indicated a highly negative relationship. Species belonging to the genus *Crematogaster* interfered more with the predator activity than the ant *O. smaragdina* (Vinod Kumar et al. 2008a). About 27 species of ants have been recorded world over in association with different species of homoptera attacking coffee. Thirteen species, namely *Crematogaster* sp., *Anaplolepis longipes* Jerdon, *Myrmica brunnea* Saunders, *Plagiolepis* sp., *Paratrechina longicornis* Latreille, *Camponotus rufogalaucus* Jerdon, *Anoplolepis gracilipes* (F. Smith), *Tapinoma melanocephalum* (Fabricius), *Oecophylla smaragdina* (Fabricius), *Acropyga* sp., *Technomyrmex albipes* Smith, *Solenopsis geminata* Fabricius, *Monomorium* sp., have been recorded from coffee tracts of South India (Venkataramaiah and Abdul Rahiman 1989).

Of the ant species so far recorded, *Plagiolepis* sp. is widespread and seen in almost every estate in the coffee growing regions. *Acrophaga* sp. is recorded from Kodagu district of Karnataka state. The presence of ant *O. smaragdina* along with mealybugs is not a limiting factor for the establishment of introduced parasitoid *Leptomastix dactylopii* attacking *P. citri* in the field. The ant species associated with mealybugs recorded from other coffee growing countries are: *Camponotus* sp. in Brazil, *Lepisiota incise* (Forel) in Kenya, *Myrmelachista ramulorum* Wheele, *Paratrechina jaegerskioeldi* (Mayr) in Kenya, *Solenopsis punctaticeps* (Mayr) in Kenya (James 1933), *Pheidole speculifera* (Emery) in Kenya, *Lepisiota capensis* (Mayr) in Kenya, *Monomorium pharaonis* (Linnaeus) in Kenya, *Myrmicaria natalensis eumenoides* (Gerstaeker) in Kenya, *Pseudolasius gowdei* (Wheeler) in Uganda, *Pheidole punctulata* (Mayr) in Kenya and *Technomyrmex albipes* (F. Smith) in Kenya.

70.5 Natural Enemies

Several indigenous predators and parasitoids have been recorded from mealybugs on coffee in India. They exert considerable pressure on the bug population in ideal conditions. If conditions are suitable or made suitable for the activity of the indigenous natural enemies, then no external effort to manage the mealybug is required (Chacko 1987; Venkataramaiah and Ramaiah 1988; Prakasan et al. 1992; Reddy et al. 1992). *Spalgis epeus* (Lepidoptera: Lycaenidae) the indigenous butterfly predator of the mealy bugs is highly efficient in bringing down the population of the mealybugs (Aitken 1894; Vinod Kumar et al. 2008b). The biology of this predator has been studied extensively (Vinod Kumar et al. 2006) and the method of field augmentation standardized for achieving the desired control (Vinod Kumar et al. 2009). Exclusion of the ants frequenting mealybug infested coffee plants assists the natural enemies in becoming more active. Ant control alone can be a very effective method to tackle any mealybug on coffee estates. Several species of natural enemies have been recorded on mealybugs in India. On *Planococcus citri*, the parasitoids namely *Alamella flava* Agarwal, *Aprostocerus purpureus* (Cameron), *Anagyrus agraensis* Saraswat, *Anagyrus inopus, Cryptochetum* sp., *Leptomastix nigrocoxalis* Compere, *Prochiloneurus* sp., *Coccidoxenoides perminutus* are known to parasitise in coffee ecosystem in India (Pruthi and Mani 1940; Reddy et al. 1990; Chacko et al. 1977; Prakasan and Gokuldas Kumar 1985). And the predators namely *Cryptochaetus* sp., *Dicrodiplosis* sp., *Pseudoscymnus pallidicollis* (Mulsant), *Pullus pallidicollis, Spalgis epeus* (Westwood), *Domomyza perspicax* (Knab) are known to attack coffee ecosystem in India (Reddy et al. 1990). On *Planococcus lilacinus*, the parasitoids namely *Anagyrus* sp., *Apenteles* sp. nr. *sauros* Nixon, *Gonatocerus* sp., *Gyranusoidea* sp., *Alamella flava, Tetracnemoidea india* (Ayyar), *Leptacis* sp. were recorded in India (Reddy et al. 1990). And the predators namely *Dicrodiplosis* sp., *Hyperaspis maindroni*, *Leucopis luteicornis*, *Pullus pallidicollis, Scymnus (Nephus) severini*, *Spalgis epeus* (Westwood), lycaenidae, *Brumiodes suturalis* (Fabricius), *Horniolus vietnamicus* (Coccinellidae) *Pseudoscymnus pallidicollis* (Mulsant) are known to attack coffee ecosystem in India (Reddy et al. 1990, 1992; Balakrishnan et al. 1991; Chacko and Bhat 1976; Le Pelley 1968; Irulandi et al. 2000; Prakasan et al. 1992). On *Ferrisia virgata*, the parasitoids namely *Aenasius advena* Compare, *Anagyrus qadrii* (Hayat Alam & Agarwal), *Anicetus annulatus* Timberlake, *Blepyrus insularis* (Cameron) were reported in India (Balakrishnan et al. 1991). And predators namely *Alloprapta javana* (Weidemann), *Brumiodes suturalis* (Fabricius), *Scymnus* sp., *Gitona* sp., *Leucopis* sp., *Mallada* sp., *Scymnus* sp., *Spalgis epeus* (Westwood), *Diadiplosis coccidivora* (Felt) are known to attack mealybugs present in the coffee ecosystem in India (Balakrishnan et al. 1991; Chacko and Bhat 1976). In Cuba, the cecidomyiid *Diadiplosis cocci* was the most abundant natural enemy, followed by *Leptomastix dactylopii*, two encyrtid species, *Signiphora* sp. and an eulophid. *Signiphora* sp. was recorded as a parasitoid of this pest complex for the first time (Martinez et al. 1995).

70.6 Management

70.6.1 Cultural Control

During the dry season, frequent checks should be conducted for the presence of scales and mealybugs on the coffee plants and the movement of ants. Colonies of mealybugs are commonly attended by ants because of the sweet substance called 'honey dew' excreted by them. Ants make nests on the coffee plants or on shade trees by joining two or more leaves. Such nests have to be cut down and burnt frequently. If it is possible to trim the branches of the coffee plants in such a way that they do not touch the soil and nearby shade trees, it should be done. If the branches touch the ground or the shade tree, this would be used as bridge by the ants to travel on to the coffee plants. Once the plants are isolated, banding with grease may be tried on the main stem. Grease should not be directly applied on the coffee plant.

A newspaper may first be tightly tied on the stem and over this paper, grease may be applied. Optimum shade maintenance helps in regulating the micro-climate around the coffee plants. Plants exposed to sunlight are favourable to mealybug attack. Since many of the common weeds found in the coffee plantations harbour mealy bugs, it is best to destroy the weeds regularly.

70.6.2 Chemical Control

Control of mealybugs on coffee using insecticides was the choice option before stress was placed on biological control (Rangashetty et al. 1959). Several trials were conducted using insecticides for achieving affordable control of mealybugs (Sekhar and Narayana Rao 1964; Chacko et al. 1976; Vinod Kumar and Prakasan 1992). The insecticides tried were mostly organophosphates. Synthetic pyrethroids did not show any promise against the mealybugs. But most of these insecticides were highly toxic to the introduced natural enemies as well as indigenous natural enemies (Chacko et al. 1979; Stephen et al. 1981; Reddy et al. 1988; Vinod Kumar et al. 2010). In the case of severe incidence, quinalphos 20EC at 300 ml in 200 L of water plus 200 ml of any wetting agent is recommended as hot spot application and not as a blanket spray. If the root region is infested with the mealybug *P. lilacinus*, a soil drench with dimethoate 30EC at 660 ml in 200 L of water is found to be extremely useful (Vinod Kumar and Prakasan 1992). Kerosene, as spray, can also be used as a milder measure to tackle the mealybugs. For spray use 4 L of kerosene in 200 L of water along with a wetting agent. The solution should be mixed thoroughly with the wetting agent so that any risk of un-emulsified kerosene falling on the plants is avoided (Gokuldas Kumar et al. 1989). Plant products, like neem formulations, have also been tested against *P. citri* and some of them have been found to affect the mealybug population considerably and bring about reduction (Irulandi et al. 2000). Iimidacloprid at 0.01 % was known to cause 94 % *P. lilacinus* on coffee after 21 days of spraying in India (Irulandi et al. 2000). In Brazil, imidacloprid and thiamethoxam in the liquid form, applied to the base of the plant, cause 100 % mortality of the coffee root mealybug, *Dysmicoccus texensis*, independent of the coffee plant's age, in a single application (Souza et al. 2007).

Planococcus kenyae only be controlled by a combination of measures. Ant management practices included banding the coffee plants with 20 cm wide plastic bands covered with a sticky-substances mixed with insecticide chlorpyrifos. Removal of suckers that touch the ground is to be done to prevent ants. Spraying on the ant nests in the ground with the insecticides is to be carried out to control the ants,

The other management includes the application of oils (such as vegetable oils, neem oil or mineral oils) or soapy solutions (1–2 %) to kill mealybugs by suffocation. Spraying cow urine fermented for 1 day, in a ratio of 1 urine : 4 water can cause moderate reduction of mealybug population. Spraying with dimethoate, diazinon, ethion and carbaryl are more toxic (class II, moderately hazardous) (http://www.plantwise.org/FullTextPDF/2013/20137803401.pdf). In Brazil, with systemic insecticides for the control of *Dysmicoccus cryptus* (Hemp.) (*Planococcus cryptus*), which attacks the roots of coffee, mortality was complete and no reinfestation occurred for more than 60 days when granules containing 10 % aldicarb had been placed in a furrow (10 cm deep at a radius of 30 cm from the trunk) at the rate of 75 g/tree, or when an emulsion spray containing 0.06 % vamidothion was applied to the foliage at 2 l/tree. Good initial results were also obtained with granules containing disulfoton, phorate or aphidan [S-((ethylsulfinyl) methyl) O, O-bis (1-methylethyl) phosphorodithioate] (Cavalcante 1975).

70.6.3 Biological Control

Several indigenous natural enemies on their own are capable of keeping the mealybug population in check (Reddy et al. 1992). This is particularly true in the case of *P. lilacinus*, the dipterans *Triommata coccidivora* Felt were able to suppress the mealybug population up to 96 % (Prakasan et al. 1992).

In Kenya, the release of *C.montrouzieri* failed to suppress the coffee mealybug *Planococcus kenyae*. In Celebes, substantial control of *Rastrococcus iceryoides* in coffee was obtained with *C. montrouzieri* . Control of the mealybug, *Ferrisia virgata*, in coffee plantation of Java was attempted in 1918 using *C. montrouzieri.* Establishment of *Cryptolaemus* occurred throughout the eastern Java on *Planococcus citri* but with determinable effect on mealybug infestations which declined. In Dutch East Indies, an attempt was made to use *C. montrouzieri* against *F. virgata* on coffee.

In India, severe infestations of mealybugs (*Planococcus* spp.) occurred in many estates in South Wayanad, Kerala. At Shevaroy hills, adults and grubs of *C. montrouzieri* were seen on San Ramon hybrid coffee where mealybug infestation was virtually cleaned up (Chacko 1979). A release rate of five beetles per mealybug infested Robusta coffee, three beetles per Arabica coffee and two beetles per San-ram Coffee plants has been recommended to control the coffee mealybugs in India (Singh 1978). The drawback is that *C. montrouzieri* becomes active when the mealybug population reaches high levels by which time the damage to the flower buds and tender berries would have been already caused leading to crop loss (Chacko 1982). *Leptomastix dactylopii* (Hymenoptera: Encyrtidae), a parasitoid of *P. citri*, was introduced into India during 1983 from Trinidad through the then Project Directorate of Biological Control, now the National Bureau of Agriculturally Important Insects, Bangalore (Chacko 1987). A total of 15,000 *Leptomastix* parasitoids were released at 11 locations in Kodagu district having mixed plantations of coffee with oranges against *P. citri*. The parasitoid has established within two months of release. Parasitism reached as much as 100 % in some colonies (Nargatti et al. 1992). The parasitoid *L. dactylopii* has established in the robusta coffee fields in the Wayanad district of Kerala state and is bringing about appreciable reduction in the population of the mealybugs (Abdul Rahiman and Naik 2009a) There exists an interference of the predator *C. montrouzieri* with the performance of the parasitoid *L. dactylopii* in the field as the predator is not able to discriminate between parasitized and healthy mealy bugs (Prakasan and Bhat 1985).

The fungus *Beauveria bassiana* (Bals.-Criv.) Vuill. (UEL 114) and the nematode *Steinernema carpocapsae* (Weiser) are known to cause high mortality in short time of adult female mealybugs *Dysmicoccus texensis* (Tinsley) (Andalo et al. 2004). Entomopathogenic nematodes (EPNs) have potential for biological pest control and have been successfully used in several countries in soil and cryptic pests control, as for example the coffee root mealybug *D. texensis*. Greenhouse results demonstrate that aqueous suspension (JPM3) was more efficient with 70 % control efficiency. In field experiments, treatments with aqueous suspensions of insecticide Actara 250 WG (thiamethoxam), used for comparison, and JPM3 were the only ones statistically different from control (Alves et al. 2009). *Heterorhabditis bacteriophora* Poinar strain HC1 was known to cause 100 % mortality in the inoculated the coffee mealybug complex (Rodriguez et al. 1997).

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