REPUBLIC OF KENYA

Papaya Mealybug

A Technical Brief - Description, Identification and Sustainable Management Strategies in Kenya

Version 1, 2020

Contents

Foreword

This technical brief was reviewed by a technical team drawn from the Ministry of Agriculture, Livestock, Fisheries and Cooperatives (MoALF&C), County Governments of Mombasa, Kilifi and Kwale, CAB International (CABI), Kenya Agricultural & Livestock Research Organization (KALRO), Kenya Forestry Research Institute (KEFRI), Plant Health Inspectorate Service (KEPHIS), National Museums of Kenya (NMK), University of Nairobi (UoN), and Precision Agriculture for Development (PAD). The brief contains the latest, agreed advisory for papaya mealybug management in Kenya and will be used to support the development of a range of information materials for use by extension workers, agro-dealers and farmers. This brief has been reviewed by all parties and is hereby authorized for use with effect from 24th February 2020.

Joshua Oluyali
Head: Horticultural Crops Division
State Department for Crop Development & Agricultural Research
Ministry of Agriculture, Livestock, Fisheries and Cooperatives

1 Introduction

The Papaya mealybug, *Paracoccus marginatus* (Williams & Granara de Willink, 1992) is a soft insect pest belonging to the Order Hemiptera and Family Pseudococcidae. The term "mealybug" is derived from the mealy or waxy secretions that cover the bodies of these insects. Papaya mealybug is native to Central America. It is not a serious pest in that region, probably due to the presence of an endemic natural enemy complex. The wingless female is known to be a small polyphagous sap sucking insect that attack at least 133 plants belonging to 40 plant families (Lawrence *et al*., 2013), mostly tropical and sub-tropical fruits, vegetables and ornamental plants, with preference for papaya (*Carica papaya*), commonly referred in Kenya as pawpaw.

This pest was first reported in Kenya in 2016, and has since rapidly spread across the country reaching epidemic levels in pawpaw and other horticulture crops growing locations (Macharia *et al*., 2017, Mulwa *et al.*, 2019). Typically, mealy bugs in their countries of origin are not pest problems because naturally occurring parasitoids and predators keep their numbers in check. The most serious outbreaks occur when mealybugs are accidentally introduced to new countries without their natural enemies like has happened in Kenya.

The pest often attains high numbers if not managed, killing the host plant by depleting the sap and occasionally by injecting toxins, transmitting viruses, or by excreting honeydew, which is a suitable medium for the growth of sooty moulds. The mould often covers the plant to such an extent that normal photosynthesis is severely reduced. Papaya mealybug has caused severe damage to economically important crops and huge losses to farmers in Kenya. Macharia *et al.* (2016) reported a mean yield loss of 91% on papaya due to papaya mealybug infestation in Kenya. Farmers also reported economic loss due to production of poor-quality fruits. Studies by CABI in May 2019 in five counties in Kenya – Mombasa, Kilifi, Kwale, Taita Taveta (coastal), and Machakos (eastern) on the economic losses due papaya mealybug estimated losses at 56.7% for sampled communities. Losses were experienced in terms of loss of harvest, poor quality fruits that cannot be sold and bitterness of fruits, or total destruction of orchards.

Papaya mealybugs cause indirect economic losses related to the purchase and application of insecticides, including extra labour for application of management practices. A social economic survey conducted in June 2019 by KALRO and KEFRI in three coastal counties of Kwale, Kilifi and Mombasa showed that farmers spent up to KES 58,000 annually on pesticides to control this pest. Moreover, the ability of papaya mealybug to form dense colonies, particularly within the shoot and apex, often makes routine chemical control quite

difficult. The surveys further report that farmers are using organophosphates (Macharia *et al.*, 2016), which are known to have long persistence in the environment, and have adverse effects on livestock and human health, pollinators and natural enemies, respectively.

Unfortunately, like any other invasive pest, identification and management methods are usually not known by affected farming households and sometimes local extension officers to aid in quick response and control of such pests. This technical brief aims to provide a description of the pest (identification, biology and ecology), evidence of impacts, and sustainable management practices. This will help extension service providers to effectively identify the pest and provide appropriate recommendations for its management in order to reduce its impacts on livelihoods in Kenya.

2 Identification of Papaya Mealybug

1. Papaya mealybug infestations are typically observed as clusters of cotton-like masses on the above-ground portion of infested plants (Figure 1). Fruits and lower leaf surfaces are the preferred habitats; however, in heavy infestation all parts and surfaces of the plant are infested.
2. Adult females are yellow in colour, wingless and are covered with a white waxy coating. They are approximately 2.2 mm long (1/16 inch) and 1.4 mm wide. A series of short waxy caudal (tail-end) filaments less than 1/4 the length of the body exists around the margin. They move by crawling short distances.
3. Adult males are approximately 1.0 mm long, with an elongate oval body that is widest at the thorax (0.3 mm). Adult males have ten-segmented antennae, a distinct aedeagus, lateral pore clusters, a heavily sclerotized thorax and head, and well-developed wings (Figure 2).

Figure 1: Adults, nymphs and egg sacs (orange arrow) of papaya mealybug, *Paracoccus marginatus* (Source: (Walker, Hoy and Meyerdirk, 2018))

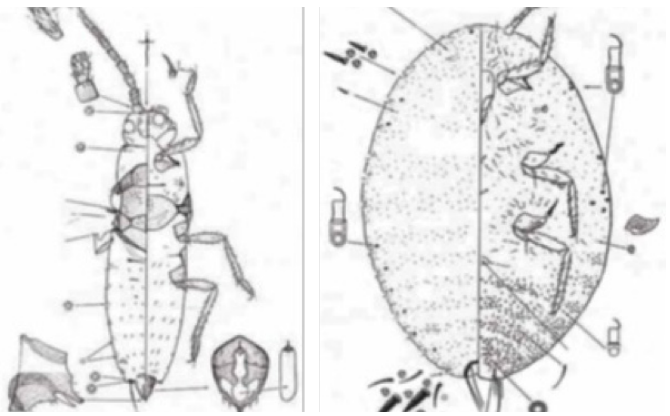

Figure 2: Morphology of papaya mealybug: Adult male (left) and adult female (right).

Source: (Walker et al. 2018)

Low infestation of papaya mealybug on papaya fruits

Low infestation of papaya mealybug on papaya fruits

Medium-heavy infestation of papaya mealybug on papaya fruits

Heavy infestation of papaya mealybug on papaya branches

Heavy infestation of papaya mealybug on papaya branches

Heavy infestation of papaya mealybug on papaya fruits

3 Biology and Ecology

1. Papaya mealybug reproduces sexually. Females lay eggs (100- 600) that are greenish-yellow in an ovisac (three to four times the body length),
2. Eggs hatch in about 10 days, and nymphs begin to actively search for feeding sites,
3. The nymphs are generally referred to as “crawlers”. Crawlers are quite active and move freely to settle on the soft portion of the stems and leaves,
4. They start feeding by sucking the sap with its piercing and sucking mouth parts. Normally, once settled, they do not move except when disturbed. They are able to only crawl short distances or blown in air currents. The nymphs secrete and embed themselves in white waxy coating,
5. The female mealybug has three immature stages before moulting to the larviform adult stage. The male has two immature larval stages that feed, followed by non-feeding pre-pupal and pupal stages before it moults to a short-lived, winged adult. Figure 3 shows four instars and the adult.
6. There is no distinguishable difference between male and female crawlers, and male and female early second instars,
7. Papaya mealybugs are most active in warm, dry weather. As with most scale insects, heavy rain causes increased mortality of papaya mealybug, especially of the mobile first-instar crawlers.

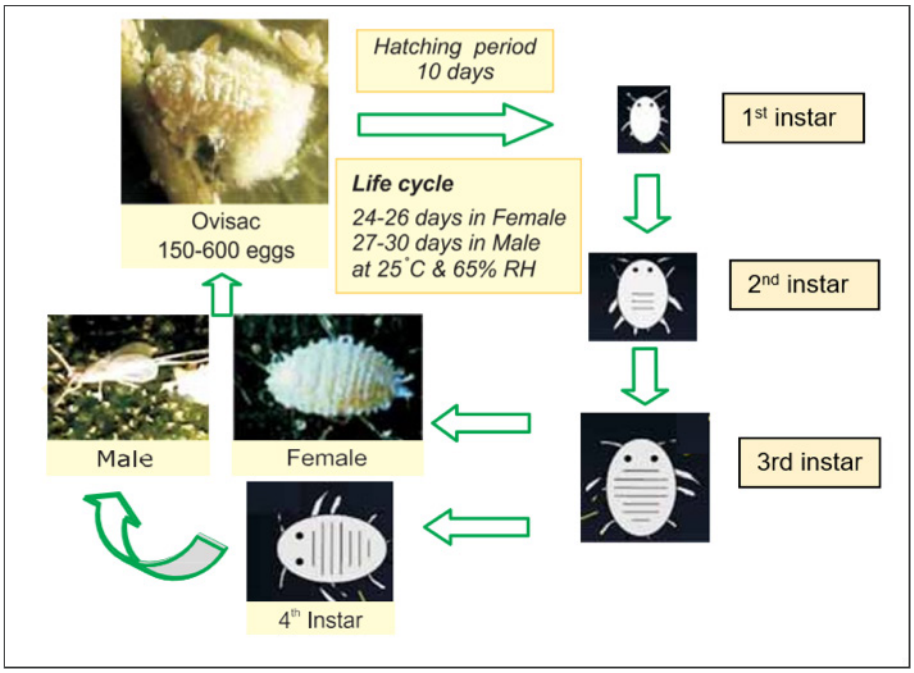

Figure 3: Lifecycle of Papaya mealybug (Source: Tanwar et al. 2010)

4 Factors Responsible for Pest Spread and Population Build-Up

1. With rapid development, high survival rate, and enormous reproductive capacity, papaya mealybug population could potentially reach an epidemic level within a very short period of time.
2. Dry periods, which is common across the country are also favourable for fast multiplication.
3. Movement of crawlers through air, irrigation water, or farm equipment, and movement of people and machinery on farm help in fast spread of the mealybug.
4. Presence of ants provide protection to mealybug from parasitoids and predators and aids in the dispersal of the pests.
5. Absence of effective natural enemies in Kenya.
6. Wax layer and waxy fibres over the ovisac and body of mealybug nymphs and adult females protect them from adverse environmental conditions, natural enemies and routine chemical pesticides application.
7. Availability of wide host range, alternate hosts / weeds around fields and orchards, and its subsequent adaptability.
8. Porous borders and illegal trade of fruits and planting materials promote spread of the pest.
9. Lack of domestic quarantine measures allowing for free movement of fruits, seedlings, vegetables and other material between regions, which may be infested.
10. Piecemeal pruning of infested crop provides sufficient time for migration and settlement of crawlers from the old infested crop to the pruned crop.

5 Mode of Dispersal

1. Juvenile mealybugs can crawl from one infested plant to the non-infested plant, therefore spreading out the infestation further.
2. The small crawlers get readily dispersed by wind, rain, irrigation water, birds, ants etc. Passing animals, including humans, may accidentally pick up crawlers as they brush past infested plants, and transfer them to new host plants. Vehicles moving through a crop, or pruning and harvesting activities, can help carry crawlers from one plant to another.
3. Passive dispersal also occurs when the wax, which sticks to each ovisac and nymphs is moved on clothes or equipment.
4. The honeydew secreted by mealybugs attracts some species of ants, such as those of the genus Acropyga which help in dispersing them from one plant to the next (Krishnan *et al.*, 2016). Queens have been observed carrying adult female and immature mealybugs when establishing new colonies (LaPolla and Dlussky, 2010).

5. Long distance dispersal in papaya mealybug is mainly through transport of infested fruits, seedlings and other vegetative parts from one farm to another, or one area to another.

6 Host Plants

Attack by papaya mealybug has been observed on a wide range of cultivated crops, fruits, ornamental and weed hosts belonging to different plant families. Sakthivel *et al.* (2012) reported high host preference on 33 hosts followed by 31 hosts with medium damage while 56 hosts recorded low levels of damage and 13 with incidental damage. Table 1 shows some of the crops reported to be attacked by papaya mealybug. Pawpaw is the most preferred host among others as indicated below.

Table 1: Host range of papaya mealybug

Host category	Botanical name	Common name	Family
Main crop hosts	*Carica papaya* L.	Papaya (pawpaw)	Caricaceae
	Annona squamosa L.	Sugar apple/ soursop	Annonaceae
	Coffea spp	Coffee	Rubiaceae
	Manihot esculenta Crantz	Cassava	Euphorbiaceae
	Solanum melongena L.	Brinjal/egg plant	Solanaceae
	Capsicum annuum	Bell pepper	Solanaceae
	Persea americana	Avocado	Lauraceae
Other crop hosts	*Cajanus cajan L.*	Pigeon pea	Leguminaceae
	Phaseolus	Beans	Fabaceae
	Citrus sinensis	Navel orange	Rutaceae
	Gossypium hirsutum L.	Cotton	Malvaceae
	Theobroma cacao L.	Cocoa	Malvaceae
	Mangifera indica	Mango	Anacardaceae
	Morus alba L.	Mulberry	Moraceae
	Psidium guajava L.	Guava	Myrtaceae
	Punica granatum	Pomegranate	Punicaceae
	Rosa	Roses	Rosaceae
	Solanum lycopersicon L.	Tomato	Solanaceae
	Solanum nigrum	Black nightshade	Solanaceae
	Vigna	Cowpea	Fabaceae
Other non-crop hosts	*Hibiscus sabdariffa*	Roselle	Malvaceae
	Hibiscus rosa sinensis L.	Shoe flower	Malvaceae
	Jatropha curcas L.	Jatropha	Euphorbiaceae
	Acacia	Acacia / wattles	Fabaceae
	Achyranthes aspera L.	Devil's Horsewhip	Amaranthaceae
	Commelina benghalensis L.	Spider wort/wandering jew	Commelinaceae
	Convolvulus arvensis L.	Chandvel / Field Bindweed	Convolvulaceae
	Euphorbia hirta L.	Garden sprug / Asthma-plant	Euphorbiaceae
	Phyllanthus niruri L.	Hazardani / gale of the wind	Euphorbiaceae
	Ocimum sanctum L.	Tulasi / tulsi / holy basil	Lamiaceae
	Parthenium hysterophorus L.	Congress grass/Parthenium	Asteraceae
	Trianthema portulacastrum L.	Giant pig weed	Aizoaceae
	Tectona grandis L.	Teak	Verbanaceae

7 Damage Symptoms

Papaya mealybug infestations are typically observed as clusters of cotton-like masses on the above-ground portion of plants with long waxy filaments. Infestations on the stem results to stunting, deformation of new growth, and death of the plant. On the leaves the pest causes yellowing, deformation, curling and early drop of leaves. On the fruits, there is a heavy build-up of honeydew and waxy secretions. The sooty mould develops due to the sugar in honeydew, which is the waste matter of the mealybugs. Fruits also become hard and very bitter to taste. Figures below show signs and symptoms of papaya mealybug infestation on some of the crops commonly grown in Kenya.

Cotton-like masses on pawpaw fruits (F. Makale CABI)

Advanced papaya mealybug infestation on pawpaw leaves (F. Makale CABI)

Papaya mealybug infestation on Brinjal (F. Koome KEPHIS)

Mealybugs on mango Kilifi County (Source: Maxwell Billah)

Mealybugs on cassava in Nairobi County (L. Wasilwa KALRO)

Mealybugs on soursop (graviola) in Kisumu County (L. Wasilwa KALRO)

Mealybugs on cocoa in Kilifi County (L. Wasilwa KALRO)

Mealybugs on cotton in Makueni County (L. Wasilwa KALRO)

Mealybugs on pomegranate in Nairobi County (L. Wasilwa KALRO)

Mealybugs on tree tomato in Muranga County (L. Wasilwa KALRO)

Mealybugs on bell pepper in Busia County (L. Wasilwa KALRO)

Mealybugs on apple in Muranga County (L. Wasilwa KALRO)

Mealybugs on guava in Kisumu County (L. Wasilwa KALRO)

Mealybugs on caliandra in Muranga County (L. Wasilwa KALRO)

8 Determining the infestation levels

Infestation levels for papaya mealybug can be categorised as; incidental, low, medium or high (Table 2). Infestation levels help to determine the management practices to apply.

Table 2: Determining the infestation levels

Level	Description
Incidental	Only a few individuals of the mealybug casually found. No breeding observed.
Low	All stages of mealybug found in low numbers. No adverse symptoms like deformation of leaf observed on the plant.
Medium	All stages of mealybug found in large numbers. Wilting and yellowing of plant leaves observed. Infested plants normally survived.
High	All stages of mealybug found in very large numbers. Almost all plant parts (stem, leaves, flowers and fruits) covered with mealybug showing white appearance. Leaves, fruits and inflorescences covered with honey dew excretion and sooty mould. Excessive leaf and fruit shedding. Most of the plants died in the infested area

9 Management of Papaya Mealybug

9.1 Prevention

Effective management of agricultural pests starts with growing healthy crops in healthy soils. These preventive measures help to avoid infestations in the field and/or reduce pest population build up. Prevention practices include:

i. Use clean planting material. Source planting material from certified nurseries (Link:https://www.hortinews.co.ke/2016/01/27/kephis-certfied-nurseries/), and inspect seedlings during purchase before taking them to your farm. If any infestation is observed, disinfect the seedling by manually removing the mealybug.

ii. Observe field hygiene: e.g. cultural and mechanical control of weeds / alternate host plants like Hibiscus, *Parthenium* etc from the field.

iii. Restrict movement of planting material: Avoid movement of infested plant materials from farm to farm. When handling fruits after consumption, dispose the material by placing them in sealed plastic garbage bags for 2-3 days to suffocate any pest that maybe present. Do not throw fresh trash in the garden, use the garbage pit.

iv. Ensure proper post-harvest handling of fruits: Sort harvested fruits by removing infested and bruised fruits. Any infested fruits should be properly disposed by burning or burying deep. Clean harvested produce with water before marketing.

v. Apply manures or fertilizer to enhance and maintain high soil fertility. This will make your crops grow well and make them withstand pest infestation.
vi. Practice crop rotation with non-host plants where possible in order to break the pest cycle.

9.2 Field scouting

Monitoring and scouting help to detect early presence of the papaya mealybug. Routinely (at least once a week) scout the field for damage and signs of infestation by papaya mealybug.

i. Randomly select five points in the field, and observe plants in those selected spots. Always start from a different point but ensure entire farm is covered.
ii. Examine each selected plant within the field. Observe for ants going up the plant, check the foliage for infestation and the surrounding plants and fruits.
iii. If any infestation is observed, manage the pest starting with cultural and mechanical practices.

Figure 4: Ensure the entire fields covered when doing scouting

9.3 Cultural and mechanical control

i. Application of sticky bands or alkathene sheet or a band of insecticide around the trunks of the papaya plant and other host plants to prevent movement of crawlers and attendant ants.
ii. Prevention of the movement of ants and destruction of already existing ant colonies.
iii. Sanitize farm equipment before moving it to the uninfected crop or field. Use 1% bleach (available chlorine) solution, or high-pressure water to clean the tools.

iv. When numbers of papaya mealybug are low they may be rubbed or picked off plants by hand. Dabbing individual pests with an alcohol-soaked cotton swab or neem-based leaf shine will also work when infestations are light.
v. Prune infested branches when the crop is at a manageable height and kill off the mealybugs.
vi. Avoid flood irrigation to prevent spread of mealybug to other areas through irrigation water.
vii. Water jetting – this involves physical force which hits on the infested plant parts to dislodge and washout, and dislodges the insects from plant surfaces so that the crop is kept free from the population of the pests by directing a powerful jet at infested plant parts. The force and pressure from the water injures most of the mealy bugs (which are soft- bodied) and also, the fallen bugs are exposed to predators.

9.4 Biological control

i. Natural enemies of the papaya mealybug include the commercially available mealybug destroyer ladybird beetles (*Cryptolaemus montrouzieri*). Some of the registered mealybug destroyer products in Kenya include Cryptobug and Cryptobug-L.
ii. Other generalist natural enemies such as lacewings, hover flies, Scymnus sp. and certain hymenopteran and dipteran parasitoids exist and can control papaya mealybug populations. When activity of natural enemies is observed, care should be taken to delay spraying operations and measures should be taken to conserve them. Conservation measures include judicious use of pesticides, and maintaining diversity of crops on the farm.
iii. Several parasitoids, *Anagyrus loecki* Noyes, *Acerophagus papayae* Noyes & Schauff, and *Pseudleptomastix mexicana* Noyes & Schauff (Hymenoptera: Encyrtidae), have been used successfully in several countries in the Caribbean, South America, as well as Indonesia, India, Pakistan and West Africa. There is a need to introduce such exotic parasitoids in Kenya to contain the pest without harming the environment.

Cryptolaemus montrouzieri larva (left) and adult (right). Source: Tanwar et al. 2010

Predatory ladybird beetle, *Scymnus sp*. (left) and Dipteran parasitoid parasitizing papaya mealybug (*right*). Source: Tanwar *et al*. 2010

9.5 Farmers' management practices

Farmers have reported use of several practices against papaya mealybug with varying levels of success. However, they have not been validated by research, and should generally be applied or recommended with caution. Studies into efficacy of farmer practice (indigenous knowledge) and other botanical products e.g. garlic, basil, thyme, pepper etc. is needed to standardise formulations and expand the scope and alternatives in the management of mealybug and scales.

i. Use of plant extracts. Farmers in Mombasa County reported use of a mixture of garlic, African Birds Eye Chilli (ABEC), ginger, onion and tobacco, locally known as "*Afya duara hot*" with considerable levels of success.
ii. Dusting ash on affected fruits.
iii. Application of solution of detergent soap or bar soap mixed with water on affected plants.

9.6 Chemical control and recommended pesticides

Mealybug are generally difficult to control chemically due to the thick waxy secretion covering their body, and their ability to hide in the damaged buds and leaves without being exposed to the insecticide. In addition, with polyphagous insects such as papaya mealybug, it is difficult to manage them with just insecticides and to achieve long-term control given the wide variety of host plants that they feed on. Insecticides should be used as last option in the control of papaya mealybug. Excessive use and/or overreliance on pesticides is not only costly and unsustainable, but also hazardous to the environment, beneficial insects including natural enemies, human and animal health.

i. Locate ant colonies and destroy them with drenching of chlorpyriphos 20 EC at 2ml/litre of water.
ii. Drenching soil with chlorpyriphos around the collar region of the plant to prevent movement of crawlers of mealybug and ant activity is useful.
iii. Spot application of insecticide immediately after noticing mealybug on some plants in the crop field is advised.
iv. If the activities of natural enemies are not observed, use of botanical insecticides such as neem oil (1 to 2%), NSKE (5%), or *Metarhizium anisopliae* (marketed as Campaign Metarhizium in Kenya), or Fish Oil Rosin Soap (25g/litre of water) should be the first choice.
v. Apply recommended chemical insecticides as the last resort. Table 3 shows registered pesticides in Kenya that can be used against papaya mealybug. If the chemical is not oil based, always mix with a sticking agent to enable the pesticide to penetrate through the mealybug waxy layer. Request sticking agent from the pesticide supplier.
vi. Pesticide use during flowering should be minimised to avoid killing pollinators - which will result to less fruit set.

Table 3: List of pesticides that can be used against papaya mealybug

Trade name	Active ingredient(s)	Dosage	Company	WHO CLASS
RELDAN 40 EC (Emulsifiable Concentrate)	Chlorpyrifos methyl 400g/L	20ml/20L	Lachlan (K) Ltd Distributor: Farm chem Ltd	III
SULBAN 48 EC (Emulsifiable Concentrate)	480g/L Chlorpyrifos	30-40ml/20L	Osho Chemical Industries Ltd.	II
APPLAUD 40% SC (Suspension Concentrate)	Buprofezin 400g/L	15ml/20L	Twiga Chemical Industries	III
BASUDIN 600 EW (Oil-In-Water Emulsion)	Diazinon 600g/L	16ml/20L or 80ml/ha	Ultravetis E.A. Ltd	II
FASTAC 10 EC (Emulsifiable Concentrate)	Alpha cypermethrin 100g/L	16ml/20L or 80ml/ha	Topserve East Africa Ltd	II
Campaign	*Metarhizium anisopliae*	4ml/20L or 200ml/ha	Real IPM	n/a
Nimbecidine	*Azadirachtin 0.03%*	50ml/20L	Osho Chemical Industries Ltd	n/a

10 Good Practices when Using Pesticides

When using pesticides, ensure the following good practices, to reduce risks to the applicator, crops, farm animals and the environment:

1. Nationally registered, labelled pesticides should be chosen, with a preference for those that are locally available and have a low health risk. Fake and banned products must be avoided. Always obtain recommended/registered chemicals from authorized agro-dealers, and ensure the product is clearly stated for the said target pest. When unsure check with your local agricultural extension service provider. Always check the expiry date of the pesticide before buying and applying on your crops.
2. Farmers should use proper personal protective equipment and follow the guidance provided on the pesticide label for rates of application, re-entry and pre-harvest intervals. After using pesticides, wash your hands before smoking or eating.
3. When applying pesticides, do not exceed the dose rate indicated on pesticide label. Read instructions on the label before using the pesticide. Do not mix different insecticides, as this may harm you and your crops.
4. Do not use paraffin, battery acid or diesel to control scale insects. This may harm your

crops and poses a health risk to humans and livestock. Mix pesticides outdoors or in well-ventilated areas. However, avoid handling pesticides during windy conditions and close the doors and windows to your home. Make sure children, pets, and anyone non-essential to the application of pesticides is out of the area before mixing and applying pesticides.

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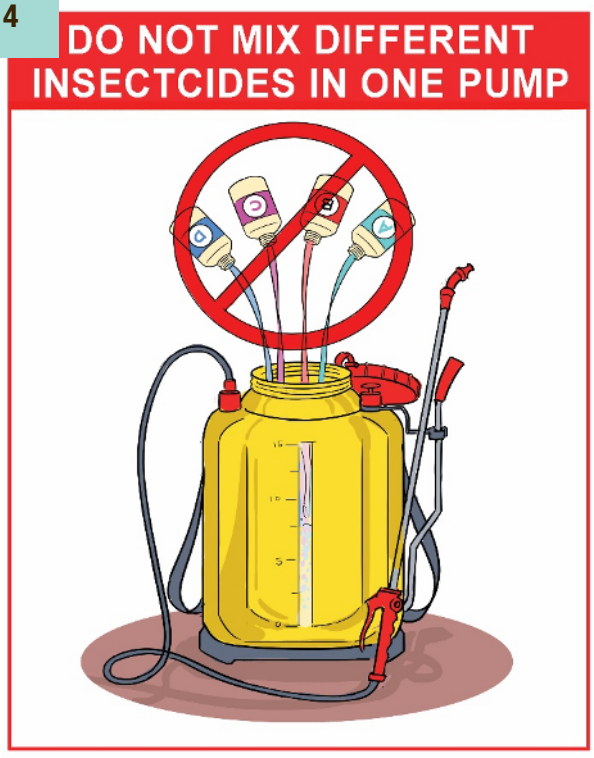

11 Government effort in the management of papaya mealybug

1. Creation of awareness through extension officers.
2. Training farmers on pest control and management practices.
3. Certification of nursery operators in collaboration with Agriculture and Food Authority (AFA) and KEPHIS.
4. Phytosanitary controls measure through KEPHIS.
5. Enlightening farmers on use of clean and certified planting materials through extension officers.
6. Provision of clean planting material through institution such as KALRO, KEFRI, Kenya Prisons Service.
7. Capacity building through institutions of higher learning (FTCs, TVETs, colleges and universities).

12 Partners

Ministry of Agriculture, Livestock, Fisheries and Cooperatives (MoALF&C)
County governments of Mombasa, Kilifi and Kwale
CAB International (CABI)
Kenya Agricultural and Livestock Research Organization (KALRO)
Kenya Forestry Research Institute (KEFRI)
Kenya Plant Health Inspectorate Service (KEPHIS)
National Museums of Kenya (NMK)
University of Nairobi (UoN)
Precision Agriculture for Development (PAD)

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References

Biswas, M.J.H., Khan, M.A.M., Ahmed, K.S., 2015. Control Strategies of Papaya Mealybug, *Paracoccus marginatus* Williams and Willink in the Laboratory Condition. Int. J. Appl. Sci. Biotechnol. 3, 687. https://doi.org/10.3126/ijasbt.v3i4.13979.

CABI *Paracoccus marginatus* (papaya mealybug). https://www.cabi.org/isc/datasheet/39201 (Accessed in Dec 2019).

Galanihe, L., Jayasundera, M., Vithana, A., Asselaarachchi, N., Watson, G., 2011. Occurrence, distribution and control of papaya mealybug, *Paracoccus marginatus* (Hemiptera: Pseudococcidae), an invasive alien pest in Sri Lanka. Trop. Agric. Res. Ext. 13. https://doi.org/10.4038/tare.v13i3.3143.

Goergen, G., Umeh, V., 2014. Classical Biological Control of Papaya Mealybug in West Africa 2–4.

Gullan, P.J., Cranston, P.S., 2010. The Insects an Outline of Entomology, 4th ed. Wiley-Blackwell, West Sussex, U.K.

Khan, M., Biswas, M., Ahmed, K., Sheheli, S., 2014. Outbreak of *Paracoccus marginatus* in Bangladesh and its control strategies in the fields. Progress. Agric. https://doi.org/10.3329/pa.v25i0.24066.

Krishnan, J.U., George, M., Ajesh, G., Jr, J., Nr, L., 2016. A review on Paracoccus marginatus Williams , papaya mealy bug (Hemiptera : Pseudococcidae). J. Entomol. Zool. Stud. 4, 528–533.

LaPolla, J.S., Dlussky, G.M., 2010. Review of Fossil Prenolepis Genus-Group Species (Hymenoptera: Formicidae) . Proc. Entomol. Soc. Washingt. 112, 258–273. https://doi.org/10.4289/0013-8797-112.2.258.

Lawrence, L., Indhu, P., Cherian, T., Anitha, S., Jimcymaria, T., 2013. Host range and distribution pattern of papaya mealy bug, *Paracoccus marginatus* Williams and Granara de Willink (Hemiptera: Pseudococcidae) on selected Euphorbiaceae hosts in Kerala.

Macharia, I., Kimani, E., Koome, F., Kosiom, T., Heya, H., Otipa, M., Oronje, M., 2017. First Report and Distribution of the Papaya Mealybug, Paracoccus marginatus , in Kenya. J. Agric. Urban Entomol. 33, 142–150. https://doi.org/10.3954/JAUE17-02.1.

Mani, M., Shivaraju, C., Shylesha, A.N., 2012. *Paracoccus marginatus*, an Invasive Mealybug of Papaya and its Biological. J. Biol. Control 26, 6–11.

Mastoi, M.I., Adam, N.A., Muhamad, R., Ghani, I.A., 2014. Survey of Papaya Mealybug, *Paracoccus Marginatus* (Hemiptera: Pseudococcidae) and Its Natural Enemies in Penninsular Malaysia. Pak. J. Agri., Agril. Engg., Vet. Sci., 30, 172–186.

Meyerdirk, D.E., Muniappan, R., Warkentin, R., Bamba, J., 2004. Biological control of the papaya mealybug, *Paracoccus marginatus* (Hemiptera: Pseudococcidae) in Guam. Plant Prot. Q. 19, 2000–2004.

Muniappan, R., Meyerdirk, D.E., Sengebau, F.M., Berringer, D.D., Reddy, G.V.P., 2006. Classical Biological Control of the Papaya Mealybug, *Paracoccus marginatus* (Hemiptera: Pseudococcidae) in the Republic of Palau. Florida Entomol. 89, 212–217. https://doi.org/10.1653/0015-4040(2006)89[212:CBCOTP]2.0.CO;2.

Muniappan, R., Shepard, B.M., Watson, G.W., Carner, G.R., Sartiami, D., Rauf, A., Hammig,

M.D., 2008. First Report of the Papaya Mealybug, *Paracoccus marginatus* (Hemiptera: Pseudococcidae), in Indonesia and India. J. Agric. Urban Entomol. 25, 37–40. https://doi.org/10.3954/1523-5475-25.1.37.

Mulwa J, Otipa M. and Wasilwa L. (2019). Papaya Mealybugs (*Paracoccus marginatus*). KALRO E-Mimea Plant Clinic Factsheet KALRO/CHP Factsheet No. 300. www.kalro.orgRoltsch, W.J., Meyerdirk, D.E., Warkentin, R., Andress, E.R., Carrera, K., 2006. Classical biological control of the pink hibiscus mealybug, *Maconellicoccus hirsutus* (Green), in southern California. Biol. Control 37, 155–166. https://doi.org/10.1016/j.biocontrol.2006.01.006.

Sakthivel, N., Qadri, S.M.., Balakrishna, R., Kivrsur, M. V, Helen, S.M., 2012. Management Strategies of Papaya Mealybug Infesting Mulberry.

Sakthivel, P., P. Karuppuchamy, M. Kalyanasundaram and T. Srinivasan. 2012. Host Plants of Invasive Papaya Mealybug, *Paracoccus marginatus* (Williams and Granara de Willink) in Tamil Nadu. Madras Agric. J., 99 (7-9): 615-619.

Seni, A., Chongtham, S., Watson, G.W., 2013. Papaya Mealybug *Paracoccus marginatus*Williams & Granara De Willink (Hemiptera: Pseudococcidae), a Current Threat to Agriculture - a Review 34, 216–222.

Tanwar, R.., Jeyakumar, P., Vennila, S., 2010. Papaya Mealybug and management strategies: Technical Bulletin 22 National Centre for Integrated Pest Management. New Delhi.

Walker, A., Hoy, M., Meyerdirk, D., 2018. Papaya Mealybug,*Paracoccus marginatus* Williams and Granara de Willink (Insecta: Hemiptera: Pseudococcidae). Biol. Control 1–7.

Zeddies, J., Schaab, R. P., Neuenschwander, P., & Herren, H. R. (2001). Economics of biological control of cassava mealybug in Africa. *Agricultural Economics*, *24*(2), 209–219. https://doi.org/10.1016/S0169-5150(00)00064-5.