Scoping study: management options for mealybug in persimmon

Dr Lara Senior
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(FINAL REPORT)

Project Number: PR11000 (1st December 2012)

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Queensland Department of
Agriculture, Fisheries and Forestry

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Purpose of the report: This final report reviews research and management options for mealybug in persimmon.

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Media summary

Citrus mealybug, longtailed mealybug and citrophilous mealybug are important pests in persimmon. These insects and the sooty mould associated with them reduce plant vigour and contaminate fruit. The project reviewed worldwide research, with the following aims:

- To collate current information on mealybug in Australian persimmon.
- To identify control techniques not currently available to, or utilised by, the Australian persimmon industry, prioritised according to their potential for adoption.
- To identify future research and development required to manage mealybugs in persimmon appropriately, especially for access to export markets, using the control techniques identified during the review process.

The findings, documented in this report, will provide the basis for decisions on future research.

Current information was collated in the areas of biology, distribution, life-cycle and seasonal activity of the three pest species, as well as methods currently employed for their control. Growers are heavily reliant on a limited number of mostly broad spectrum insecticides. This has hindered the development of an integrated pest management (IPM) system for persimmon.

Control techniques with potential for control of mealybug in Australian persimmon and areas requiring further R&D were documented. The following were categorised as high priority:

- Increase the number of IPM-compatible insecticides available to growers for control of mealybug and other persimmon pests, and phase out broad spectrum chemistry. This will allow natural enemies to suppress mealybug populations and insecticide resistance to be managed.
- Trial adjuvants: these chemicals can increase insecticide efficacy through enhanced coverage and penetration of the mealybugs' waxy coating.
- Determine the most effective timing of insecticide applications for maximum efficacy. For instance, contact insecticides must be timed to coincide with the exposed and dispersing crawlers and young stages undergoing moults.
- Develop an effective monitoring system for mealybug in persimmon, utilising pheromone lures as well as other methods such as targeted visual assessments, based on a better understanding of the biology, behaviour and seasonal activity of the pest species.
- Obtain registrations or permits for effective chemical controls for ants. These insects can protect mealybugs and other honeydew-producing pests from natural enemies and contribute to their spread.
- Trial postharvest disinfestation techniques such as hot water immersion, cold storage and oils as a postharvest dip.

It is recommended that future research should be focused on these priority areas. These elements will form the basis of an IPM system for mealybug in persimmon, incorporating a range of complementary control methods and informed by efficient monitoring.

Technical summary

Mealybug is a major issue for the Australian persimmon industry. Citrus mealybug (*Planococcus citri*) is the dominant pest species in Queensland, longtailed mealybug (*Pseudococcus longispinus*) mainly occurs in the southern states, and citrophilous mealybug (*Pseudococcus calceolariae*) has a limited distribution, generally restricted to small areas within the southern states. These insects feed by sucking sap from the host plant, excreting sugary honeydew which encourages the growth of sooty mould fungi. As a result, heavy infestations damage plants by reducing vigour and causing leaf and shoot deformation. Mealybugs and sooty mould also contaminate product for export and contribute to post-harvest issues such as reduced shelf life and downgrade due to blemish.

The project took the form of a review of worldwide research, with the following aims:

- To collate current information on mealybug in Australian persimmon. This background information is required in order to understand how control techniques can be applied most effectively.
- To identify control techniques not currently available to, or utilised by, the Australian persimmon industry, prioritised according to their potential for adoption.
- To identify future research and development required to manage mealybugs in persimmon appropriately, especially for access to export markets, using the control techniques identified during the review process.

A comprehensive review process was undertaken by conducting extensive literature searches, encompassing a range of mealybug species in tree crops, vineyards and other related cropping systems. The review also took the form of communication with key researchers, growers, consultants and industry partners. The resulting information was evaluated to identify those control strategies with potential for use in Australian persimmon, and to determine knowledge gaps where further research would be useful to develop these strategies and to enhance understanding of the pest. These were prioritised following consultation with the persimmon industry. The findings, documented in this report, will provide the basis for decisions on future research.

Current information was collated in the areas of biology, distribution, life-cycle and seasonal activity of the three pest species, as well as methods for their control. Growers are heavily reliant on a limited number of insecticides, the majority of which are not compatible with biological control. This encourages the development of resistance, impacts on natural enemies and has been linked to outbreaks of mealybug and other sucking pests. The reliance on broad spectrum chemistry, coupled with the lack of an effective monitoring system, has hindered the development of an integrated pest management (IPM) system for persimmon.

Control techniques with potential for control of mealybug in Australian persimmon and areas for future R&D were documented. Several were categorised as high priority, as follows.

Increasing the number of IPM-compatible insecticides available to growers for control of mealybug and other persimmon pests was identified as a high priority, coupled with a phasing out of broad spectrum chemistry. This will reduce the impact of insecticides on natural enemies, which aid in the suppression of mealybugs and other orchard pests. Additional insecticide options will also reduce the reliance on buprofezin and hence help to manage resistance, ensuring that this valuable pesticide remains effective. The use of the most appropriate adjuvants will also increase insecticide efficacy, aiding coverage and penetration of the mealybugs' protective waxy coating.

Insecticides must be used in an informed, targeted manner to ensure maximum impact on pests and minimum impact on beneficials. Timing of insecticide applications is dependent on insecticide type and mode of action (e.g. systemic or contact); accurate timing is vital in order to achieve maximum efficacy. For instance, applications of contact insecticides must be timed to coincide with the most vulnerable mealybug stages: exposed and dispersing crawlers and young stages undergoing moults. Older mealybugs have developed their waxy coating and often settle in feeding sites affording protection from sprays. Appropriate timing of insecticide sprays is dependent on an understanding of the seasonal phenology of mealybugs: this is not adequately understood and requires further research. Accurate timing of insecticide applications is also dependent on the development of an effective monitoring system for mealybug. Pheromone lures are a simple, effective tool which can be used to determine when mealybugs first become active early in the season and to track increases in populations. For accurate monitoring, pheromone trapping should be combined with other techniques, such as targeted visual inspections based on a better understanding of the biology, behaviour and seasonal activity of the pest species.

Some ant species can protect mealybugs and other honeydew-producing pests from natural enemies and contribute to their spread. Therefore registrations or permits for effective ant controls are also a priority.

Finally, postharvest disinfestation techniques such as hot water immersion, cold storage and oils as a postharvest dip should be investigated. These methods are currently used successfully in other commodities and it is likely that they could be adopted relatively easily by the Australian persimmon industry with only moderate expense.

It is recommended that future research should be focused on these priority areas. This will enable the development of an IPM system for persimmon, utilising chemical, biological and cultural control methods, and based on an understanding of mealybug activity through efficient monitoring. Effective in-field control combined with appropriate postharvest treatments will help to ensure that quarantine requirements are met and export income maximised.

1. Introduction

Mealybug is a major issue for the persimmon industry. In grower surveys, mealybugs were rated as the most important pest of persimmon in South Australia and Victoria; in Queensland and northern NSW they were ranked third (after Queensland fruit fly and clearwing moth) (George *et al*, 2011). Three species are important pests of persimmon in Australia: citrus mealybug (*Planococcus citri*), longtailed mealybug (*Pseudococcus longispinus*) and citrophilous mealybug (*Pseudococcus calceolariae*). All are polyphagous with a very wide host range encompassing many plant families. Mealybugs feed by sucking plant fluids, excreting sugary honeydew which forms a sticky deposit on the plant. This provides a medium for sooty mould fungi, which contaminate fruit and damage plants by reducing light available for photosynthesis (Ben-Dov, 1994). Mealybugs and sooty mould contribute to post-harvest issues such as reduced shelf life and downgrade due to blemish. Heavy infestations can affect the plant by reducing vigour and causing leaf and shoot deformation.

The most serious problem is contamination of product for export. Exported persimmons currently require a phytosanitary certificate to be moved into the very lucrative market of Thailand. However, large quantities of premium quality Australian persimmons are continually redirected to the less lucrative, sometimes over supplied domestic market because of phytosanitary failure due to mealybug infestation. The Malaysian export market handles a significant amount of Australia's bulk export and currently does not require a phytosanitary certificate. It is very likely in the near future that this market will also have a phytosanitary requirement from Australian exported persimmons. This will account for a major loss in Australian persimmon export revenue if the present phytosanitary failure to current markets continues. To make export matters worse, the Australian dollar could continue to be very strong both in the short and long term future. The Australian persimmon industry needs to open new, more profitable markets such as Taiwan and Korea to stay competitive. Both these markets require a phytosanitary certificate for market access, and the major hurdle will be mealybug.

Currently the industry relies on a very limited number of contact chemical sprays for control of mealybug (George *et al*, 2011). Control is made particularly difficult by the fact that this pest is often located beneath the calyx of the fruit, where it is able to avoid contact with many pesticide sprays. Moreover, mature mealybugs are difficult to control with most contact insecticides: sprays must be targeted against the younger stages to be effective. Hence effective mealybug control with insecticides will require access to newer, more effective insecticides, accurate spray timing based on a good understanding of pest and fruit phenology, and spray technology capable of providing high-level coverage. Chemical control should form one part of an integrated pest management (IPM) program. Targeted application of selective insecticides is therefore preferable in order to minimise effects on natural enemies. Effective monitoring techniques, releases of beneficial insects, cultural control strategies, post-harvest disinfestation and other management tools such as mealybug sex pheromones all form further components of an IPM system.

The important mealybug pest species and their distribution in Australia have been documented. However, there has been comparatively little work on the phenology of the pests in relation to region or crop phenology. A better understanding of the biology of the pest species is required in order to target control options most effectively.

This report reviews literature relevant to management of mealybugs in persimmon and other tree fruit crops. Control options are discussed with regard to the persimmon industry.

2. Method

A review of worldwide research relevant to management of mealybug in persimmon was conducted. This encompassed three areas, discussed in detail in the following report. Firstly, the current knowledge regarding the biology of the key mealybug pest species in Australian persimmon was reviewed, including their distribution, life-cycle and phenology (section 3 Mealybug biology). Secondly, the control methods available to the Australian persimmon industry and current management practices were documented and evaluated (section 4 Current control methods). This background information was required in order to understand where current control methods are deficient, and also where further research might be beneficial in order to better understand the pest and the most effective application of control techniques. Finally, potential control methods were explored (sections 5 to 10). These included chemical control (including reference to the recent Strategic Agrochemical Review Process conducted by the persimmon industry), biological control, cultural control, post harvest disinfestation, sex pheromones as management tools, and monitoring. As there was very limited information on mealybug in persimmon, the literature search encompassed a range of mealybug species in tree crops, vineyards and other cropping systems, in Australia and overseas.

The review was undertaken by conducting literature searches as well as communication with key researchers, consultants and industry partners, as follows:

- A visit was made to Plant and Food Research (New Zealand). This organisation was identified as conducting leading research in the area of pest management in summerfruit, including persimmon. Their recent research has included the use of mealybug sex pheromones for monitoring and mass trapping, biocontrol, chemical control and postharvest disinfestation techniques. Of the three key mealybug pests in Australian persimmon (citrus, longtailed and citrophilous mealybug), two (longtailed and citrophilous mealybug) are important in New Zealand. Furthermore, many of the natural enemies of mealybug in New Zealand were accidentally imported from Australia. Two Plant and Food research centres were identified as conducting relevant research: Mt Albert (Auckland) and Hawke's Bay (Havelock North). Meetings were arranged with key researchers at each of these locations, with the objective of discussing past research and recent advances in mealybug management techniques. A report on the trip is presented in appendix D.
- Growers were contacted in order to determine the extent and severity of the problem in different growing regions of Australia, and the control techniques currently employed. Communication with growers took the form of phone calls, face-to-face meetings and a survey (distributed via the 'Persimmon Press' newsletter) (appendix A). Meetings were also held with two New Zealand persimmon growers, in the Auckland and Northland regions of North Island (appendix D).
- Leading Asian researchers were consulted, via Robert Nissen (ACIAR project AGB 2006/066 Improving Productivity and Fruit Quality of Sweet Persimmon in Vietnam and Australia, reports presented in appendix C).
- Key persimmon industry representatives were consulted at regular intervals: Kent Andrew and Nick Hobbs (President and Vice President of Persimmons Australia),

Jeanette Wilson (Secretary of Persimmons Australia), Alison Fuss (Executive Officer of the Australian Persimmon Export Co Pty Ltd).

- Peter Dal Santo (AgAware Consulting Pty Ltd) was consulted during the early stage regarding current and future chemical control options.

The collated information was reviewed to determine knowledge gaps where further research would be useful to enhance understanding of the pest, and to identify control strategies with potential for use in the Australian persimmon industry. These were prioritised following consultation with the persimmon industry.

3. Mealybug biology

3.1 Description

Mealybugs (Hemiptera: Pseudococcidae) are sexually dimorphic. Adult females are small (3 – 5 mm), wingless, with an elongate oval-shaped body. They are covered in a protective white, waxy coating which is water repellent. They have short antennae and legs but may be quite mobile. Adult males are smaller than females: they are fragile insects with one pair of wings and non-functional mouthparts. The males do not feed and are short-lived, their only purpose being to mate with the females. Juvenile stages are similar in appearance to the females, but smaller.

Three species are important pests of persimmon in Australia: citrus mealybug, longtailed mealybug and citrophilous mealybug. According to Jeppson (1989) these three species can be distinguished by differences in the waxy covering and wax filaments around the body margin: the posterior filaments of the long-tailed mealybug are longer than the body and slender; in the citrus mealybug the filaments are short and thick, with the posterior ones slightly longer than the laterals; in the citrophilous mealybug the two posterior filaments are long and stout, with the others tapering towards the tip, and the waxy covering is incomplete giving the appearance of four longitudinal dorsal lines. Additionally, the body fluid of the long-tailed and citrus mealybugs is light coloured, whereas that of the citrophilous mealybug is dark. A diagnostic key and detailed description of adults and immature females of these three species is provided in Williams (1985) and Wakgari & Giliomee (2005):

Citrus mealybug, *Planococcus citri* (Risso). Adult females are approximately 3 mm long, 2 mm wide (including wax) (plate 1). De-waxed, the body is reddish-brown to yellowish-brown in colour. There is a distinct median longitudinal line. The wax filaments around the body margin are well developed, the posterior filaments slightly longer than the others. The body fluids (ejected when touched, or detected by squashing the insect) are a pale yellow.

Plate 1. Citrus mealybug, *P. citri* (Photo: Robert Nissen)

Longtailed mealybug, *Pseudococcus longispinus* (Targioni-Tozzett). Adult females are about 2.5 mm long, 1.5 mm wide (including wax) (plate 2). De-waxed, the body is yellowish-brown. Dorsal segmentation is less distinct compared with *P. calceolariae* and a broad median longitudinal dorsal line is visible. The posterior filaments are longer than the entire body length, a distinctive feature. The body fluids are a pale yellow. Adults and immature stages are more active than other mealybug species.

Plate 2. Longtailed mealybug, *P. longispinus* (Photo: Robert Nissen)

Citrophilous mealybug, *Pseudococcus calceolariae* (Maskell). Adult females are approximately 3.2 mm long, 2 mm wide (including wax) (plate 3). De-waxed, the body is dark brown to reddish-brown. Dorsally, there is a pattern of four dark-claret, longitudinal lines where the wax covering is thinner. Body segmentation is distinct dorsally, but no median longitudinal line is visible. The wax filaments around the body are roughly equal in size, the posterior pair approximately one-quarter of the body length. Body fluids are a dark claret-red.

Plate 3. Citrophilous mealybug, *P. calceolariae* (Photo: Chris Freebairn)

3.2 Distribution

The main sweet persimmon production areas are southern Queensland, northern New South Wales, Coffs Harbour, Sydney, northern Victoria (Cobram, Shepparton, Sunraysia), north-eastern South Australia (Riverland) and south-western West Australia (George *et al*, 2005). The distribution of mealybug species varies throughout Australia: the dominant pest species in Queensland is the citrus mealybug, whereas in the southern states the more important species are citrophilous mealybug and longtailed mealybug, as detailed below. This is important when considering effective chemical and biological control strategies.

Citrus mealybug is a major cosmopolitan pest, damaging glasshouse plants in temperate regions and many outdoor crops in the tropics and sub-tropics (Ben-Dov, 1994). This author lists host plants from 60 families. Widely distributed as a result of international trade, its origins are uncertain: South America, the Far East and South America have been suggested (Franco *et al* 2004). The citrus mealybug occurs across a relatively wide area of Australia (Smith *et al*, 1997; Williams, 1985). However, it is much more common in coastal districts and areas north of Sydney in the eastern states (Queensland Government Department of Agriculture, Fisheries and Forestry, 2012). It is the most common mealybug species in citrus in Queensland (Ceballo *et al*, 1998) and an occasional or minor pest in New South Wales and Western Australia (Gullan, 2000). In a survey of citrus growing regions in New South Wales, Victoria and South Australia, citrus mealybug was always at low incidence (Baker & Keller, 1998).

Long-tailed mealybug is also established in many tropical and subtropical parts of the world on a wide range of host plants, and is found in protected cropping in temperate regions. It is thought to have originated from Australia (Charles *et al*, 2010). Unlike the citrus and citrophilous mealybugs, the longtailed mealybug is not found on the roots of plants. It occurs across a wide area of Australia (present in all states except NT according to Williams, 1985), but is mainly a pest in the southern states. In a survey of citrus in south-east Queensland, no long-tailed mealybugs were found at any sampling sites (Ceballo *et al*, 1998). Baker & Keller (1998), sampling in citrus growing regions in the southern states found long-tailed and citrophilous mealybugs to be the dominant species, the relative abundance varying between regions: long-tailed mealybug was dominant in most of the Sunraysia, Murray Valley, the Riverina and Narromine. In vineyards, longtailed mealybug is a pest in humid coastal vineyards of Australia (Retallack & McMichael, 2007), and has become increasingly abundant in vineyards in Western Australia (Learmonth, 2005).

Citrophilous mealybug feeds on a wide variety of host plants and has a world-wide distribution. It is native to Australia (Debach & Rosen, 1991), most likely originating from the eastern sea-board (Baker & Keller, 1998). However, it is less wide-spread in Australia than the other species. According to Gullan (2000) this species is a major pest in the Riverland (South Australia) and an occasional or minor pest in New South Wales. Baker & Huynh (2000) also found it only in the Riverland and Sunraysia regions, the latter with a limited and patchy distribution. Baker & Keller (1998) found it to be the dominant species in Riverland, Hillston, Barham and Sydney citrus growing regions. In Queensland, *P. calceolariae* is restricted to the Granite Belt (Ceballo *et al*, 1998).

3.3 Life-cycle

Citrophilous and citrus mealybugs produce eggs in a cottony pouch (egg sac), beneath the female, where eggs are accumulated until hatching (Wakgari & Giliomee (2005): up to 500 eggs for citrophilous mealybug, and 300—600 for citrus mealybug (Smith *et al*, 1997). The longtailed mealybug has no egg sac as this species produces live young, deposited under the female's body. About 200 live young are produced over 2 – 3 weeks (Smith *et al*, 1997). After hatching, the first instar stage (termed a crawler) moves away to look for a sheltered feeding site. Soon after beginning to feed they develop the distinctive white, waxy coating that gives them their name. The immature mealybugs moult several times before becoming adult, as described by Gullan (2000). The female has three nymphal instars and no pupal stage; adults resemble larger versions of the nymphs. Males have four instars, the third and fourth of which are termed the prepupal and pupal stages, respectively. The last instar pupates in a silk cocoon, emerging as a small, winged adult male.

The adult male is mobile, able to seek out females via a sex pheromone. However, according to Barrass *et al* (1994) males were rarely observed to fly. Instead, aerial dispersal of the small first and second instars is thought to be a key factor in colonising new areas, with the potential for rapid spread over large distances. Ants also help to disperse mealybugs.

3.4 Population dynamics and phenology

Development time is largely dependent on temperature. Smith *et al* (1997) give the life-cycles for each species as follows: citrophilous mealybug 2 months in midsummer, 3-4 months in winter; longtailed mealybug 6 weeks in summer, 12 weeks in winter; citrus mealybug 6 weeks during the summer. There are several generations per year. Most mealybugs overwinter as slowly-developing juveniles, reaching the adult stage in late winter/early spring. This results in a largely synchronised population, with a spring generation of crawlers which disperse to feeding sites. In cooler areas generations may remain broadly synchronised, but in warmer areas generations may overlap considerably.

Although temperature is a major influence on development time, population dynamics are also directly influenced by host plant phenology. Most research in this area has been in crops other than persimmon. For instance, working on citrus in Portugal, Franco (1992) found that during the spring flush (shoot growth and blooming) overwintering adults settled at the bottom of young shoots, their development paralleling shoot growth. During this phase and during dormancy, the mealybugs were mainly dispersed in the tree canopy. At fruit set and development there was a rapid increase in population and the mealybugs tended to become aggregated on the fruits. In Californian grape vineyards, seasonal population dynamics of the vine mealybug (*P. ficus*) has been found to be dependent on a number of factors such as temperature, vine phenology and impact of natural enemies (reviewed by Daane *et al*, 2012): mealybugs overwinter primarily under the bark and on the roots, then follow the movement of plant resources from roots to shoots to leaves from spring to summer, finally moving into the berries as they ripen. Following harvest there is a rapid decline in population as a result of biological controls, high temperatures and vine senescence.

Some observations of mealybug phenology in persimmon have been made. In Vietnam, citrus mealybug was observed to shelter in the top layer of soil at the base of persimmon trees during the winter months, moving up onto the new developing shoots in spring (Nissen *et al*, 2012). A similar seasonal pattern has been observed for citrus and longtailed mealybug in persimmon in south east Queensland (Robert Nissen, personal communication, 27 September 2012). At the end of winter, mealybugs were found toward the base of large branches and on the trunk. At this time of year they were easily seen, perhaps because of the lack of foliage. At leaf emergence they moved to the base of newly developing shoots: nymphs on the leaves, including the growing tip, and egg-producing adults in more sheltered spots towards the base of the shoots and lower leaf axils. Nymphs moved onto the fruit during early fruit set, the population reaching a peak as the fruit neared maturity. At this stage both nymphs and adults were observed to be present on the fruit, often under the calyx. Small cracks under the calyx, which often occur during the final stage of rapid fruit expansion, exude sap which appeared to attract mealybugs and ants. It is surmised that the increase in mealybug activity is associated with high levels of sugar in the ripening fruit.

Mealybug population dynamics are is influenced by ant activity. Ants not only protect mealybugs from natural enemies, but also contribute to their spread. Working in persimmon in south east Queensland, Robert Nissen (personal communication, 27 September 2012) noted that ant and mealybug populations both exhibited an increase in activity as temperatures increased at the beginning of spring. There was a correlation between the increase in ant and mealybug populations during the late summer months. During the final stage of fruit growth, ants were observed to transfer mealybugs to the fruit. The role of ants in management of mealybug is discussed further in section 6.3.2 Control of ants.

It should be noted that efforts to determine the seasonal population dynamics of mealybugs are limited by the sampling method used. Although it is often reported that the highest levels occur during summer months to late autumn, this observation may be exaggerated by mealybugs being more visible during this time, whereas earlier in the season they may be concealed (e.g. under bark).

Specific information for each species is given below:

Longtailed mealybug: Smith *et al* (1997) (in citrus) state that in Queensland and the Northern Territory there are 4-6 generations per year, and 3-4 generations per year in New South Wales, Victoria and South Australia. The spring generation of crawlers migrates to young fruit in late November and early December, with considerable overlap of stages by the third generation. Most over-winter as juveniles, which reach adulthood by August-September. Furness (1976) found that longtailed mealybug in the Riverland area of South Australia had three discrete generations per year due to lack of reproduction through the winter months, with population peaks on the leaves coinciding with a higher proportion of crawlers in the population.

Citrophilous mealybug: there are 3-4 generations per year in New South Wales, Victoria and South Australia (Smith *et al*, 1997), with the spring generation of crawlers migrating to young fruit in late November and early December, and considerable overlap of stages by the third generation. Most over-wintering citrophilous mealybugs are juveniles (a mixture of stages) which develop slowly, reaching adulthood by August-September. Baker & Keller (1998), sampling in citrus in the Riverland/Sunraysia districts, found that this species breeds continuously throughout the year, with at least three broadly-overlapping generations each year, resulting in two peaks in abundance on fruit. However, synchronisation of reproduction did not occur at all sites and there were significant differences in seasonal activity and peak numbers of mealybugs among different properties.

Citrus mealybug: in Queensland and the Northern Territory there are at least 6 generations per year, 4-5 in New South Wales and probably 3-4 in Victoria and South Australia (Smith *et al*, 1997). Young mealybugs move onto fruit in late spring. In citrus, this species begins egg-lay in spring in sheltered sites on the trunk and limbs. The crawlers move on to the fruit in late spring (Swaine *et al*, 1991). Monitoring in Queensland citrus, Ceballo *et al* (1998) found that in Brisbane and Nambour, mealybug were present mostly during April and May, whereas in Mundubbera they were most abundant in December and January after growth flushes had appeared and flower set had started. Infestations declined to undetectable levels between February and April then were found again at fruit maturity in May. Responses from a grower survey indicated that Queensland growers experienced the highest level of mealybug infestation over the summer months through to late autumn (refer to appendix A).

4. Current control methods

The following section reviews the mealybug management techniques currently available to the Australian persimmon industry.

4.1 Chemical control

The persimmon industry relies on a limited number of contact chemical sprays for control of mealybug. Current insecticide registrations and permits for control of mealybug in fruit trees are listed below (source Infopest).

- Buprofezin (e.g. Applaud) – registered for control of mealybug and scale in persimmon.
- Fenthion (e.g. Lebaycid) – permitted for control of mealybug on inedible peel varieties of persimmons only (PER13841).
- Methidathion (e.g. Supracide) – permitted for control of a variety of pests, including mealybug, in persimmon (PER13694).
- Insecticidal soaps/fatty acids – registered for control of a variety of pests, including mealybug, on fruit trees.

In addition, a number of other insecticides with efficacy against mealybug are registered or permitted for use in fruit trees for control of other pests. Although these insecticides cannot be applied for control of mealybug, they may provide an additional measure of suppression when applied against the pests for which they are registered.

- Petroleum oils – permitted for control of scale in persimmon (PER9861) and applied during the dormancy period.
- Chlorpyrifos (e.g. Lorsban) – registered for control of a variety of pests (not including mealybug) in fruit trees and commonly applied (refer to grower survey, appendix A).
- Pyrethrins – registered for control of a variety of pests (not including mealybug) in fruit trees.

Buprofezin can be effective for control of mealybug, and is less detrimental to natural enemies than some of the other chemical options available: Mgocheki & Addison (2009a) found that buprofezin had no toxicity to *Anagyrus* spec. nov. near *pseudococci* or *Coccidoxenoides perminutus*. According to the label it should not be applied within 60 days of release of *Cryptolaemus*, although it has been suggested that this period could be shortened considerably (George *et al*, 2011). As buprofezin is an insect growth regulator, applications must be targeted against the juveniles and take up to two weeks to have an effect, hence timing is critical. The first application is generally made in the spring to coincide with the first batch of crawlers, with a second application made 14 days later. In order to limit resistance development, it should not be applied more than twice per year. However, according to George *et al* (2011) it is commonly used, with some growers applying it up to four times a year.

Fenthion and **methidathion** are broad spectrum insecticides (organophosphates) and therefore disruptive to IPM. They are currently under review by APVMA: fenthion has been restricted for use in inedible peel varieties of persimmon only. Methidathion is commonly applied for control of a number of persimmon pests, both alone and in combination with an oil (refer to grower survey, appendix A); according to George *et* *al* (2011) is the most commonly used insecticide to control mealybugs in persimmon. However, according to the recent persimmon SARP review process, its efficacy is questionable.

4.2 Biological control

4.2.1 Commercially available biocontrols

A number of mealybug biological control agents are commercially available in Australia. The main control agents are *Leptomastix dactylopii* (commonly called leptomastix or citrus mealybug parasite) and *Cryptolaemus montrouzieri* (common names cryptolaemus beetle or mealybug ladybird), both of which are available from Bugs for Bugs (Mundubbera, QLD). The green lacewing, *Mallada signata* is a generalist predator that can also help to control mealybug species. The following information is taken from Richard (2002) unless specified otherwise.

L. dactylopii (Hymenoptera: Encyrtidae) is a small (3 mm long) parasitoid wasp, the larva of which develops within the body of the mealybug. It is specific for control of *Planococcus citri,* and performs most effectively at temperatures of 25°C and above. Originating from Brazil, it was introduced to Queensland from California in 1980 (Smith *et al*, 1988; Smith *et al*, 1997). Leptomastix parasitises third instars and adults, and is able to control citrus mealybug even at low densities. George *et al* (2011) recommend releasing 10,000 wasps per hectare during late December to late February, either in one release or in up to three releases. These authors recommend releasing leptomastix when more than 25% of fruit have one or more large mealybugs present, and less than 20% of the infested fruit show no sign of natural enemies.

C. montrouzieri (Coleoptera: Coccinellidae) is a ladybird species endemic to Australia and a very efficient predator of many species of mealybug, its preferred prey. The adult beetle is approximately 4 mm long, with a shiny black body and a dull orange head and abdominal tip. The larvae superficially resemble mealybugs, but are larger (10 mm) with much longer waxy filaments. Both the larvae and adult beetles feed voraciously on mealybugs, particularly the egg masses. George *et al* (2011) recommend a release rate of 25 adults per tree for rapid establishment: lower release rates (as little as 5 beetles per tree) may be sufficient to establish the predator if carried out early. These authors suggest that releases should be made from mid-January to mid-February on fruit at least 5 cm in diameter and showing some sign of mealybug infestation. Smith *et al* (1997) noted that cryptolaemus can be slow in locating mealybug infestations, but that numbers then build up rapidly. According to Jim Walker (personal communication, 12 July 2012) it requires high host densities to be effective. Robert Nissen (personal communication, 27 September 2012) observed mealybugs and their natural enemies over four seasons on persimmon in south east Queensland. Cryptolaemus was the main predator, the population increasing at fruit maturity as the mealybug population peaked. However, it was also noted that this predator had great difficulty attacking mealybugs present under the calyx.

M. signata (Neuroptera: Chrysopidae), a green lacewing, is a generalist predator which will attack a range of pests including mealybugs of various species. The adult is slender, green and delicate in appearance. The larvae are predatory. According to Bugs for Bugs, whereas leptomastix and cryptolaemus can spread quickly from the point of release, lacewings (released as larvae) stay in the vicinity of the release site and are therefore good for cleaning up infestation ‘hot spots’ (Wes Allen, personal communication, 22 May 2012). The recommended release rate is a minimum of 2000 lacewing larvae per hectare, with at two to three releases 10-14 days apart.

Biological controls are not as commonly used in persimmon orchards as they are in some other tree crop industries, such as citrus. However, releases of cryptolaemus and lacewings have been used with some success for control of mealybug in persimmon (Wes Allen, personal communication, 22 May 2012).

4.2.2 Natural enemies

Many naturally occurring predators and parasitoids can help to keep mealybugs under control. Overseas, ladybirds, lacewings, various species of predatory bugs, predaceous mites and spiders are predators of mealybugs in Californian vineyards (Daane *et al*, 2008). Reviewing collections made in New Zealand vineyards, Charles *et al* (2010) found seven species of parasitoid and four species of predator to be common and ubiquitous, many of which are native to Australia. Natural enemies have been found to provide effective suppression of mealybug in New Zealand pipfruit and wine grapes if managed correctly (Jim Walker, personal communication, 12 July 2012). Surveys of mealybug natural enemies in Australia have returned variable results dependent on crop and location: Learmonth (2005) (vineyards, WA); Mo (2005) (citrus, NSW); Furness (1976) (orange, grape, pear, Riverland SA); Baker & Keller (1998) (citrus, Riverland and Sunraysia); Ceballo *et al* (1998) (citrus, SEQLD). The most commonly occurring natural enemies in Australia are detailed below.

4.2.2.1 Parasitoids

Anagyrus fusciventris (Hymenoptera: Encyrtidae) is a native Australian parasitoid of longtailed and citrophilous mealybug (Smith & Peña, 2002; Charles *et al*, 2010). It is one of the major parasitoids of *P. calceolariae* in south-eastern Australia (Smith & Peña, 2002). It was introduced to the Riverland area of South Australia in the 1970s for control of longtailed mealybug, and its presence in this region has since been confirmed by Furness (1976) (orange, grape pear in the Riverland) and Baker & Keller (1998) (citrus in the Riverland and Sunraysia districts). An unknown species of *Anagyrus* was commonly found parasitising citrus mealybug in citrus in south-east Queensland (Ceballo *et al*, 1998).

Tetracnemoidea spp (Hymenoptera: Encyrtidae) are commonly associated with mealybug in Australia, including the native *T. brevicornis* and *T. sydneyensis* (Smith & Peña, 2002). ***T. brevicornis*** was introduced to the Riverland for biological control circa 1990, and has since been found in surveys of this region (Baker & Keller, 1998; Baker & Keller, 2000). It is one of the major parasitoids of citrophilous mealybug in south-eastern Australia (Smith & Peña, 2002) and in New Zealand (Charles, 1993). ***T. sydneyensis*** is listed as an important parasitoid of longtailed mealybug in south-eastern Australia by Smith *et al* (1997). This species was released in the Riverland for biological control in 1972 (Furness, 1977b). Although this author concluded that the parasitoid failed to establish, sampling by Baker & Keller (1998) found it to be widespread in the region. Furness (1977b) also introduced the exotic ***T. peregrina***, however this species has not been recovered in subsequent sampling and therefore does not appear to have established.

Ophelosia spp (Hymenoptera: Pteromalidae) are common mealybug parasitoids in citrus (Smith & Peña, 2002). ***O. crawfordi*** was frequently found parasitising longtailed mealybug in orange, grape and pear crops in the Riverland (Furness, 1976). Baker & Keller (1998) found ***O. bifasciata*** (a native species) to be one of the most common parasitoids associated with citrophilous and longtailed mealybug in citrus in the Riverland and Sunraysia districts. An unknown species of ***Ophelosia*** was associated with citrus mealybug in citrus in south-east Queensland (Ceballo *et al*, 1998).

Coccophagus gurneyi (Hymenoptera: Aphelinidae), an Australian native (Smith & Peña, 2002), primarily parasitises citrophilous mealybug, although it has been reared from longtailed mealybug (Charles *et al*, 2010). It is an important parasitoid of citrophilous mealybug on the east coast of Australia (Smith & Peña, 2002). Releases have been made in the Riverland region, with initial monitoring confirming its presence at most release sites (Baker & Keller, 2000); however subsequent monitoring has failed to find evidence that *C. gurneyi* did successfully establish (Greg Baker, personal communication, 6 November 2012).

Other parasitoids found associated with mealybugs in Australia include ***Cryptanusia* nr. *comperei*** (Encyrtidae), ***Chartocerus* sp** (Signiphoridae) (Baker & Keller, 1998; citrus in Riverland and Sunraysia), ***Allotropa* sp** (Platygasteridae) (a common parasitoid of citrophilous mealybug in south-eastern Australia; Smith *et al*, 1997) and the non-native Encyrtids ***Coccidoxenoides perminutus*** (= *P. peregrinus*) and ***Leptomastidae abnormis*** (Ceballo *et al*, 1998 and Smith *et al*, 1988; citrus mealybug in citrus in south-east Queensland). *C. perminutus* was found to be the most common parasitoid of citrus mealybug in Mundubbera citrus (Ceballo *et al*, 1998; Ceballo & Walter, 2005), but only achieved very low parasitism levels, thought to be a consequence of a short adult life and the harsh (low humidity) environment in southeast Queensland citrus (Ceballo & Walter, 2005).

Evidence from New Zealand suggests that further important mealybug parasitoids may be present in Australia despite not being recorded in surveys. For instance, the parasitoid *Pseudaphycus maculipennis* was introduced from Australia into New Zealand for control of the obscure mealybug, *Pseudococcus viburni* (Charles, 2001). The Aphelinid parasitoid *Alamella mira* is thought to be an important natural enemy of long-tailed mealybug in New Zealand (John Charles, personal communication, 11 July 2012; Jim Walker, personal communication, 12 July 2012). Although not reported in Australia, Shaw *et al* (2012) suggested it may have been accidentally introduced from that country along with its mealybug host. Likewise, Charles (1993) listed *Parectromoides varipes* (a native to Australia) as a parasitoid of longtailed mealybug in persimmon and other crops in New Zealand.

4.2.2.2 Predators

Mealybugs have a typically patchy distribution: generalist predators can be particularly useful for suppression of mealybug populations as they are able to eradicate a point source (John Charles, personal communication, 11 July 2012).

Diadiplosis koebeli (Diptera: Cecidomyidae) is a predatory midge, the larvae of which feed on mealybug eggs. Smith *et al* (1997) stated that it is not regarded as a major predator, but according to George *et al* (2011) it can be quite effective in controlling high populations of mealybug. It is also listed as a predator of mealybugs in vineyards by AWRI (2011) and was the most widely distributed predator found in a survey of mealybug natural enemies in New Zealand (Charles, 1993).

Lacewings (Neuroptera) other than the commercially available *M. signata* include *Oligochrysa lutea* (Smith *et al*, 1988), *Chrysopa* sp (Furness, 1976; Learmonth, 2005), *Micromus tasmaniae* (Furness, 1976) and *Plesiochrysa ramburi* (Smith *et al*, 1997). The dusky lacewing (*Cryptoscenea australiaensis*), a native to Australia, is thought to be an important mealybug predator in New Zealand (Jim Walker, personal communication, 12 July 2012).

Ladybirds (Coleoptera: Coccinellidae) other than the commercially available cryptolaemus include *Rhizobius ruficollis* (Furness, 1976; Baker & Keller, 1998; AWRI, 2011) and *Scymnus* sp. (Furness, 1976). A number of other species will also attack on mealybugs, e.g. *Diomus notescens*, *Halmus chalybeus* and *Harmonia conformis* (Smith *et al*, 1997).

Other generalist predators which may contribute to mealybug control include hoverfly (Syrphidae) larvae, tree frogs, spiders and assassin bugs (Learmonth, 2005; George *et al*, 2011; Smith *et al*, 1997). In New Zealand, predatory mites such as the Bdellid and Anystid (whirligig) mites are associated with mealybug overwintering in burr knots on pome fruit, and thought to be important for their control (Jim Walker, personal communication, 12 July 2012).

4.3 Cultural control

A number of cultural control methods can be employed for the management of mealybug and other orchard pests. These are predominantly concerned with reducing the spread of mealybugs and creating conditions to optimise chemical and biological control techniques.

Effective pruning can open up the canopy and maintain a tree size and shape suitable for good spray penetration and coverage (Baker & Keller, 2000; Franco *et al*, 2004; Charles, 2005). Pruning and general tree maintenance removes shelter and overwintering sites such as old spurs or canes, mummified fruit and loose bark (Charles, 2005). Some New Zealand growers routinely remove moss and lichen from their trees as part of their mealybug management program (Jeremy Noakes and Lance Walters, personal communication, 10 July 2012). Fruit thinning can help to control mealybugs and some other pests by eliminating fruit crowding (Ullio, 2003), and hedging trees to prevent them from touching can limit the spread of the pest (Kerns *et al*, 2004).

Good orchard hygiene and sanitation practices such as washing down machinery and destroying infested prunings can limit the spread of an infestation. Water blasting will dislodge some insects (Tenbrink & Hara, 2007): Queensland persimmon grower Mick McGinnis reported that he uses water blasting primarily to control clearwing moth, but has found it also helps to suppress mealybug populations (personal communication, 19 July 2012).

A post-harvest inspection including checking beneath the calyx is used to screen export fruit for the presence of mealybug. Some growers use physical methods to remove mealybugs, such as brushing or pressurised air. However, this method does not easily remove sooty mould, which results in downgrading of fruit after harvest.

Although primarily planted for the purpose of preventing wind damage, tree windbreaks can also help to maintain orchard conditions that are suitable for natural enemies. George *et al* (2005) provide a list of windbreak species suitable for Queensland.

4.4 Control of ants

Ants protect mealybugs and sap-sucking pests from natural enemies and contribute to their spread (George *et al*, 2011) (discussed in detail in section 6.3.2). Insecticide ground sprays are commonly used for their control: of the seven growers in the survey who reported a problem with ants, five used insecticides for their control (mainly Lorsban) (appendix A). Chlorpyrifos (Lorsban) and fipronil (Regent) are effective controls, but are not currently registered or permitted for use in persimmon for this purpose. Ant baits containing hydramethylnon are effective and registered for use against ants in persimmon orchards. However, newer baits containing fipronil are not currently permitted for use in persimmon.

Other control methods include physical destruction of ant nests (George *et al*, 2011). Tree skirting, trunk banding (application of sticky barriers) and weed control can restrict ant movement up into the tree canopy (Smith *et al*, 1997; George *et al*, 2005 & 2011). Managing ground cover may also be of benefit.

4.5 Monitoring

Guidelines for monitoring and action thresholds for treatment of mealybug have been developed for the persimmon industry (George *et al*, 2005 & 2011). These are based on recording the presence or absence of mealybugs and their natural enemies on randomly selected fruit. However, the cryptic behaviour and clumped spatial distribution pattern of mealybugs makes it difficult to monitor effectively using conventional methods. A high number of samples from a number of locations on the trees and throughout the orchard are required in order to achieve any degree of accuracy. In New Zealand, a variety of sampling methods have been trialled, based on monitoring numbers of crawlers in the spring, such as inspections of fruitlets, shoots or burr knots (in apple) and sticky trunk bands. However, these were only found to be a reliable indicator of mealybug infestation at harvest at high populations (more than 10% of fruit infested) (Jim Walker, personal communication, 12 July 2012). Feedback from industry also indicates that visual sampling is not effective: growers reported that mealybugs are often rarely seen until harvest, and low levels of mealybug are often not picked up in random sampling (Jeremy Noakes, personal communication 10 July 2012; Mick McGinnis, personal communication, 19 July 2012).

4.6 Limitations of current control methods

Pest management in persimmon is currently heavily reliant on chemical control, based largely on organophosphate insecticides. According to the grower survey conducted for this project, the most commonly applied insecticide for control of persimmon pests was chlorpyrifos, followed by methidathion, oils and fenthion (appendix A). However, mealybugs are difficult to control with chemical sprays, for a number of reasons (McKenzie, 1967). They prefer protected sites, such as crevices in the bark and under the calyx of the fruit, where they are able to avoid contact with many pesticide sprays. Their waxy coating repels water based insecticides; the eggs, protected in the waxy egg sac, are particularly difficult to reach. Densely foliaged trees can also make it difficult to achieve good coverage. This can be overcome by using a hand-wand to spray inside the tree, but is time consuming and dangerous for the operator (George *et al*, 2011). High volume applications and spray equipment capable of delivering complete coverage are essential (Charles, 2005). For most effective control, insecticides must be targeted against the early instar nymphs. Accurate spray timing based on a good understanding of pest and fruit phenology, coupled with effective monitoring systems, is therefore critical. Current mealybug monitoring methods are not effective, making it difficult to time applications correctly, which can lead to control failures.

Overseas, mealybug species have developed resistance to organophosphate insecticides (reviewed in Franco *et al*, 2004 and Charles, 2005). This is exacerbated by ineffective control combined with the fact that mealybugs have several (often overlapping) generations per year (Franco *et al*, 2004). The risk of resistance to buprofezin developing in Australia is recognised, with a recommendation that no more than two applications should be made to a crop per season. However, the limited number of available insecticides makes rotation between chemical groups difficult, resulting in a tendency to overuse the few effective products available.

Use of broad spectrum insecticides is disruptive to naturally occurring predators and parasitoids and incompatible with augmentative releases of biocontrol agents. In fact there is evidence that mealybug infestations are often the result of excessive use of organophosphates (reviewed in Franco *et al*, 2004 and Furness, 1977a), with infestations showing a marked decline when use of organophosphates is discontinued (Jim Walker, personal communication, 12 July 2012). The Australian persimmon industry would benefit from access to a greater number of effective soft option insecticides for control of mealybug and other key persimmon pests.

Although natural enemies can effectively suppress mealybug populations under favourable conditions, they may not be able to achieve adequate levels of control, particularly in warmer regions. Moreover, a very low level of infestation can result in rejection of exported fruit, and additional controls are required to completely eradicate mealybugs. Some ant species are disruptive to biological control, particularly invasive species such as the Argentine ant and coastal brown ant. Currently there are few options for control of ants in persimmon.

In summary, management of mealybug in persimmon is constrained by the lack of selective chemistry compatible with biological control, and the lack of an effective system for monitoring mealybug populations. The over-reliance on old chemistry for mealybug and other persimmon pests is a barrier to adoption of IPM, and the lack of a simple decision-making system for mealybug means that pesticide applications may be ineffective or unnecessary. Buprofezin is an effective, IPM compatible option for mealybug and scale; however it is vulnerable to resistance development through overuse. Access to additional soft option insecticides for persimmon pests is a key requirement, but these should be used in a targeted manner as part of an IPM system in order to achieve a long-term solution.

5. Potential control methods: chemical control

5.1 Insecticides with potential for mealybug control in persimmon

A number of insecticides have demonstrated efficacy against mealybug species, but are not currently registered or permitted for control of this pest in persimmon. These are reviewed below.

5.1.1 Spirotetramat

Spirotetramat is a relatively new insecticide marketed by Bayer CropScience as Movento® 240 SC. It is in the group 23 mode of action, targeting lipid synthesis and growth regulation. It has activity against a broad spectrum of sucking insects, and is particularly effective against juvenile stages as well as significantly reducing adult fecundity and fertility (Nauen *et al*, 2008). It is mobile in both the xylem and phloem, thereby protecting the entire plant. This is of particular benefit for control of mealybug which can be difficult to target with conventional insecticides. It also has a long residual effect. It is currently registered for suppression of citrus mealybug in citrus and mango: according to information on the manufacturer's website, trial results with Movento against citrus mealybug are variable, and therefore only suppression of this pest is claimed (Bayer CropScience Pty Ltd, n.d.).

Spirotetramat has been found to have good activity against a number of mealybug species in field trials: vine mealybug (*Planococcus ficus*) in grapes (Mansour *et al*, 2010a); *Pseudococcus* spp. and *Planococcus* spp. in grapes (Brück *et al*, 2009); cotton mealybug (*Phenacoccus solani*) in cotton (Kumar *et al*, 2008). Recent glasshouse trials with solenopsis mealybug (*Phenacoccus solenopsis*) found it to have limited efficacy (Miles, 2011), however this may have been due to the fact that only one application was made against a mixed population of adults and immature stages. Trial work at Plant and Food Hawke's Bay has found that spirotetramat is effective for control of mealybug in apple and winegrapes, subject to correct timing of applications (Peter Lo, personal communication, 12 July 2012). Two applications were found to be more effective than a single application.

A small scale trial conducted at Maroochy Research Facility (Queensland) assessed spirotetramat (Movento®), applied as a drench at 6 g product per tree (Bignell *et al*, 2012). Spirotetramat was more effective than the control and a number of neonicotinoid products, with no mealybug recorded on fruit at harvest.

A number of studies have concluded that spirotetramat is soft on many beneficial insects. For example, Schnorbach *et al* (2008) classed spirotetramat as harmless to slightly harmful to the majority of beneficial arthropods assessed, with the exception of ladybird beetles (harmless to moderately harmful dependent on species) and predatory mites (moderately harmful to some species). Mansour *et al* (2011) found it to have little effect on the mealybug parasitoid *Anagyrus* sp. near *pseudococci*.

HAL-funded project PR12000 (Australian sweet persimmon industry development – phase 3) is currently trialling spirotetramat for efficacy against mealybug in persimmon orchards.

5.1.2 Neonicotinoid insecticides

Insecticides in the neonicotinoid group (4A mode of action group) act on the nervous system. A number of insecticides in this group are approved for use in various tree crops in Australia (not including persimmon): clothianidin (e.g. Samuarai®, Sumitomo Chemical), imidacloprid (e.g. Confidor®, Bayer CropScience), thiacloprid (e.g. Calypso®, Bayer CropScience) and thiamethoxam (e.g. Actara®, Syngenta Crop Protection). In addition, acetamiprid is registered for use in cotton (Intruder®, DuPont) and ornamentals (Crown®). Imidacloprid was introduced to the world market by Bayer in 1991 (and to Australia in 1994), followed more recently by second-generation neonicotinoids such as thiamethoxam (Maienfisch *et al*, 2001).

Neonicotinoids are systemic with a long residual activity, mainly against sucking insects but also some chewing species. Clothianidin and imidacloprid are currently registered for control of mealybug species in crops other than persimmon: clothianidin for control of longtailed mealybug in apples, pears and grapes; imidacloprid for control of citrus mealybug and longtailed mealybug in ornamentals. Trials assessing neonicotinoid insecticides for efficacy against mealybugs in various crops have achieved mixed results, with efficacy at least partially dependent on application method.

Daane *et al* (2006) assessed imidacloprid for control of vine mealybug in Californian vineyards. These authors found that application via drip-irrigation provided the greatest control; it was less effective when delivered through a furrow-irrigation system, possibly due to poor uptake of the chemical as a result of a widespread root zone. Efficacy was also affected by soil conditions (e.g. soil type and moisture content, which impact on uptake of the chemical by the plant) and timing of application. Mansour *et al* (2010c) also achieved good, long-term control of vine and citrus mealybug in Tunisian vineyards with imidacloprid applied through drip irrigation. Lo & Walker (2011), found that imidacloprid applied as a soil drench was very effective for control of citrophilous mealybug in grapevine, reducing abundance by over 99% compared with untreated controls. They found that the rate was more important than time of application.

Suresh *et al* (2010), working in cotton, found that foliar applications of imidacloprid and thiamethoxam resulted in 100% mortality of solenopsis mealybug (*P. solenopsis*) after two or three days, respectively. Likewise, Miles (2011) found a single foliar application of acetamiprid or clothanidin had good efficacy against *P. solenopsis* on cotton in glasshouse trials. Karar *et al* (2009) had less success with foliar applications of acetamiprid for control of mango mealybug (*Drosicha mangiferae*) in mango, achieving only a 48% reduction in population.

Castle & Prabhaker (2011) evaluated imidacloprid and thiamethoxam against pink hibiscus mealybug (*Maconellicoccus hirsutus*) on mulberry trees. The insecticides were injected into the root zone of each plant. They found both treatments were able to severely reduce or even eliminate infestations in individual trees. However, results were highly variable, with some infestations failing to respond to treatment.

Trials have also been conducted to assess imidacloprid against mealybug in persimmon in Australia, with mixed results. Applied at bud break it was found to be very effective at rates as low as 4.5 ml Confidor® per litre, however later in the season it was ineffective (Grant Bignell, personal communication, 16 May 2012). A more recent trial assessed imidacloprid (Confidor®, 7.25 ml product per tree), clothianidin (Samurai®, 3 g product per tree) and thiamethoxam (Actara®, 6 g product per tree), each applied as a soil drench (Bignell *et al*, 2012). Mealybug mortality on treated fruit was slightly higher in the Samurai® and Actara® (but not Confidor®) treatments than the control. However, the percentage mealybug infestation compared with the control was not reduced in any of the insecticide treatments.

According to research conducted by the team at Plant and Food Research Hawke's Bay, the timing of application of neonicotinoids can be critical to efficacy (Peter Lo, personal communication, 12 July 2012). They found that autumn applications of imidacloprid gave better control than spring applications due to a lag between application and uptake (Lo & Walker, 2011). They also found that moisture in the soil is important for successful uptake, and that imidacloprid can become bound up in organic content in the soil, adversely affecting efficacy.

In conclusion, neonicotinoids can provide effective control of mealybug, particularly when soil-applied. However, it appears that the method and timing of application is critical to efficacy and further trial work would be required to determine the optimum application in persimmon. Moreover, neonicotinoids are toxic to bees and other pollinators, leading to their use being restricted in many countries. They have detrimental effects on natural enemies such as cryptolaemus and leptomastix (Rocha *et al*, 2011; Cloyd & Dickinson, 2006). Management of neonicotinoid resistance in mealybug and other pest species should also be considered. HAL-funded project PR12000 is currently trialling several neonicotinoids for efficacy against mealybug in persimmon orchards.

5.1.3 Sulfoxaflor

Sulfoxaflor is a new insecticide from Dow AgroSciences. According to information from the manufacturer (Robert Annetts, personal communication, 9 May 2012), registration in Australia is expected in early 2013 under the tradename Transform™. Sulfoxaflor is systemic, with translaminar activity in the plant on a broad range of sap-feeding insects and has extended residual control. It has a unique mode of action (a unique interaction with the nicotinic acetylcholine receptor) and will therefore have a new IRAC classification (4C). It is claimed to have no cross resistance with any other insecticide group. Dow will be registering sulfoxaflor on a broad range of pests and crops, including mealybugs in a wide range of crops.

Sulfoxaflor was assessed against *P. solenopsis* in glasshouse trials (Miles, 2011). A single foliar-applied application resulted in excellent control, similar to methidathion. Control was significantly improved by the addition of an organosilicone additive (Maxx®).

HAL-funded project PR12000 (Australian sweet persimmon industry development – phase 3) is currently trialling sulfoxaflor for efficacy against mealybug in persimmon orchards.

5.1.4 High grade petroleum and paraffinic oils

Petroleum oils are not registered for control of mealybug in persimmon, but are commonly applied during the dormant period for control of scale. Oils have also been shown to be effective against mealybug without harming beneficials, although care must be taken to ensure they do not damage plants. One or two sprays are required depending on pest pressure. In citrus, the recommendation is to spray petroleum oil at 1% and 10,000-14,000 L/ha, with applications made after harvest and before new season fruit start to touch, targeted against the youngest mealybug stages (Smith *et al*, 1997). However these authors also state that petroleum oil sprays alone are not usually able to provide sufficient control of citrophilous mealybug on export fruits. Oils can be used as an adjuvant in combination with other insecticides: a mixture of Supracide® 400 (methidathion) and D-C-Tron® Plus (mineral oil) was found to give excellent control of mealybug on persimmon in Vietnam (Nissen *et al*, 2012).

5.1.5 New chemistries

There are a number of active ingredients with novel modes of action and demonstrated activity against mealybug species, which are not currently registered for use in Australian horticultural crops. Although not available at present, they may be worthy of investigation in the future.

5.1.5.1 Flonicamid

Flonicamid is a new selective systemic insecticide in the pyridinecarboxamide class, discovered by ISK (Ishihara Sangyo Kaisha Ltd). According to information on the manufacturer's website (Ishihara Sangyo Kaisha, Ltd, n.d.) it has been in development since the late 1990s but only recently launched onto the market in several countries (Japan, South Korea, Europe, USA, Brazil and Colombia). It is primarily an aphicide but also exhibits moderate insecticidal activity against other sucking insect pests including mealybugs, through foliar or soil application. It works by rapid inhibition of feeding. The manufacturers claim systemic and translaminar activity, long-term control, with cross-resistance to conventional insecticides unlikely. It has been found to be generally harmless to cryptolaemus and leptomastix (Cloyd & Dickinson, 2006).

Current registrations include Aria™ (USA, FMC Corporation), registered for control of mealybugs on ornamentals. Aria™ has been demonstrated to give excellent control of citrus mealybug, long-tailed mealybug and Madeira mealybug (*Phenacoccus madeirensis*) (FMC Corporation, 2005). Beleaf® (USA, FMC Corporation) is currently registered for control of aphids and other pests on a variety of horticultural crops, but is not registered for control of mealybug. An application for approval of flonicamid and registration of ISK Flonicamid 500 WG insecticide has been made to APVMA (Application summary for Application No 53527).

5.1.5.2 Pyrifluquinazon

Pyrifluquinazon is a new insecticide under development by Nichino / Nihon Nohyaku Co Ltd, registered in Japan in 2010 and described in Maienfisch (2007). It is a close analogue of pymetrozine and works by inhibiting feeding. It has activity against a broad spectrum of hemipteran and some thysanopteran pests, with no observed cross-resistance with other insecticides, and is reportedly safe to beneficials. It was launched in Japan as 'Colt' in 2012 (Nihon Nohyaku Co., Ltd, n.d.). A decision on registration in the US is expected by the US EPA in late 2012 (US Environmental Protection Agency, 2012).

Sipcam Pacific Australia Ltd is currently developing pyrifluquinazon (coded NNI 0101) for use in cotton. However, they have not evaluated it for efficacy on mealybugs, and have not done trials in any crops other than cotton. Registration is expected to be some years away (Nic Tydens, Sipcam Pacific Australia Ltd, personal communication, 14 June 2012).

5.1.5.3 Tolfenpyrad

Tolfenpyrad is another new insecticide from Nichino / Nihon Nohyaku Co Ltd, in the pyrazole class. It has activity against a broad spectrum of sucking and lepidopteran pests, including mealybugs (Nonaka, 2003). Tolfenpyrad is currently registered in 13 countries, e.g. as Hachi-Hachi® (SePRO, USA). However, Nihon Nohyaku has no plans to develop it in Australia at present (Masakazu Kawamura, Nihon Nohyaku, personal communication, 18 May 2012).

5.1.6 Carbamates, organophosphates and synthetic pyrethroids

A number of older, broad spectrum insecticides have been shown to have efficacy against mealybugs. These include carbamates (e.g. aldicarb, carbaryl and methomyl), organophosphates (e.g. chlorphyrifos, diazinon, dichlorvos, dimethoate, fenitrothion, maldison, methidathion, omethoate, and trichlorfon) and the synthetic pyrethroid bifenthrin (Baker & Keller, 2000; Franco *et al*, 2004; Learmonth, 2005; Saeed *et al*, 2007; Suresh *et al*, 2010; Ahmad *et al*, 2011; Nissen *et al*, 2012). However, many of these are currently under APVMA chemical review and are likely to be subject to restrictions. They are also generally harmful to beneficials and may flare other pests. Use at a reduced rate mixed with oil is potentially less toxic to natural enemies, as demonstrated for chlorpyrifos (Baker & Keller, 2000).

5.1.7 Azadirachtin

Neem oil (azadirachtin) has been shown to have a repellent effect on mealybugs. Mourier (1997) found that neem treated leaves were less attractive to cassava mealybug (*Phenacoccus manihoti*) than untreated leaves, and those nymphs that fed on treated leaves died in their second instar. Three applications to plants in a greenhouse provided good protection. However, phytotoxic effects were observed. Ahmad *et al* (2011) found that neem oil was not particularly effective at reducing large infestations of cotton mealybug, but recommended it for control of low infestations. Neem is currently only registered in Australia for use in ornamentals and potting mix.

5.2 Optimisation of spray application

5.2.1 Coverage

Optimal spray coverage is important to ensure that contact insecticides reach the mealybugs, which are often located in protected sites where they can avoid contact with pesticide sprays. High volume applications made to run-off are essential (Charles, 2005), and spray apparatus should be capable of achieving good spray cover. Smith *et al* (1997) reviewed a number of types of spray equipment and found that the oscillating boom spray was most effective for control of sedentary pests such as mealybug: this type of spray apparatus can give at least 90% coverage of the whole tree. Furthermore, Nissen (2012) noted that the epicuticular wax and lack of stomata on the upper surface of persimmon leaves makes the absorption of chemicals through the leaf surface difficult. Good coverage and spray penetration into the canopy is important to ensure that sprays target the lower surface of the leaves.

Baker & Keller (2000) found that many citrus growers' spray plants were inadequately set up, and highlighted this as a critical weakness in citrus pest management. The authors recommended that an oscillating boom spray must be operated at a pressure of at least 500 psi (at the jets) / 600-700 psi (at the pump) with an oscillation rate of 100-110/min. They also recommended a high volume spray of at least 8 – 10,000 L/ha to fully wet the canopy. These authors trialled a prototype four-head (Hydra) emitting fan sprayer. They found this prototype was able to achieve control equivalent to the oscillating boom using only half the spray volume and amount of active ingredient per unit area. Multi-fan sprayers are now a mainstream product, with high use in crops such as mango and avocados (Geoff Furness, personal communication, 12 October 2012).

Spray coverage can also be improved by some cultural practices which improve spray penetration, such as pruning to open up the canopy. The type of training system can also affect spray penetration into the canopy. For instance it has been reported that good spray penetration is easier to achieve in a vertical (palmette) trellis system compared with a closed V-trellis (Jeremy Noakes, NZ persimmon grower, personal communication, 10 July 2012).

5.2.2 Adjuvants

Adjuvants may be used to enhance performance of insecticides. Miles (2011) evaluated a number of insecticides for activity against solenopsis mealybug and found that the addition of organosilicone adjuvants significantly increased the efficacy of some. Likewise, researchers at Plant and Food Research Hawke's Bay found that organosilicone adjuvants enhance the performance of systemic insecticides, whereas alkylsilicones (oil surfactants) are most effective for use with buprofezin. The adjuvant Boost® (ammonium sulphate), which is used as a buffering agent and to improve water quality, was found to increase efficacy of spirotetramat and neonicotinoid insecticides (Peter Lo, personal communication, 12 July 2012).

Nissen (2012) noted that the epicuticular wax and abundance of hairs present on the upper surface of persimmon leaves makes it particularly difficult to achieve good coverage and penetration to the leaf surface. This author recommended the use of a non-ionic surfactant or sticker.

5.2.3 Timing of applications

Optimal timing of applications is critical to ensure that insecticides achieve maximum impact on the mealybug population. Applications of contact insecticides must be timed to coincide with the most vulnerable stages: exposed and dispersing crawlers, and young stages undergoing moults. Older mealybugs are protected by their waxy coating, and often settle in feeding sites affording protection from sprays. Likewise, the insect growth regulator buprofezin must be targeted against the immature stages.

Mealybug populations may be largely synchronised following the overwintering period, with a spring generation of vulnerable, dispersing crawlers. The number of generations per year and the degree to which they overlap is influenced by temperature. Appropriate timing of insecticide sprays is dependent on an understanding of the life-cycle of the mealybug species, which is in turn dependent on a number of factors including the climatic conditions and phenological cycle of the tree in each growing region. An understanding of mealybug biology, coupled with effective monitoring, is therefore critical in order to time applications appropriately.

Learmonth (2005), assessing insecticide treatments for control of longtailed mealybug in vineyards in WA, found early vine drenches with chlorpyrifos and bifenthrin at pre bud burst to be effective. Furness (1977a) found a two-spray program with applications in August and late November was most effective for longtailed mealybug control in Riverland citrus. These sprays were made to coincide with periods when crawlers were dispersing and the host plant afforded least shelter. However, Baker & Keller (1998) found significant differences in seasonal activity of the citrophilous mealybug in citrus at different sites within the Riverland area, concluding that this pest must be managed on a property by property basis.

Plant and Food Research Hawke's Bay have carried out considerable research to investigate the most effective timing for insecticide application in apples and grapes. During the early season (spring) the mealybug population densities are at their lowest point, following an over-wintering period. Insecticides must be applied before populations become too large, but can be ineffective if applied too soon after the dormant period due to insufficient mealybug activity. Hence there is a very brief window during which optimum control can be achieved: as little as two weeks can make the difference between effective or poor control (Jim Walker, personal communication, 12 July 2012). This team found that foliar applications made later in the season (November/December) were more effective than those made earlier, although late applications are limited by the withholding period (Peter Lo, personal communication, 12 July 2012). However, they also found that autumn applications of soil-applied neonicotinoid insecticides (e.g. imidacloprid) gave better control than spring applications, due to the extra time required for these chemicals to take effect.

Nissen (2012) reviewed the effect of persimmon phenology and physiology on the efficacy of chemical control of mealybug. Applications of systemic chemicals should be timed such that maximum uptake can be achieved by the plant. This occurs when the first leaves mature on new shoots and the first root flush begins, at which point there is an increase in uptake of water and nutrients. This author also recommended that chemical applications before flowering are most effective, especially to coincide with the period when young mealybugs are hatching and moving onto new leaf growth. The spring period is therefore a critical time for application of systemic insecticides.

Environmental factors can also affect the uptake of systemic insecticides by impacting on the movement of xylem and phloem (reviewed by Nissen, 2012). For instance temperature affects photosynthesis, leaf evaporation and rate of water uptake by the roots. Water uptake is also influenced by humidity and soil moisture, hence irrigation is important to ensure plant sap movement and hence uptake of soil applied insecticides.

5.3 Resistance management

Resistance in mealybug to organophosphates has been documented overseas (reviewed by Franco *et al*, 2004; Charles, 2005). In New Zealand, dependence on organophosphate insecticides resulted in high levels of resistance in the obscure mealybug and loss of natural enemies, causing widespread control failures (Jim Walker, personal communication, 12 July 2012). Resistance to buprofezin is of particular concern: there is evidence that this chemical is overused for mealybug control (according to the persimmon strategic agrochemical review process conducted in 2011). However, the limited number of chemical options available to growers makes it difficult to rotate between different insecticide mode of action groups. The availability of additional options would enable a spray program to be developed.

6. Potential control methods: biological control

6.1 Predators and parasitoids

Surveys have found a variety of natural enemies of mealybugs in Australian orchard and vineyard crops (reviewed in section 4.2.2 Natural enemies); an unsurprising finding given that both the long-tailed and citrophilous mealybugs are native to Australia. Moreover, several commercially available beneficials are available for supplementary release. Observation suggests that use of a combination of biological controls (e.g. cryptolaemus, lacewings and leptomastix) can be very successful for control of mealybug in Queensland fruit orchards (Wes Allen, Bugs for Bugs, personal communication, 22 May 2012). In New Zealand pipfruit orchards under organic production, natural enemies are the principal control method for mealybugs. Evidence from overuse of broad spectrum insecticides, resulting in a loss of natural enemies and a concomitant increase in mealybug populations, suggests that natural enemies have a strong suppressive effect on mealybug (John Charles, personal communication, 11 July 2012; Jim Walker, personal communication, 12 July 2012).

Although the predators and parasitoids of mealybug pest species are reasonably well documented, there is insufficient understanding of their ecology and the role they play in pest suppression. The presence of large numbers of a particular natural enemy does not necessarily guarantee that it is an effective biological control agent. For instance, *C. perminutus* was the most commonly occurring parasitoid of citrus mealybug in Mundubbera citrus, yet achieves only very low parasitism levels in the field (Ceballo & Walter, 2005). The typically patchy distribution of mealybug in orchards makes it a difficult pest to study. This partially explains the lack of research into the impact of natural enemies (John Charles, personal communication, 11 July 2012). Baker & Keller (2000) attempted to assess the impact of natural enemies on citrophilous and longtailed mealybugs in citrus using exclusion cages, however failed to show any impact due to very low mealybug populations. Furness (1977a) also failed to demonstrate a significant reduction of mealybug by natural enemies in Riverland citrus. Smith *et al* (1988) used chemical disruption (monthly applications of 0.1% DDT) and physical exclusion to assess the efficacy of natural enemies for control of *P. citri* in Queensland citrus orchards. This trial was carried out prior to the introduction of the leptomastix parasitoid in 1980. The authors found that naturally occurring populations of natural enemies (in particular cryptolaemus and *L. abnormis*) resulted in considerable control of *P. citri*, although not sufficient to produce first grade production fruit. Augmentative releases of cryptolaemus failed to increase the numbers of this predator.

Although it is accepted that an increase in natural enemy activity can result in suppression of mealybug populations, there are few quantitative studies of the impact of the key parasitoids and predators on mealybugs. A better understanding of the interaction between mealybugs and their natural enemies is vital if they are to be used as part of a mealybug management strategy (Charles *et al*, 2010).

6.2 Entomopathogens

The entomopathogenic fungus *Isaria farinosa* (formerly *Paecilomyces farinosus*) is widely distributed, with a relatively wide host range (biology, ecology and use in biocontrol reviewed by Zimmermann, 2008). Demirci *et al* (2011) evaluated *I. farinosa* for efficacy against *P. citri*, applied over a range of inoculum densities and relative humidities and under laboratory conditions. At the highest inoculum concentration (1 x 10^8 conidia ml^{-1}) and 95% relative humidity it caused between 54% and 89% mortality of *P. citri*, dependent on life stage. However, efficacy was greatly reduced as humidity decreased. The related *I. fumosorosea* (formerly *Paecilomyces fumosoroseus*; biology, ecology and use in biocontrol reviewed by Zimmermann, 2008) is produced commercially for use in the USA (Preferal™, SePRO). Label applications include mealybugs on fruit trees.

Panyasiri *et al* (2007) screened a number of entomopathogenic fungi against glasshouse pests, including the mealybug *Pseudococcus cryptus*. The best performing entomopathogen was an isolate of *Metarhizium anisopliae*, which caused 73% mortality of mealybug in laboratory trials. When tested on caged tomato plants (30 – 35°C, 80-85% RH), a dose of 2.35 x 10^6 conidia ml^{-1} resulted in 85% mortality of mealybugs. It should be noted that there was substantial variation between different isolates, with another *M. anisopliae* isolate failing to produce any mortality.

Lemawork *et al* (2011) found that isolates of *M. anisopliae* and *Beauveria bassiana* were highly effective against enset root mealybug (*Cataenococcus ensete*) under laboratory conditions, resulting in up to 100% mortality of adults. Mortality was also high (up to 97% control corrected) in pot trials, however efficacy of all strains was greatly reduced under field conditions (12 – 49% control corrected mortality). Foliar sprays of the commercially available *Verticillium lecanii* or *Beauveria bassiana* are recommended for control of grape mealybug in grapevine in India (Tanwar *et al*, 2007). However, these are only effective during periods of high humidity.

In conclusion, entomopathogenic fungi can cause high mortality in mealybug species in the laboratory. However, although conidia can survive for long periods at low humidity, high humidity is needed for germination, which can result in poor efficacy under field conditions. Applications of entomopathogenic fungi may be effective if they can be timed to coincide with periods of rainfall, which can result in high moisture levels for several days. However, considerable research would be required to develop a viable fungal bio-pesticide for mealybug control in Australian persimmon orchards.

6.3 Techniques to enhance biological control

6.3.1 Reduction of non-selective insecticide use

A number of studies have examined the link between pesticide use, adverse effects on natural enemy populations and mealybug outbreaks. Franco *et al* (2004) stated that the frequent use of non-selective insecticides in citrus orchards, coupled with the lack of efficacy of many of these insecticides against mealybugs, was a likely cause of mealybug outbreaks. These authors reviewed numerous studies where outbreaks of mealybug were linked to a reduction in mealybug natural enemies caused by the routine use of broad spectrum insecticides for other pests. Similarly Furness (1977a) reviewed reports of mealybug outbreaks occurring following the use of organophosphates to control mealybug and other pests such as scale. Charles *et al* (2010), sampling in New Zealand vineyards, reported that a reduction in pesticide use over recent years had resulted in a widespread resurgence in natural enemy populations. In research carried out between 1992 and 1993, Plant and Food Research New Zealand found higher mealybug parasitism levels in unsprayed persimmon orchards (20-44% parasitism, n = 5) than in sprayed orchards (6-7% parasitism, n = 2) (John Charles, personal communication, 11 July 2012). Similarly, in a trial to compare insecticide treatments, the team at Plant and Food Research Hawke's Bay found that the highest mealybug numbers occurred in the chlorpyrifos treatment, and the lowest in the untreated control (Jim Walker, personal communication, 12 July 2012).

Tables of pesticide toxicity to some citrus natural enemies are given in Smith *et al* (1997). Broad spectrum insecticides such as organophosphates, carbamates and pyrethroids are known to be very toxic to cryptolaemus (Bugs for Bugs, n.d. a) and leptomastix (Bugs for Bugs, n.d. b), and neonicotinoids have been shown to be harmful to cryptolaemus and leptomastix (Rocha *et al*, 2011; Cloyd & Dickinson, 2006). New chemistries are often more selective and therefore have less of an impact on natural enemies. However, care should be taken with their use; for instance buprofezin may affect development of immature cryptolaemus.

A recent persimmon grower survey (appendix A) suggested that growers currently rely heavily on broad spectrum insecticides such as chlorpyrifos and methidathion for control of mealybug and other persimmon pests. This is likely to change in the near future as APVMA reviews result in the withdrawal of some of these less selective insecticides. Use of broad spectrum insecticides could also be reduced by ensuring that pesticides are applied only where and when needed (i.e. spot sprays), through the use of improved monitoring techniques and action thresholds. A better understanding of the biology and seasonal movements of mealybugs would also help to predict the optimum times to spray.

6.3.2 Control of ants

The link between ants and honeydew producing pests has been well studied. For instance, James *et al* (1997), working in citrus in New South Wales, found 3-12 times more scale insects on trees containing foraging ants (*Iridomyrmex rufoniger* gp spp) than trees with ants excluded. In a companion study, James *et al* (1999) found that numbers of beneficial arthropods were reduced by as much as 75% when ants were present, particularly during spring and summer, suggesting a link between ants, beneficials and scale infestations. Invasive ant species such as the Argentine ant (*Linepithema humile*) are particularly disruptive. In Californian vineyards the Argentine ant is clearly associated with increased mealybug densities (Daane *et al*, 2007), due to its disruptive effects on natural enemies and other benefits such as removal of honey dew from the mealybug habitat. However, not all natural enemies are affected. Daane *et al* (2007) found that whereas densities of certain parasitoids (e.g. *Leptomastix epona*) were lowered in the presence of Argentine ants, densities of cryptolaemus were higher on ant-tended vines, where there were more mealybugs. It has been suggested that this predator mimics mealybugs to avoid disturbance by ants. James *et al* (1999) found predatory beetles and spiders were the most affected by the presence of *I. rufoniger* gp spp, and parasitoid wasps and lacewings the least.

In Australia, ants in the *I. rufoniger* group are regarded as the most important in limiting efficacy of biological control of honeydew-producing pests in southeast Australian citrus (Stevens *et al*, 2007). The meat ant, *I. purpureus*, is also important but more localised. *Iridomyrmex* species were found to occur in over 80% of samples collected in citrus orchards in New South Wales, Victoria, South Australia and southern Queensland (Smith *et al*, 1997). The introduced species *L. humile* is dominant in the small area of citrus grown in Western Australia (James *et al*, 1997; Madge, 2002): the spread of this aggressive species into citrus in the eastern states is likely to increase the importance of ant induced problems in citrus (Buchanan, 1996). However, generally the ant fauna of citrus groves in Australia has not been well studied (James *et al*, 1997), and little information exists on ants in other orchard crops. Buchanan (1996) noted that the *Iridomyrmex* ant species dominant in citrus in inland areas of eastern Australia are adapted to the hot, dry, minimal ground cover conditions characteristic of these areas. Therefore the ant species important in persimmon orchards may be different and dependent on region. George *et al* (2011) listed the coastal brown ant, *Pheidole megacephala* and the black house ant, *Ochetellus glaber* (formerly *Iridomyrmex glaber*) as the main species affecting persimmon.

Not all ant species are associated with mealybugs. Smith *et al* (1997) stated that, in addition to nuisance species, other ants such as *Tetramorium bicarinatum*, *Pheidole* spp. and *Rhytidoponera* sp are present in citrus but cause minimal or no damage to IPM systems. Greg Baker noted that in the Riverland (South Australia), ants are not generally observed to interfere with mealybug IPM (personal communication, 6 November 2012). Working in citrus in South Africa, Samways *et al* (1982) found that of the 123 species of ants recorded, only 25 were observed in association with honeydew-producing Homoptera, of which two were important widespread pests, directly or indirectly precipitating outbreaks of Homoptera. One species was beneficial due to its predacious activity. This highlights the importance of correctly identifying ants present in the orchard and understanding their potential impact on mealybug populations.

A number of studies have evaluated methods of controlling ants in orchards and vineyards, with a brief review of ant control in citrus given by Franco *et al* (2004). Many studies have concentrated on the use of chemicals, applied either directly to the tree trunks or to barriers placed around the trunks. Physical barriers and directed sprays of chemicals are least disruptive to natural enemies (Mgocheki & Addison, 2009b). According to Smith *et al* (1997), some barrier types can provide at least three years' protection from *Iridomyrmex* spp. James *et al* (1998) found controlled release chlorpyrifos trunk bands successfully excluded ants from citrus tree canopies and remained toxic for 229 weeks, whereas trunk applications of chlorpyrifos or gamma-cyhalothrin emulsion gave very short-lived control. Likewise, Madge (2002) found that trunk bands impregnated with chlorpyrifos reduced ant activity and reduced populations of honeydew-producing pests, but only at sites with high initial levels of ant activity. They were particularly effective against *L. humile*. Stevens *et al* (1995) evaluated proprietary trunk barriers (AntCaps™), with and without the addition of alpha-cypermethrin, as a means of excluding ants from the canopies of young orange trees. Untreated AntCaps™ were ineffective, but those treated with alpha-cypermethrin reduced trunk movements by up to 92%. However, the installation of trunk barriers is labour intensive and they require maintenance to remain effective, e.g. trees must be skirted and weeds kept in check (Stevens *et al*, 2007; Madge, 2002). In order to justify their high establishment costs, trunk treatments must be sufficiently long-lived to provide control for at least four seasons (James *et al*, 1998).

Phillips & Sherk (1991) successfully reduced mealybug infestations in Californian vineyards through control of ants using chlorpyrifos treatments, applied to the vine trunk, its supporting stake, and the surrounding soil. However, Smith *et al* (1997) noted that chlorpyrifos ground sprays often last only a short time, subterranean colonies generally survive and numbers quickly recover, plus spray drift and volatilisation can harm beneficials. Ground sprays of chlorpyrifos and fipronil are used to control ants in custard apple, but are not currently registered for use in persimmon orchards (George *et al*, 2011). However, a permit (PER11614) allows the use of chlorpyrifos as a ground spray for control of ants in close proximity to irrigation sprinklers: ants can cause significant problems during dry periods by blocking sprinklers. Fipronil is particularly effective for control of ants as it has a delayed lethal effect, allowing it to be transferred back to the nest where it can spread to other ants in the colony.

Buchanan (1996) found that a granular bait containing hydramethylnon provided three to six months control of ants in citrus. However, bait preference (carbohydrate or protein) of *I. rufoniger* was found to alter throughout the season. As bait preference also varies according to species, a knowledge of which ant species are dominant in the orchard is necessary in order for baits to be used effectively. Most new ant baits contain fipronil, however there are currently no permits for application of baits containing this chemical in persimmon orchards, nor permits for growers to mix their own baits George *et al* (2011). The longevity of ant baits can be increased by the use of a bait station (water-proof container) to protect the bait from the elements (Robert Nissen, personal communication, 25 October 2012). These stations are reusable and can be moved to different locations within the orchard as ant nests appear.

Other methods of ant control include the use of ant-repellent semiochemicals, applied to tree trunks to disrupt foraging, e.g. farnesol (Shorey *et al*, 1996; Sisk *et al*, 1996; Buchanan, 1996) and methyl eugenol (Buchanan, 1996). Sticky bands can also be applied to trunks as a physical barrier (Madge, 2002; George *et al*, 2011). However, these methods are labour intensive. Charles *et al* (2010) suggested cultivation or other physical means and repellent plant species as potential techniques for ant control. Stevens *et al* (2007) postulated that maintaining ground cover to conserve inter-row vegetation might aid in management of pest ant species in citrus, but failed to achieve reliable suppression using this method. Other cultural controls include ensuring that trees and skirted regularly and weeds kept under control, to reduce access of ants into the tree canopy (Smith *et al*, 1997), as well as physical destruction of ant nests.

Timing of chemical applications for ant control is important. Phillips & Sherk (1991) recommended that chemical treatments for ant control in Californian vineyards should be applied as ants start actively foraging for food in the early spring, before they rebuild colony size. Stevens *et al* (1998) found that ant numbers in New South Wales citrus were positively correlated with temperature, being less active during winter, although relative activity varied according to species. These authors therefore suggested that ant control programs should start in late August to early September. In custard apple, ground sprays of chlorpyrifos are usually applied in December as ants start foraging, and again later in the season if necessary (George *et al*, 2011). Smith *et al* (1997) recommended that in citrus action should be taken to control ants if they are present on 50% or more of shoots examined for scales, mealybugs or other pests. These authors suggested that monitoring should be carried out from September to May in southern areas, and throughout the year in Queensland.

6.3.3 Augmentative releases of natural enemies

A wide range of indigenous and introduced natural enemies are present in Australia with potential for effective suppression of the three pest mealybugs found in persimmon: introducing exotic predators or parasitoids is probably unnecessary, as well as impractical. However, redistribution of existing species may be useful; for instance introductions of the parasitoid *T. brevicornis* have been made successfully in citrus-growing regions of South Australia (Baker & Keller, 1998, 2000).

Inundative releases of mass-reared beneficials such as cryptolaemus and leptomastix have been used in citrus to augment existing populations, as described in Smith *et al* (1997) and reviewed by Franco *et al* (2004). However, despite the availability of these biological controls, there has been little evaluation of their efficacy in persimmon and other orchard crops. Smith *et al* (1988) investigated augmentative releases of leptomastix for control of citrus mealybug in Queensland citrus. They found that although natural populations of this parasitoid reached high levels by early March, it was slow to recover after winter and unable to prevent excessive levels of sooty mould. Augmentative releases in November and December resulted in high population levels of the parasitoid from mid January and good control of the pest. Augmentative releases were also successful in restoring parasitoid populations after methidathion applications. Releases of cryptolaemus, leptomastix and green lacewing have resulted in successful mealybug control in orchard and vineyard crops (Wes Allen, Bugs for Bugs, personal communication, 22 May 2012), and are currently being made in at least one persimmon orchard in southeast Queensland.

6.3.4 Use of behaviour-modifying chemicals to manipulate natural enemy populations

Sex pheromones are emitted by female mealybugs to attract males (described in greater detail in section 9.1 Sex pheromones of mealybug pests of persimmon). These pheromones have been found to act as kairomones, helping parasitoids to find their mealybug hosts. Once isolated and synthesised, mealybug sex pheromones can potentially be used to manipulate natural enemy populations, through recruitment of parasitoids from areas outside the crop and their subsequent retention within the crop. For example, da Silva *et al* (2009) found that female *Anagyrus* spec. nov. near *pseudococci* were attracted to the sex pheromone of *Planococcus ficus*, using it as a kairomonal cue in host selection. In further trials, Mansour *et al* (2010b) and Franco *et al* (2011) demonstrated that the presence of *P. ficus* sex pheromone also increased parasitism of the citrus mealybug by *A.* spec. nov. near *pseudococci*: parasitoids were attracted in greater number and at a faster rate. These authors hypothesised that the sex pheromone acts as an arrestant.

Tabata *et al* (2011) isolated a component of the sex pheromone of the Japanese mealybug (*Pl. kraunhiae*) which was attractive to *Anagyrus sawadai*, an important parasitoid of several pest mealybug species, though not a natural parasitoid of Japanese mealybug. Field tests found that baited traps could attract wasps from a distance, and hence may have potential to recruit the parasitoid. Further work by Teshiba *et al* (2012) found this attractant increased parasitism of *Pl. kraunhiae* by *A. sawadai* and also attracted a second parasitoid, *L. dactylopii*.

Mealybug sex pheromones have been exploited in mating disruption and mass trapping techniques for mealybug (section 9.3 Mating disruption and mass trapping): it is important that the kairomonal responses of parasitoids are taken into consideration in these situations. For instance use of the sex pheromone of *P. ficus* in traps is also likely to result in trapping of its parasitoid, *A.* spec. nov. near *pseudococci*. However, the sex pheromone of *P. citri* does not appear to act as a kairomone: trials have demonstrated that the parasitoids *A.* spec. nov. near *pseudococci* and *Leptomastidea abnormis* exhibited no response to the pheromone, suggesting that it could be used safely in mass trapping (Suma *et al*, 2001; Franco *et al*, 2008; da Silva *et al*, 2009).

It is likely that the kairomonal activity of mealybug sex pheromones will be most useful as an aid in gathering information about mealybug parasitoids, rather than for manipulation of their populations. For instance, in New Zealand the recently introduced mealybug parasitoid *Pseudophycus maculipennis* was found to be attracted to the pheromone of the obscure mealybug. This discovery simplified monitoring to determine the establishment of this parasitoid post introduction (Bell *et al*, 2006). Monitoring of mealybug parasitoids could also aid in the understanding of their biology and phenology relative to the pest species.

Chemical attractants have also been used for recruitment and retention of generalist predators into crops. For instance, methyl salicylate has been shown to increase populations of predatory insects (including lacewings, predatory bugs, ladybirds and hoverflies) in grapes and hops in the USA (James & Price, 2004). ‘PredaLure’ dispensers that emit methyl salicylate are available commercially in Australia.

6.3.5 Habitat manipulation

Manipulation of the environment within and surrounding the orchard can provide a favourable environment for natural enemies through the provision of food sources and protective habitats. Smith *et al* (1997) described cultural control practices to conserve natural enemies such as the use of windbreak trees (e.g. *Eucalyptus torelliana*) and sod culture (cultivation of selected grasses or legumes). They also recommended minimising dust by sealing or watering access roads as this can be hazardous to beneficial insects such as small parasitoid wasps.

Silva *et al* (2010) examined the effect of ground cover vegetation on natural enemies in citrus orchards (Portugal). They found more beneficial arthropods in trees where there was resident vegetation or sowed selected species compared with bare soil. However, these authors noted that negative effects may also occur: for instance the vegetation may provide an over-wintering site for pests; vegetation may negatively affect the crop through competition for resources; beneficials may prefer the cover vegetation to the crop environment. Working in Australia, Bone *et al* (2009) evaluated a range of cover crops in Victorian apple orchards. They found that not only did the cover crops have little impact on natural enemies in the orchard canopy, but some species had a negative impact by increasing russetting and decreasing yield, presumably by competing for moisture or nutrients. Likewise, shelter belts (commonly used in New Zealand persimmon orchards) can act as sources of pests as well as beneficials: willow, poplar and *Leylandi* cypress are known to be high risk species for scale insects (John Charles, personal communication, 11 July 2012). The benefits and disadvantages of cover crops for management of orchard pests have been reviewed by Bugg & Waddington (1994). They concluded that while resident vegetation and seeded cover crops can provide resources for beneficials, the relationships between the type of cover crop, its management, the pests and beneficial species harboured and their movements are complex and require further investigation.

7. Potential control methods: cultural control

7.1 Nutrition and tree health

Healthy plants are better able to withstand pest attack than stressed trees, and provide a better microhabitat for beneficial insects (Smith *et al*, 1997). Trees that suffer from some form of stress appear to be highly susceptible to attack from pests long before symptoms appear (Robert Nissen, personal communication, 25 October 2012). These stresses can be due to a variety of factors, including inadequate nutrition, irrigation or damage to the tree (e.g. root loss to fungal attack; long periods of water-logging or drought). For example, in Ethiopia, Gemu *et al* (2007) found that providing enset (*Ensete ventricosum*) with better nutrition (farmyard manure) led to improved growth and a decreased incidence of enset root mealybug. However, over-fertilisation, leading to excessive levels of nitrogen, can exacerbate pest problems (Smith *et al*, 1997). Williams (1985) suggested that nutritional differences could explain why some plants are infested while neighbouring plants remain free from attack. Hogendorp *et al* (2006) demonstrated that high nitrogen concentrations, in the form of supplemental fertilisers, favoured the development of citrus mealybug, resulting in increased egg loads, larger mature females and shorter development times. Nissen (2012) also noted that mealybugs are particularly attracted to persimmon trees with high nitrogen content.

Stress conditions caused by drought or over-watering can also lead to an increase in soluble amino acids, which favour mealybug infestations (Williams, 1985). Persimmons are more sensitive to water stress than apple, peach or grape (Nissen, 2012). Franco *et al* (2004) noted a link between mealybug outbreaks and physiological changes in citrus plants under water stress or under high levels of nitrogen fertilisation. Calatayud *et al* (2002) demonstrated that water stress in cassava plants favoured the development and reproduction of the cassava mealybug (*Phenacoccus herreni*), speculating that this was most likely due to changes in levels of carbohydrates and amino acids. These authors also found that water stress had a negative impact on parasitism. The provision of suitable growing conditions is therefore important: for instance, mealybug has been associated with citrus groves planted on heavier soils with a lot of tree shading (Kerns *et al*, 2004).

The link between high nitrogen and pests has also been observed by some persimmon growers: biodynamic grower Heinz Gugger believes that achieving the correct balance of mineral nutrients (including boron and silica) can help to prevent mealybug infestations (personal communication, 16 December 2011). This grower also believes that soil health and microbial activity both have a large impact on pest levels.

7.2 Varietal differences

Boavida & Neuenschwander (1995) found that genetic differences between two mango varieties resulted in differences in host plant quality and hence in population densities of mango mealybug (*Rastrococcus invadens*). Female mealybugs on the susceptible tree had a shorter reproductive period and higher fecundity, and immature stages had a better survival rate. The leaf nitrogen content was higher in the more susceptible tree compared with the less susceptible variety. Karar (2010) also found significant differences in populations of mango mealybug (*Drosicha mangiferae*) on different mango cultivars. This author correlated mealybug population with the chemical content of leaf and inflorescence samples from each cultivar: the highest mealybug population occurred on a cultivar with the highest carbohydrate leaf content, while a comparatively resistant cultivar had significantly lower carbohydrate content. Mealybug populations were also positively correlated with the potassium content of the leaves and with the nitrogen content of the inflorescence. Janaki & Suresh (2012) found that total carbohydrate content and sugar content were higher in a mealybug-susceptible variety of brinjal compared with a less susceptible variety.

It has been suggested that the susceptibility of certain citrus varieties to mealybug may be associated with the fast growth of their fruits (Gross & Mendel, 2004 cited in Franco *et al*, 2004). Mealybugs aggregate in plant organs that are strong nutrient sinks, such as the growing shoots and fruits (Franco *et al*, 2004).

Sepal morphology may also have an effect on mealybug populations, both through provision of a suitable habitat for the pest and protection from parasitism. Berlinger & Gol'berg (1978) demonstrated differences in mealybug infestation and parasitism rate between different citrus species: grapefruit were more heavily infested and had a lower parasitism rate compared with orange, lemon and Troyer citrange. These latter species have smaller sepals compared with the large, convex sepals found on grapefruit.

However, Boavida *et al* (1992), sampling mealybug (*R. invadens*) in mango orchards in Benin, found marked differences between trees regardless of variety. It is therefore possible that any small varietal differences would be insignificant in terms of impact on mealybug population in comparison with other variables.

7.3 Alternative hosts for mealybug

A wide range of weed species, ornamental plants and other crops can host mealybugs (Smith *et al*, 1997). These authors listed weed hosts of citrophilous mealybug such as nightshade, three-corner jack, bridal creeper and caltrop. Some sources recommend keeping ground cover in the orchard low, in order to reduce mealybug populations (Charles, 2005). In New Zealand it has been found that flax, passion fruit and grapes all harbour mealybug (John Charles, personal communication, 11 July 2012), as well as other fruit crops such as cherimoya (Jeremy Noakes, personal communication, 10 July 2012). Windbreak trees (shelter belts), which are common in New Zealand persimmon orchards, can also harbour a variety of pests, including mealybug: Charles (2005) recommended planting non-host plants such as *Casuarina* and bamboo.

However, the relationship between mealybugs, the crop and alternative hosts is complex. Baker & Keller (1998) investigated the link between weeds and infestations of citrophilous mealybug in citrus. These authors frequently observed citrophilous mealybug on black-berry nightshade but found no link between the severity of infestation in the orchard and the presence of this weed, suggesting that specific control was not warranted. Alternative hosts may also act as a sink if preferred over the crop. In some organically managed New Zealand vineyards, large mealybug populations observed on inter-row weeds did not appear to cause a problem on the crop (Jim Walker, personal communication, 12 July 2012). Further study is required to better understand the relationship between non-crop vegetation, pest species and beneficial species.

7.4 Other cultural control methods

A number of cultural control methods are currently employed to help manage mealybug, such as pruning to remove overwintering sites and open up the canopy for good spray penetration, and good orchard hygiene to limit spread. Water blasting of trees during the dormant period is used by some growers to help control clearwing moth. This treatment can also significantly reduce mealybug populations, both directly and by removal of overwintering sites. The incorporation of a very dilute oil solution (e.g. D-C-Tron® Plus) could further enhance the efficacy of this management technique (Robert Nissen, personal communication, 30 October 2012). Habitat manipulation (section 6.3.5 Habitat manipulation) can provide an environment favourable to natural enemies. A number of practices have been used for other pest mealybug species, such as hoeing to expose pupating male mango mealybugs (Karar, 2010; Karar *et al*, 2010). Although not directly applicable to the pest species in persimmon, a better understanding of the life-cycle of the species in persimmon orchards might reveal additional potential control techniques.

8. Potential control methods: post harvest disinfestation

8.1 Hot water immersion

Lester *et al* (1995) assessed hot water immersion as a disinfestation treatment for longtailed mealybug in persimmons: immersion for 26.1 minutes at 48°C or 22.1 minutes at 50°C resulted in 99% mortality of mealybugs, including those under the calyx. Immersion at these temperatures and durations did not cause any damage to the persimmons (Lay-Yee *et al*, 1997). According to Allan Woolf (personal communication, 11 July 2012) persimmons are particularly tolerant of high temperatures compared to many other fruits. Gould & McGuire (2000) confirmed that no mealybugs (*P. citri* and *Pseudococcus odermatti*, on limes) were able to survive hot water immersion at 49°C for 20 minutes. Hara & Jacobsen (2005) examined the effects of hot water immersion on different life stages of the pink hibiscus mealybug (*Maconellicoccus hirsutus*), finding that eggs inside ovisacs were the most tolerant. They suggested that 20 minutes at 49°C would be sufficient for controlling mealybugs on longan and lychee, but that longer immersion may be needed for other fruit, such as persimmon, where the calyx affords some protection.

A hot water dip is practiced by some New Zealand persimmon growers. The current recommendation to industry is to dip for 20 minutes at 51°C (Lisa Jamieson, personal communication, 11 July 2012). According to this source, hot water dipping is not only effective for removal of mealybugs and other pests, but also reduces disease and aids in storage of the fruit. Valley View Orchard (Kamo, New Zealand) routinely dips a large proportion of its fruit, primarily as a phytosanitary measure to remove contaminant pests such as spiders and slaters (Lance Walters, personal communication, 10 July 2012). After experimenting with different temperatures and immersion times, they now use 52.5°C for a maximum of 20 minutes. However, they are of the opinion that this treatment is not particularly effective for removal of mealybugs.

8.2 Heat treatment and cold storage

Cowley *et al* (1992) concluded that exposure of longtailed mealybug adults (off fruit) to hot air treatment at 47°C for 15 minutes resulted in 100% mortality, and therefore had potential as an effective postharvest disinfestation technique. Dentener *et al* (1996) investigated hot air treatment for disinfestation of longtailed mealybug on persimmons. They found that exposure to 48-50°C for approximately 4 hours (including a 2 hour warm-up period) resulted in 99% mortality. Further work by Dentener *et al* (1997) found that heat treatment duration could be reduced if followed by a period of cold storage. For instance, 99% mortality was achieved by exposure to 47°C for 2.9 hours (including 2 hour warm-up) followed by 6.8 days at 0°C. However, heat treatment at these temperatures and durations was found to cause browning injury at levels which, although minor, were likely to be commercially unacceptable (Woolf *et al*, 1997).

Cold storage alone may also be effective. Hoy & Whiting (1997) found that storage at 0°C resulted in 99% mortality of 2nd-3rd instar obscure mealybug and adults on apples after approximately 19 days, and complete mortality of all stages after 42 days.

In persimmon, Dentener *et al* (1997) calculated the time required to achieve 99% mortality in a mixed population (nymphs and adults) at less than 21 days at 0°C. New Zealand export protocols based in part on cold storage are currently being negotiated with China for market access of persimmons; similar protocols were recently approved for access to the USA (Lisa Jamieson, personal communication, 11 July 2012). Currently, the New Zealand persimmon industry routinely subjects persimmons to cold storage (-0.8°C for 8 to 10 weeks) in modified atmosphere bags, prior to export (Lisa Jamieson, personal communication, 11 July 2012). Likewise, cold storage is currently used by the New Zealand apple industry as part of its mealybug control strategy: 30 days storage results in 100% mortality (Jim Walker, personal communication, 12 July 2012). However, long-term storage is not currently considered a viable option in Australia as fruit harvested from wetter coastal regions has a short storage life, as little as one week (George *et al*, 2005). Fruit would need to be treated with the ethylene inhibitor 1-MCP to extend storage life (George *et al*, 2011). Cold treatment (14 days at 0°C ± 0.5°C) is an option for postharvest disinfestation of fruit fly in persimmon for interstate access (ICA-07) (George *et al*, 2011). HAL project PR12000 will evaluate cold storage with and without modified atmosphere bags and 1-MCP.

Radiofrequency heating has been proposed as an alternative to conventional heating techniques. Monzon *et al* (2007) found that treatment conditions identified as effective for control of Mexican fruit fly had no commercially significant effect on persimmon fruit quality. However, this method would require a large investment and is therefore not feasible for a relatively small industry such as persimmon (Lisa Jamieson, personal communication, 11 July 2012). Another alternative is vapour heat: Follett (2004) found a treatment time of 45 minutes at 47°C or 10 minutes at 49°C was required to kill all *M. hirsutus* using a vapour heat treatment chamber.

8.3 Metabolic stress disinfection and disinfestation (MSDD)

MSDD utilises a combination of physical (decompression and compression) and chemical (e.g. ethanol) processes to disinfect and disinfest fruit (Lagunas-Solar *et al*, 2006). Zulhendri *et al* (2012b) found a 90 minute MSDD treatment with ethanol at 371 mgL^{-1} was effective against all stages of longtailed mealybug, with little effect on the fruit (avocado). These authors found that both the physical and chemical phases were required, but that only slight changes in pressure were necessary (10% of normal atmospheric pressure), concluding that this could reduce equipment costs. However, further work by Zulhendri *et al* (2012a) found that MSDD treatment had an adverse effect on kiwifruit, although they concluded it could potentially be used for apples.

8.4 Irradiation

Jacobsen & Hara (2003) determined that the minimum dose required to ensure complete control of pink hibiscus mealybug (*M. hirsutus*) was between 100 and 250 Gy. Similarly, The *et al* (2012) found that a dose between 200 and 250 Gy could prevent reproduction of the mealybug *Dysmicoccus neobrevipes*, and 150–250 Gy was the optimum dose for sterilisation of *P. minor* (Ravuiwasa *et al*, 2009). However, although irradiation can be successful in preventing insects from reproducing, it does not kill the pest immediately; hence live insects will still be present on fruit destined for export. Irradiation has been approved for persimmon by Food Standards Australia

New Zealand (FSANZ). ICA-55 specifies a minimum absorbed dose of 150 gray (Gy) for fruit fly, 300 Gy for mango seed weevil and 400 Gy for all arthropod pests (excluding Lepidoptera that pupate internally). Hallman (2012) has suggested that a dose of 250 Gy may suffice as a generic treatment for a number of key insect groups, including mealybug.

8.5 Modified or controlled atmosphere

Modified or controlled atmosphere techniques can be used to regulate the levels of atmospheric gases such as oxygen, carbon dioxide and nitrogen. Controlled atmosphere techniques result in predetermined gas levels which remain stable over time, whereas techniques to modify the atmosphere result in a change in gas levels over time, which are not precisely controlled. Methods include oxygen absorbing sachets, direct injection of gases into a package and evacuating air from a package. Persimmons are able to withstand low oxygen atmospheres (Lisa Jamieson, personal communication, 11 July 2012).

Dentener *et al* (1992) investigated controlled atmosphere and modified atmosphere with and without cold storage for control of longtailed mealybug on persimmon. Modified atmospheres were produced by enclosing fruit in a polymeric film bag either with an oxygen scrubber or without; in the latter case, case oxygen removal was a result of metabolic activity of the fruit. Only 0.2% of mealybugs were able to survive a 7 day exposure to a controlled atmosphere of 0.5% oxygen, 5.3% carbon dioxide at 20°C. Survival under a modified atmosphere (reduced oxygen) was only effective when combined with a period of cold storage, resulting in up to 100% mortality. The authors noted that further trials would be required to investigate effects on persimmon shelf life. However, recent work found that the addition of a low oxygen treatment was little or no more effective than cold storage alone (Lisa Jamieson, personal communication, 11 July 2012; Jim Walker, personal communication, 12 July 2012).

Liu *et al* (2010) found that an ultralow oxygen treatment (30 ppm oxygen) resulted in 100% mortality of all life stages of vine mealybug (*P. ficus*) on dormant grape benchgrafts after 3 or 4 days at 25°C or 15°C, respectively. Whiting & Hoy (1997) found a combination of low oxygen and high temperature to be effective against obscure mealybug on apples. At 0.4% oxygen and 45°C, the mean time to achieve 99% mortality was 4.9 hours.

8.6 Fumigants and volatiles

Hollingsworth & Armstrong (2005) examined ozone fumigation for control of longtailed mealybugs on ornamental plants. They found that high concentrations of ozone could be effective, with efficacy enhanced by higher temperature, lower oxygen and longer exposure. For example, exposure to 100 ppm ozone for 120 minutes, combined with a temperature of 37.8°C and a pure carbon dioxide atmosphere, resulted in 96.7% mortality of mealybugs (nymphs and adults). If the ozone level was raised to 400 ppm the treatment time could be dropped to 60 minutes. Likewise, higher temperature increased treatment efficacy. However, exposure to ozone caused damage to the ornamental plants. The authors suggest that many types of fruit might be more tolerant, particularly if protected by a commercial wax covering.

Ethyl formate is a fumigant that that has been used for many years on dried fruit (Annis, 2002). A naturally occurring plant volatile, it is available in Australia as Vapormate™. Simpson *et al* (2007) evaluated ethyl formate for efficacy against grape mealybug (*Pseudococcus maritimus*) on table grapes. Eggs were the least susceptible stage, with an LC_{99} of 4.85% ethyl formate (1 hour exposure period). Elevated carbon dioxide (10%) improved efficacy (LC_{99} 3.48%). The authors also found that table grapes generally tolerated treatment with ethyl formate up to 5%, although they noted that tolerance varies with commodity.

Hammond *et al* (2000) assessed various volatile aldehydes, applied under reduced pressure, as postharvest insecticides against aphids. Three were particularly effective, resulting in 100% mortality of aphids with no or acceptable levels of toxicity to a variety of fruit and vegetable commodities: propanal, (*E*)-2-pentenal and 2-methyl-(*E*)-2-butenal. The authors noted that preliminary assays indicated efficacy against other pests including mealybugs at similar doses, although these results were not presented.

Liu (2011a & b) investigated the use of phosphine fumigation under high oxygen levels for postharvest pest control. Phosphine has been used as an alternative to methyl bromide for postharvest pest control, but it is very slow acting. Carrying out fumigation under super-atmospheric oxygen levels was found to significantly increase efficacy. Low temperature phosphine fumigation has also been proposed for use in persimmon, but was deemed impractical (Lisa Jamieson, personal communication, 11 July 2012). Fumigation with methyl bromide is a current fruit fly disinfestation option for persimmons for interstate access (ICA-04) (George *et al*, 2011).

8.7 High pressure washing

Whiting *et al* (1998) examined the use of high-pressure apple washer treatments (500 and 800 psi at 2.0 rods/s) for removal of mealybug on apples, compared to standard packhouse processing. The addition of the high-pressure treatment significantly reduced the number of mealybugs, with both pressures proving equally effective. This system was since modified and developed for commercial use (Whiting & Jamieson, 1999), and is now in widespread use by the New Zealand apple industry (Jim Walker, personal communication, 12 July 2012).

Hansen *et al* (2006) evaluated a combination of elements in a washing system for elimination of mealybug and other surface pests from pome fruit. They found that mechanical methods (pressurised sprays and rotating brushes) removed a significant proportion of mealybugs and other surface pests, including from beneath the calyx. The addition of an organosilicone surfactant (Silwet) or a silicone defoamer aided removal. A higher temperature (40 or 50°C) was no more effective than lower temperatures (10 or 27°C); rotating brushes with soft and hard bristles were equally effective; a spray pressure of 420 kPa was effective and did not injure the fruit.

8.8 Oils and surfactants

Cunningham *et al* (2011) evaluated Prospect®, a paraffinic oil from Caltex, as a postharvest dip for control of citrophilous mealybug in citrus. A 3% solution controlled a large proportion of mealybug although some were able to survive under the calyx, especially at high initial infestations. The authors recommended Prospect® as a stand-alone treatment provided that fruit have low initial numbers of mealybug, or as a combined treatment with high-pressure washers. This product has a registration for postharvest use in crops other than persimmon (citrus, rambutan, lychee). Gould & McGuire (2000) assessed two petroleum-based oils (Ampol, Caltex; Sunspray Ultra-Fine Spray Oil, Sunoco), a vegetable oil (Natural Organic oil, Custom Chemicides) and a soap (Mpede, Mycogen) each applied as a 3% dip, for control of mealybugs on limes. Only one treatment (Ampol) produced high mortality of the mealybugs (94%), although all treatments significantly reduced the number of live and dead mealybugs on the fruit. Organosilicone surfactants may also be used in combination with a pesticide dip or drench (Lisa Jamieson, personal communication, 11 July 2012).

9. Potential control methods: sex pheromones as management tools

9.1 Sex pheromones of mealybug pests of persimmon

Female mealybugs emit sex pheromones to attract males (Williams, 1985). A short review of work on mealybug sex pheromones up until the early 1980s is given by this author. Sex pheromones have the potential to be used as management tools in a number of ways: monitoring populations by trapping males; mating disruption; mass trapping; lure and kill; manipulation of natural enemy populations. The latter is discussed in detail in section 6.3.4 Use of behaviour-modifying chemicals to manipulate natural enemy populations.

The sex pheromones of the three mealybug pests of persimmon have been isolated and synthesised:

The sex pheromone of the citrus mealybug was identified and synthesised by Bierl-Leonhardt *et al* (1981), and the response behaviour of males described by Moreno *et al* (1984). The method of synthesis has since been refined to develop a cheaper and more practical method based on commercially available starting materials (Dunkelblum *et al*, 2002; Zada *et al*, 2004; Kukovinets *et al*, 2006). A homolog, which is cheaper to synthesise than the pheromone, has also been found to have strong activity (Suma *et al*, 2001; Dunkelblum *et al*, 2002). Work by Zada *et al* (2004) was carried out to determine the optimum release rate, dispenser type, loading and trap type. Lures are now available commercially for monitoring purposes (e.g. InSense Pty Ltd, Victoria), however the pheromone is not yet available in the large quantities required for mating disruption (Franco *et al*, 2009) and is not widely used in pest management (Waterworth *et al*, 2011a).

The sex pheromones of the longtailed and citrophilous mealybugs have only recently been identified and synthesised; that of the longtailed mealybug by Millar *et al* (2009) and Zou & Millar (2009), with an improved method of synthesis described by Zou & Millar (2010). More recently, a further improved synthesis derived from a readily available compound and with fewer production steps was described by Bakonyi (2012). However, at present the pheromone is not currently available in economically viable quantities (Waterworth *et al*, 2011b). The synthetic pheromone has proven to be less effective in New Zealand than in California, where it was developed: there is speculation that the longtailed mealybug is part of a species complex, with differences between populations in New Zealand (and hence most likely also Australia) and those in the USA (Vaughn Bell, personal communication, 13 July 2012).

The sex pheromone of the citrophilous mealybug was identified and synthesised by El-Sayed *et al* (2010). Unelius *et al* (2011) determined that traps baited with a mixture of stereoisomers resulted in a similar trap catch to the pure isomer, meaning that a relatively cheap precursor could be used for synthesis, in place of the more expensive, enantiomerically pure precursor. The synthetic pheromone of the citrophilous mealybug is currently being commercialised and patented by Plant and Food New Zealand (Vaughn Bell, personal communication, 13 July 2012).

9.2 Sex pheromones as monitoring tools

Effective, efficient monitoring is the basis of successful IPM, and this has proven to be the most promising application of mealybug sex pheromones to date. Current monitoring relies on visual inspections of trees, which is time consuming and inaccurate. Mealybugs can be difficult to spot early in the season, before fruit develop. Pheromone based trapping provides a much less laborious method of monitoring. It is also highly sensitive, enabling controls to be applied before infestations reach unmanageable levels. Sex pheromones have also proven to be valuable tools for gathering information about the phenology of the mealybugs and their parasitoids.

Pheromone based monitoring systems have been developed for a number of mealybug species, such as the vine mealybug, *P. ficus* (Millar *et al*, 2002; Walton *et al*, 2004). The pheromone of this species is now commonly used for monitoring purposes in US vineyards, with lures commercially available from a number of suppliers (Smith, 2012). The obscure mealybug sex pheromone has been found to be an effective monitoring tool for this species in South African pome fruit orchards (Mudavanhu *et al*, 2011), and in New Zealand orchards and vineyards (Vaughn Bell, personal communication, 13 July 2012). Trap catches of both these species were found to correlate well with mealybug densities and economic damage.

Sex pheromones of citrus, longtailed and citrophilous mealybug have all been investigated for monitoring purposes. Those of the longtailed and citrophilous mealybugs are being developed as monitoring tools for use in New Zealand apple orchards by Plant and Food Research. Trials have been performed to establish the distance over which traps are effective, and hence appropriate trap spacings. Work is ongoing to establish treatment thresholds for winegrapes based on trap catches (Vaughn Bell, personal communication, 13 July 2012). The team has determined that the citrophilous mealybug exhibits a dose response up to 10 mg (the highest dose tested), and that a dose of 1 mg is effective for an extended period of time. However, as the release rate of the pheromone is temperature dependant, the dose rate would require adjustment for use in different climates.

Waterworth *et al* (2011a) assessed the sex pheromones of longtailed, citrus and obscure mealybug as lures in ornamental plant nurseries, demonstrating a strong correlation between mealybug densities and trap catches. They also found that males were relatively insensitive to dose, responding to small doses (as little as 3.2 µg for *P. longispinus*), with trap catch levelling off above a threshold concentration and little evidence of any inhibitory effect at higher doses. Lures remained effective for up to 12 weeks. They also investigated the use of a mixture of pheromones in a single lure. Although the response of *P. longispinus* was slightly decreased by the presence of *P. citri* pheromone, the authors concluded that a combination lure would still be effective. This would be of advantage in areas where more than one mealybug species was present.

Pheromone based monitoring is reliant on a correlation between trap catches of males and the damage caused by infestations of females and nymphs. There are occasions when this correlation may be compromised, which must be taken into account when making management decisions (Waterworth *et al*, 2011a): for instance, males are more susceptible to insecticides, particularly insect growth regulators; hence these treatments may appear to be more effective than they actually are. Also, females remaining unmated for long periods tend to produce more males, resulting in a male bias in the population. Therefore to obtain an accurate assessment of mealybug populations, pheromone trapping should ideally be used in combination with conventional sampling methods (Daane *et al*, 2012).

9.3 Mating disruption and mass trapping

Some aspects of mealybug biology suggest that these pests should be susceptible to management through mating disruption or mass trapping. For instance, studies on the reproductive biology of the citrus, longtailed and citrophilous mealybug have demonstrated that females must mate in order to produce viable offspring (da Silva *et al*, 2010; Waterworth *et al*, 2011b). This means that eliminating large numbers of males should bring about a reduction in population, as unmated females would not be able to reproduce parthenogenetically. Also, as females are sessile, they are not able to move into treated areas. It has also been suggested that as males are non-feeding, any increased activity through exposure to synthetic pheromone should theoretically result in a rapid reduction in males through exhaustion of their limited energy reserves (Millar *et al*, 2005). However, laboratory experiments found no effect of pheromone on the maturation or longevity of the males (Waterworth *et al*, 2011b).

Other aspects of mealybug biology are disadvantageous to the use of mass trapping or mating disruption as a control technique. For instance, longtailed mealybug males can mate numerous times, and therefore the presence of even a few males could compromise control by mating with all the available females (Waterworth *et al*, 2011b). Furthermore, these authors found that female reproductive output was not increased by multiple copulations, and that unmated females were able to live and potentially reproduce for many weeks, meaning that treatments would need to remain completely effective for long periods of time.

A team at the University of California has been working to develop a pheromone-based mating disruption program for vine mealybug in Californian vineyards (Walton *et al*, 2006). The authors found significantly fewer mealybugs and less damage in a combined mating disruption and insecticide (buprofezin) treatment compared with insecticide alone. However, control was less effective when there was a high initial density of the pest. The authors therefore suggested that a combination of control techniques would be most successful. The vine mealybug mating disruption system is now available commercially (CheckMate® VMB-XL, Suterra LLC, Oregon, USA). Likewise, Teshiba *et al* (2009) demonstrated that a synthetic sex pheromone could be used for mating disruption of the Japanese mealybug, *P. kraunhiae* in Japanese persimmon orchards. These authors demonstrated decreased copulation rates, decreased rates of oviposition and a reduction in damaged fruit as a result of the pheromone.

Mass-trapping using the sex pheromone of citrus mealybug has been trialled in citrus orchards in Portugal, Italy and Israel (Franco *et al*, 2003). These authors were able to demonstrate a significant reduction in males as a result of trapping, but this did not significantly reduce the mealybug infestation. It was suggested that males may have been attracted from outside the trial area, and hence that applying the technique in reverse to lure males out of the orchard might be more effective, particularly early in the season when the male population is low. The team at Plant and Food Research Hawke's Bay has been refining the use of mealybug pheromones for use in grapevine. They plan to trial pheromone-based mass trapping for citrophilous mealybug (Vaughn Bell, personal communication, 13 July 2012).

9.4 Conclusions on the use of sex pheromones as management tools

Mealybug sex pheromones have proven potential for use in management strategies, and have been used successfully for control of vine mealybug. Economical, large-scale synthesis is required before mating disruption and mass trapping can be considered viable options for control of the species present in persimmon. The fact that mealybugs are insensitive to stereoisomeric mixtures is of great benefit in this respect as cheaper mixtures of isomers are as effective as the pure compound (Millar *et al*, 2005); however at present the cost is prohibitive. Moreover, the kairomonal responses of parasitoids are a complicating factor: widespread releases of pheromone for mass trapping or mating disruption may also disrupt biological control. The use of sex pheromones for monitoring is more immediately useful as much smaller quantities are required. As mealybugs are generally very sensitive to their pheromones, the traps should remain effective for a long period. Pheromone based traps would provide an accurate and efficient monitoring system, and would also be a useful tool to gather information on mealybug and parasitoid populations.

10. Potential control methods: monitoring

Current guidelines for monitoring mealybug in persimmon are based on recording presence or absence of mealybugs on randomly selected fruit (George *et al*, 2011). Action thresholds are based on the percentage of infested fruit and natural enemy activity. However, this method is not effective for detecting low infestations, or for early detection of mealybugs. An improved monitoring method, based on an understanding of the seasonal dynamics of mealybug populations, is necessary in order to apply insecticides and other controls in a targeted manner.

As discussed in section 9.2 (Sex pheromones as monitoring tools), pheromone trapping can provide a simple and sensitive method for early detection of infestations, and for monitoring changes in mealybug populations throughout the year. As pheromones are species specific, they can be used to confirm which mealybug species are present: this can be important for selection of appropriate management strategies. Pheromone traps can also provide an indication of parasitoid activity due to a kairomonal effect, as discussed in section 6.3.4 (Use of behaviour-modifying chemicals to manipulate natural enemy populations). However, pheromone trapping should be combined with conventional monitoring techniques in order to determine when treatment is required. Walton *et al* (2003) recommended the use of pheromone traps as early warning tools to detect vine mealybug in vineyards: a threshold trap catch then triggers the use of visual monitoring to determine control action. Research would be required before pheromone traps could be usefully deployed in persimmon orchards, in order to understand the relationship between trap catch, infestation and damage levels, and therefore determine action thresholds for treatment.

Mealybug populations are typically spatially aggregated and therefore difficult to estimate through random sampling. Daane *et al* (2012) listed signals of mealybug infestation in vineyards, such as the presence of ants, honeydew and leaf damage. These signals can help direct visual inspections of plants in order to detect highly localised infestations. Kerns *et al* (2004) suggested that monitoring for citrus mealybug in citrus should concentrate on areas where mealybugs are likely to occur, such as shady groves with large trees, locations with a large population of nesting birds, and areas where mealybugs have occurred in previous years. Karar (2010), studying the mango mealybug in mango orchards (Punjab, Pakistan), found more mealybugs on the sunnier south side of the trees, suggesting that this side should be sampled during pest monitoring. Boavida *et al* (1992) found that there were generally more mealybugs (*R. invadens*) on younger compared with older leaves of mango trees, and no differences in spatial distribution between the top and bottom of the trees.

A better understanding of the seasonal movement and distribution of mealybugs on persimmon would also help to target visual inspections. For example, Franco (1992) described the movement of mealybugs on citrus from overwintering sites to young shoots in the spring, and then to developing fruit. Likewise Kerns *et al* (2004) suggested that early season monitoring for overwintering mealybug in citrus should be directed to the trunks and lower branches; as the season progresses, upper branches, twigs and fruit should be inspected. Nissen *et al* (2012), working on persimmon in Vietnam, described the movement of overwintering citrus mealybug from the soil around the trunk base to developing shoots in spring. A similar pattern was observed for citrus and longtailed mealybug in persimmon in south east Queensland (Robert Nissen, personal communication, 27 September 2012). However, the seasonal distribution of mealybug species in Australian persimmon orchards has not been well documented.

Geiger & Daane (2001) compared a number of sampling methods for grape mealybug (*P. maritimus*) in Californian vineyards: sticky tape barriers on canes, excised spur counts, non-destructive spur counts, standard-sized bark sample counts and timed counts. They concluded that timed three or five minute counts resulted in the strongest correlation with absolute counts as determined through destructive sampling. This method employed experienced samplers, familiar with mealybug habits, who were flexible in the locations sampled and relied on cues such as presence of ants and honeydew. The authors also found that midseason counts were better predictors of damage at harvest than early season counts. Although these particular sampling strategies may not translate directly to persimmon orchards, the premise holds that strategies should vary according to the season and should also take advantage of periods when the pest is more easily found. Sticky bands, placed around branches, have also been used successfully to monitor Comstock mealybug (*Pseudococcus comstocki*) on pear trees (Agnello *et al*, 1992).

Martínez-Ferrer *et al* (2006) studied the spatial distribution of citrus mealybug in Spanish citrus groves, in order to make recommendations for sampling plans based on observations of mealybug under the calyx, on fruit and on trunks and main branches. Comparing enumerative and binomial sampling, they found that the latter required a higher sample size to achieve equivalent precision. Likewise Boavida *et al* (1992), examining the spatial distribution of mealybug (*R. invadens*) in mango orchards in Benin, found that binomial sampling required a much larger sample size than enumerative sampling. These authors remarked that both enumerative and binomial sampling plans were only practicable for estimating medium to high mealybug populations.

The direct correlation between temperature and an insect's rate of development (day degrees) can be used to estimate an impending infestation. Walton (2004) and Erasmus (2008) described the use of day degrees to predict vine mealybug infestations in South African vineyards: the vine mealybug requires a minimum of 16.59°C to initiate development, and a total of 235 degree days (days where the temperature rises above 16.59°C) to complete its life-cycle. These authors recommended the use of a combination of monitoring strategies, including day degrees, pheromone trapping, inspections of vines and ant activity as an indicator of mealybug presence.

11. Discussion

The Australian persimmon industry is currently reliant on a limited number of registered insecticides for control of orchard pests. Some non-pesticide alternatives are employed, such as trapping for fruit flies, pheromone-based mating disruption for clearwing moth and releases of beneficial insects. However, control is largely based on application of broad spectrum insecticides. This is not a sustainable approach: overuse of a limited number of non-selective insecticides encourages the development of resistance, impacts on natural enemies, and has been linked to outbreaks of mealybug and other sucking pests. Moreover, there is pressure from regulators and consumers for reduced use and elimination of broad spectrum pesticides: these products are gradually being withdrawn or restricted, further reducing the available control options. Therefore the development of an integrated pest management system for persimmon is imperative. IPM is used very successfully in Australian citrus (Smith *et al*, 1997). Methods for monitoring, use of beneficials and targeted insecticide application have been established and could form the basis for development of an IPM program for persimmon.

Effective monitoring is the basis of IPM. The current system for monitoring mealybug in persimmon is a visual inspection of fruit. This method is time consuming and ineffective. Mealybugs are particularly hard to spot early in the season, when insecticide applications may have the most impact on developing mealybug populations. An effective monitoring system would therefore allow pesticides to be applied in a more targeted manner. Sex pheromones show great promise as monitoring tools, providing early warning of an increase in mealybug numbers. However, only the citrus mealybug pheromone is currently commercially available in Australia. The longtailed mealybug pheromone (available from the USA) would require further research to determine its effectiveness for use against Australian mealybug populations; the citrophilous mealybug pheromone should be available from New Zealand in the near future. For all three pheromones, research would be required to determine the optimum application method (e.g. application rate and dosage) and action thresholds for use in different persimmon growing areas in Australia. In order to accurately monitor mealybug populations, trapping should be combined with other techniques such as targeted visual monitoring, based on a better understanding of the seasonal activity of the pest. The use of day degrees could also be a useful tool to predict incipient infestations.

The development of an effective monitoring strategy based on pheromone lures has a number of additional benefits. For instance it would greatly aid in developing an understanding the phenology of the three pest species, which in turn would allow insecticide applications to be timed more effectively. It would also provide a simple method of confirming the pest species present in different growing regions. Although there is a body of work on the distribution of the three mealybug species throughout Australia, this is not comprehensive and has largely been targeted at citrus growing regions. Exploitation of the kairomonal activity of the mealybug sex pheromones could provide useful information about their parasitoids. Sex pheromones also have potential for use in mating disruption and mass trapping. However as these techniques require large amounts of pheromone, the cost may currently be prohibitive. They may become a more viable option in the future if economical, large-scale methods of synthesis can be developed.

One of the more urgent priorities for the persimmon industry is to expand the chemical control options available for mealybug and other pests by obtaining more insecticide registrations or permits. This would enable growers to rotate between different chemical groups and hence manage insecticide resistance. Priority should be given to the more selective, IPM-compatible products. A reduction in use of broad spectrum insecticides would reduce the impact on natural enemies, allowing them to suppress many secondary pests such as mealybugs. Spirotetramat and sulfloxaflor are either currently registered or close to registration in Australia, have demonstrated efficacy against mealybugs, and are soft on beneficials. The neonicotinoid group should also be considered: although these chemicals can be harmful to beneficials (including pollinators) this is minimised if they are applied as a soil drench. A greater range of soft option pesticides is likely to become available in Australia in the future, although some of these may be several years away.

Exploration of technology and techniques to achieve good spray coverage is vital to maximise the effects of contact insecticides. Multi-head spray machines, as widely used in the mango industry, should be assessed for the potential benefit they may provide for controlling mealybugs in persimmon orchards. Also, adjuvants have been shown to increase the efficacy of certain insecticides. Likewise, a good understanding of the life-cycle, dispersal and population growth of mealybug species in different growing regions is required in order to ensure that insecticides are targeted accurately for maximum efficacy. Tree phenology and physiology also affects the success of chemical control methods.

There are a wide range of commonly-occurring predators and parasitoids of pest mealybug species in Australia. It has been suggested that mealybug outbreaks are associated with a local loss of these natural enemies, and that addressing this imbalance should result in improved pest suppression. This can be achieved in part by reducing the impact of pesticides, as discussed. In addition, the industry requires effective methods of controlling ants, which interfere with biological control of mealybugs and other honeydew-producing pests. Work is already underway to obtain registrations/permits for chemical controls (e.g. baits). Other methods such as use of tree bands and semiochemicals may have potential but have major drawbacks. The most productive avenue for further research is likely to be confirming thresholds and timing of ant control measures to ensure maximum effect on ant suppression with minimal effect on natural enemies. Confirmation of the pest ant species in orchards in different persimmon growing areas would also be useful, particularly considering the potential threat caused by the spread of Argentine ant and other invasive species. Other techniques for augmenting natural enemy populations might be considered, such as inundative releases to supplement existing populations and use of behaviour modifying chemicals and refuges/flowering plants to attract parasitoids. However, these are not considered high priority.

Commercially available biological controls are available for augmentative release. However, there has been little evaluation of their efficacy in persimmon and other orchard crops. An evaluation of release rates and timing of the commercially available biological controls in different growing regions would ensure their effective use. Similarly, a quantitative study of the impact of key natural enemies on mealybug populations would enable growers to better understand when additional control measures are required. Lastly, as several key biological controls are host specific, it is necessary to understand which mealybug species are most prevalent in different persimmon growing regions.

Entomopathogenic fungi can cause high mortality in mealybug species in the laboratory. However, although conidia can survive for long periods at low humidity, high humidity is needed for germination, which can result in poor efficacy under field conditions. More work would be needed for entomopathogenic fungi to be considered a viable option for mealybug control in orchards.

Several cultural or physical control measures are already employed by growers, such as pruning to remove overwintering sites and ensure good spray penetration. Potential cultural controls include optimising nutrition and tree health, exploring varietal differences and investigating the effects of alternative hosts for mealybug. These techniques may warrant further investigation in the long term. Water blasting for control of clearwing moth may also be highly beneficial for reducing mealybug populations, particularly with the incorporation of a dilute oil solution.

A number of post harvest disinfestation techniques for mealybug are used in other cropping systems, some of which may be relatively easily adopted by the persimmon industry. For instance hot water immersion, currently used by the New Zealand persimmon industry, could be adopted with only moderate expense. Likewise cold storage is known to be effective, although further treatment would be needed to extend storage life of fruit from wetter coastal regions. Oils have been shown to be effective as a postharvest dip in citrus, although the potential phytotoxicity of the treatment to persimmon would need to be assessed. Other techniques are available but would probably be prohibitively expensive for the industry to implement.

Finally, extension activities would help to assist adoption by industry of newly developed control strategies, as well as existing control techniques. This could take the form of a best practice guide for IPM in persimmon, or an update to the existing IPDM manual for persimmon (George *et al*, 2011).

12. Recommendations

Control techniques worthy of investigation for control of mealybug, and the future R&D required in order to implement them in Australian persimmon, are prioritised below according to their potential for adoption by the industry.

High priority (short term solutions):

1. Expand the selective chemistry available to persimmon growers for mealybug and other persimmon pest species by generating data which can be used to obtain registrations or permits from APVMA. Insecticides identified for control of mealybug include spirotetramat, sulfoxaflor and neonicotinoids such as clothianidin, imidacloprid, thiacloprid and thiamethoxam. The recently approved, HAL-funded project PR12000 (Australian sweet persimmon industry development – phase 3) is currently trialling spirotetramat, sulfoxaflor, clothianidin, imidacloprid and thiamethoxam.
2. Determine the most effective timing of application of insecticides (linked to points 4 and 5).
3. Trial adjuvants for increased insecticide efficacy, e.g. oil surfactants, organosilicone adjuvants and ammonium sulphate.
4. Develop an effective, efficient monitoring system for mealybugs, based on pheromone lures but incorporating other methods such as targeted visual assessments and use of day degrees to predict increases in population.
5. Monitor mealybug populations in different persimmon growing regions in order to determine the key species in each region and to gain a better understanding of seasonal and regional population dynamics of mealybug in persimmon. This will enable selective insecticide applications to be targeted more effectively. Reference should be made to previous work in other industries to avoid duplication.
6. Obtain registrations for chemical controls for ants (e.g. baits) and investigate timing of ant control measures for maximum efficacy.
7. Investigate post harvest disinfestation techniques such as hot water immersion, cold storage and oils as a postharvest dip. HAL project PR12000 will evaluate cold storage with and without modified atmosphere bags and 1-MCP.

Medium priority (long term solutions):

8. Explore the use of mealybug sex pheromones for mating disruption.
9. Explore the potential of the kairomonal activity of mealybug sex pheromones to provide information about their parasitoids (linked to point 10).
10. Confirm the natural enemies present in the different growing regions and their potential impact on mealybug populations.
11. Evaluate release rates and timing of releases of biological controls (augmentative releases).
12. Ensure targeted and effective application of insecticides through the use of effective spray equipment and good coverage.
13. Investigate the benefits of water blasting, with and without the incorporation of a very dilute oil solution (e.g. D-C-Tron® Plus), for suppression of mealybug.
14. Confirm the pest ant species present in persimmon orchards and determine the potential impact of invasive ant species (Argentine and fire ant) on mealybug.

Low priority:

15. Cultural controls e.g. nutrition, varietal differences and alternative host plants.
16. Other techniques for augmenting natural enemy populations e.g. the use of behaviour modifying chemicals and provision of a favourable environment through the use of refuges or flowering plants.
17. Entomopathogenic fungi for biological control.

Finally, extension activities would assist in the adoption by industry of new and existing control strategies.

13. Technology transfer

- Industry survey of current practices (appendix A). "Mealybug Survey – management options for mealybug in persimmon". Persimmon Press December 2011. This was accompanied by a short article (Research and Development Update, Grant Bignell and Bob Nissen) updating growers on research activities and describing the current project.
- Magazine articles in persimmons Australia (appendix B):
    - "Mealybug in persimmon". Persimmon Press December 2011. A short article describing the three pest species in persimmon, their life cycle and current methods of control.
    - "Mealybug in persimmon". Persimmon Press October 2012. An article summarising the outcomes of meetings with researchers at Plant & Food Research New Zealand, which formed part of the project.
- Outcomes from meetings with researchers at Plant & Food Research New Zealand and preliminary findings from the scoping study were presented to industry by Grant Bignell at the Industry Advisory Meeting (14^{th} September 2012) and Annual General Meeting (15^{th} September 2012), Goomboorian Qld. The presentation was well received by growers and IAC committee members.

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Appendix A Grower survey and results

A survey was circulated to persimmon growers via the industry newsletter 'Persimmon Press' (issue no. 53, December 2011).

Research and Development Update

By Grant Bignell and Bob Nissen Department of Employment, Economic Development and Innovation (DEEDI)
Email- grant.bignell@deedi.qld.gov.au Phone- 07 5453 5947

In September 2011 the persimmon industry advisory committee (IAC) met with researchers at the Maroochy research facility to discuss the findings and direction of the current Australian Sweet Persimmon Industry Development Project. This phase of the project will finish in May 2012 and has made some significant achievements over the past three years that have improved pre and post-harvest management of sweet persimmons in Australia.

A new proposal has been developed in consultation with industry for a third phase of this project which aims to finalise some of the big issues affecting the industry. These issues include long-term post-harvest storage, control of mealybug, clearwing moth and diseases such as phomopsis. This proposal will be submitted in late November and will hopefully be approved and commence in July 2012.

The project research findings from 2011 were outlined in presentations at a field day in September held in Nambour, Queensland at Stephen Jeffers' orchard. Around 20 growers attended these presentations which included results on the use of growth retardants, cincturing, calcium uptake and pest and disease management. There was healthy discussion between growers about research findings and a high level of interest in alternative management strategies. One strategy that received a high level of interest was the use of cincturing to reduce vegetative vigour, particularly in Fuyu. A number of growers are trialling cincturing for the first time this season so it will be very interesting to get feedback on its effectiveness. There has also been some interest in the results from the Sunny® growth retardant trial, however this is experimental use only and is not currently registered for persimmon. If this season's trials prove that Sunny® is effective in reducing tree vigour and increasing fruit size, the IAC will decide if an application for permit/registration will be submitted.

Further investigation into calcium uptake, cincturing, growth retardant, reflective mulch and mealybug will be carried out in the 2011/12 season. We will be trialling different types of netting to evaluate if there are any changes in fruit maturity, quality or size. We will trial bird netting and fruit fly exclusion netting as well as nets with red and blue coloured mesh.

Coloured nets modify the spectrum scattering effect and thermal components of sunlight to potentially induce a favourable response by the tree. Results from these trials will be finalised at the end of the season.

The pest and disease manual for persimmon is currently being developed and will be available in April 2012. We have been surveying growers from the major growing regions of coastal Queensland and New South Wales, Kingaroy/Burnett and South Australia and Victoria. This manual will identify major pests and diseases of these regions and include recommendations on their prevention or control.

Since bud break in September there have been a number of inquiries about diseases in growers' orchards. We have performed disease isolations on new shoots with dieback and flowers/fruit with lesions on the calyx. While none of these diseases have proven to be threatening to the crop it has been very beneficial to identify these fungi to build our knowledge of diseases that affect persimmon. We would like to encourage any growers who have any unusual diseases in their orchard to contact us or send in plant material affected.

We would also like to encourage growers to complete and return the mealybug survey that has been included with the Persimmon Press. A new study has just commenced on management options for mealybug in persimmon and is led by DEEDI Entomologist Lara Senior. This survey will give us an understanding of the impact and significance of mealybug in different growing regions, as well as control measures currently employed and environmental factors that may influence infestations. This survey can also be completed online using the following link: **www.surveymonkey.com/s/VW3FNK8**.

This study also aims to investigate the potential of new pest management technologies for application in persimmon crops.

We wish all growers the best of luck for the upcoming season and welcome enquiries on any issues affecting your persimmons.

8 **Persimmon Press** December 2011

Department of Employment, Economic Development and Innovation

[redacted]

- Farm location (postcode) - ____________________
- Topographic description (e.g. creek flat, hills, etc)

____

- How many persimmon trees do you have (approx)? ____________________
- What tree training system/s is used? ____________________
- Is your block permanently netted? Yes ☐ No ☐
- What is the size/type of netting used? ____________________
- What irrigation system is used? ____________________
- What varieties of persimmon are grown?

  Fuyu ______% Jiro ______% Izu ______ Other ______________%
- Do you send fruit for export? Yes ☐ No ☐
- What other crops are grown on your property? ____________________
- What other vegetation/crops surround the orchard? E.g. other orchards, citrus, native vegetation.

____

- What other pests do you need to control?

  Fruit Fly ☐ Scale ☐ Clearwing Moth (borer) ☐ Thrips ☐ Aphids ☐

  Fruit Spotting Bug ☐ Fruit Piercing Moths ☐ Ants ☐

  Other ____________________
- What chemicals do you use to control weeds? ____________________
- Which is the most dominant weed species on your property? ____________________
- What chemicals do you use to control the following;

  Mealybug ____________________

  Fruit Fly ____________________

  Scale ____________________

  Clearwing Moth (borer) ____________________

  Thrips ____________________

  Aphids ____________________

  Fruit Spotting Bug ____________________

  Fruit Piercing Moths ____________________

  Yellow Peach Moth ____________________

  Ants ____________________

  Other ____________________
- What post-harvest controls are used?

____

Queensland Government

- What other insect pest management techniques do you use?
  Beneficial/predatory insects ☐ Pheromones ☐ Pest monitoring ☐
  IPM ☐ Other ____________________

- How significant is mealybug as a pest in your orchard?
  Major ☐ Occasionally Important ☐ Minor ☐

- What periods of the year do you experience the highest level of mealybug infestation?

  Jan ☐ Feb ☐ Mar ☐ Apr ☐ May ☐ June ☐
  July ☐ Aug ☐ Sept ☐ Oct ☐ Nov ☐ Dec ☐

- Are some years worse than others for mealybug? Yes ☐ No ☐
- If yes please describe conditions that influence larger infestations.

  ____

- If possible could you name the type of mealybug you experience in your orchard?
  ☐ Citrus mealybug *(Planococcus citri)*
  ☐ Longtailed mealybug *(Pseudococcus longispinus)*
  ☐ Citrophilus mealybug *(Pseudococcus calceolariae)*

Thankyou for your time.
Please return survey using one of the following options:

Post
Lara Senior
Gatton Research Station
Locked Bag 7, Mail Service 437
GATTON, Qld. 4343

Fax: 07 5462 3223

Email: lara.senior@deedi.qld.gov.au

Please cut along the dotted line to remove your survey from the newsletter

Grower survey results

Ten surveys were returned, seven of which were from growers in Queensland, and one each from South Australia, Victoria and New South Wales. Findings are summarised below. Results were omitted in those cases where few growers provided an answer to a particular question, or where a mixed response was obtained and therefore no clear conclusion could be drawn.

Orchards

- The number of persimmon trees per property was between 800 and 13,700.
- The variety was predominately either Fuyu or Jiro (fig. 1), the mix varying markedly between properties.

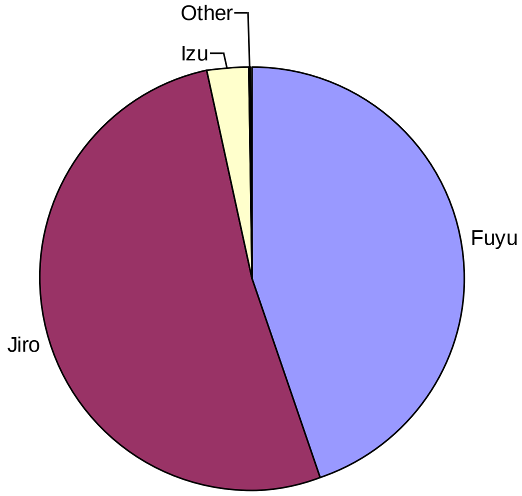

Figure 1. Average percentage of each persimmon variety

- All but one respondent also grew a variety of other types of fruit trees on their property.
- Half of the growers exported fruit.
- Six of the ten respondents had permanent netting in place.
- Irrigation was provided either by sprinkler (6 respondents), drip (3 respondents) or both types of system (1 respondent).
- The majority of orchards were surrounded by native vegetation (7 of the 10 respondents): the remainder were surrounded by other crops such as orchards or vineyards (2 respondents) or by forest and pasture (1 respondent).

Pest management

- Other pests requiring control included thrips, fruit fly, scale, clearwing moth and ants (table 1).

Table 1. Pests other than mealybug requiring control and the number of growers who reported each pest as an issue

Pest	No. growers
Thrips	9
Fruit fly	8
Scale	7
Clearwing moth	7
Ants	7
Fruit spotting bug	3
Fruit piercing moth	3
Aphid	2
Cluster grub	1
Green vegetable grub	1

- A range of predominately broad spectrum insecticides were used to control mealybug, fruit flies and other pests (fig. 3).

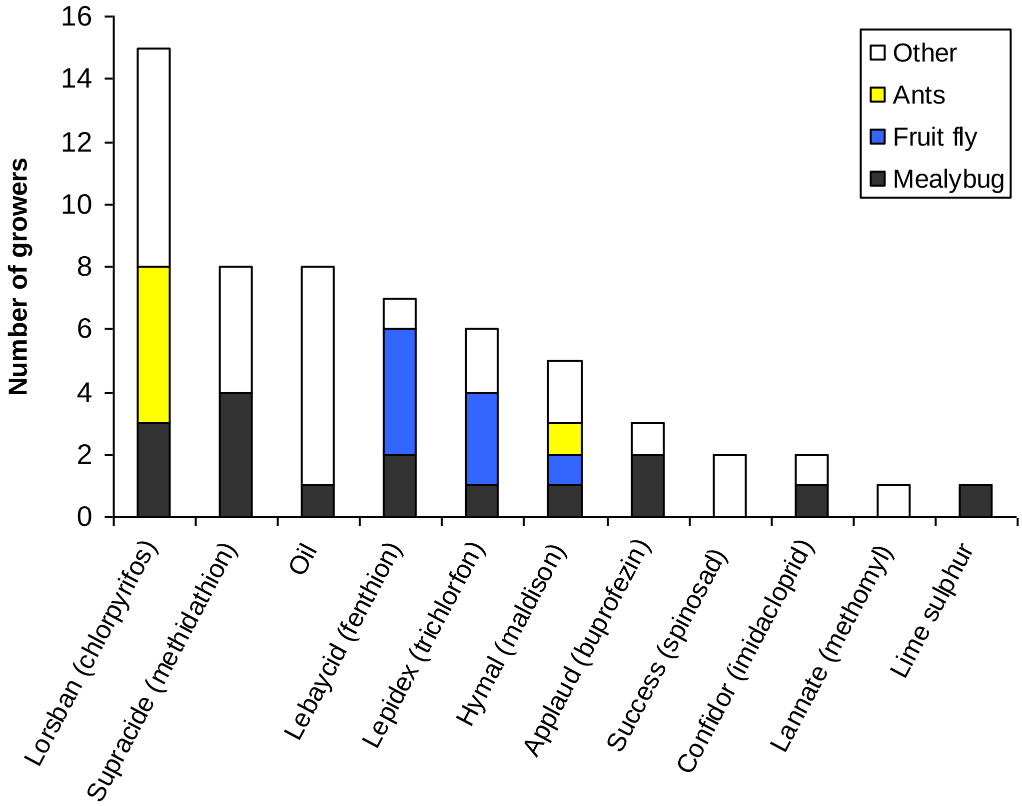

Figure 3. Insecticides applied for control of mealybug, fruit flies and other pests (the majority of insecticides applied for control of fruit flies were in the form of bait sprays)

- Post harvest controls for insects were limited to physical removal (including compressed air to remove insects from beneath the calyx) and fenthion flood spray. However, the majority of respondents (7) did not use any form of post harvest control.
- A variety of non-chemical pest management techniques were employed (fig. 4).

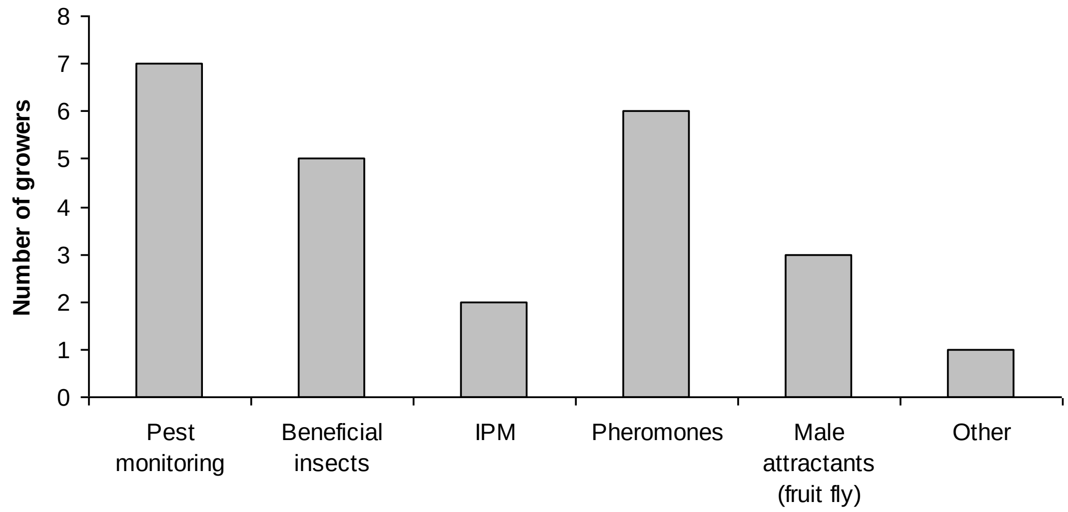

Figure 4. Non-chemical pest management techniques employed by persimmon growers (‘other’ = pruning and water blasting)

Mealybug as a pest

- The majority of growers (5) classed mealybug as a major pest. The remainder classed it as an occasional pest (4 respondents) or a minor pest (1 respondent).
- Growers experienced the highest infestations of mealybug between November and May (fig. 5).

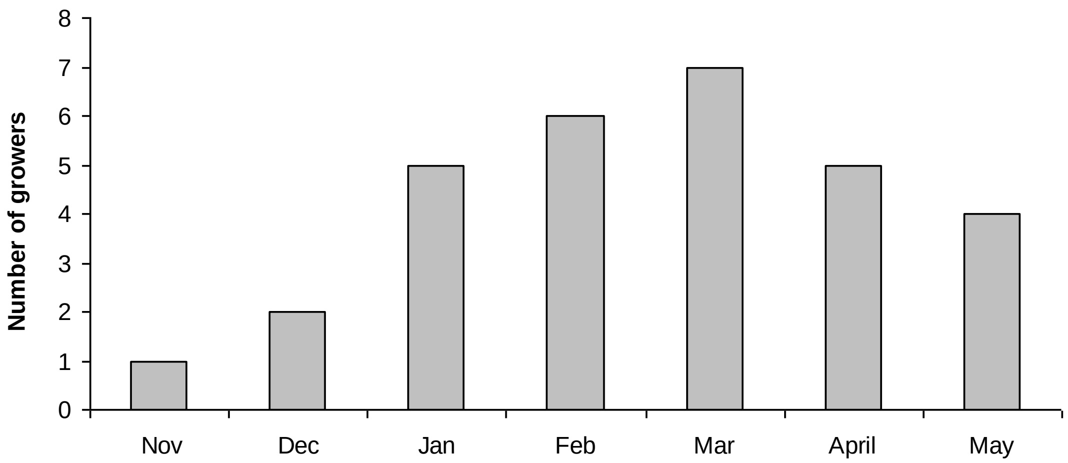

Figure 5. Months when the highest mealybug infestations were experienced

- Seven of the ten growers who responded to the survey stated that mealybug was worse some years than others. Conditions that were thought to influence high mealybug infestations included thick vegetative growth on trees (poor summer pruning), crop load and weather (including high humidity or high rainfall).

Appendix B Persimmon Press articles

'Persimmon Press' issue no. 53, December 2011

of a technological revolution which has forever changed and reshaped our existence, the way we see ourselves, others and the world we live in. It has flattened the globe and made it transparent giving us all the opportunity to see the world from our unique vantage point and to tap into people, places, thinking and products that previously only existed in the realms of science fiction and imagination.

The new way of being and seeing has demanded that we evolve the way we work and has insisted that we maintain a constant eye on the future. We must celebrate what we have already achieved, but stand ready with the knowledge that what we have done and have achieved was perfect in its time, but that tomorrow it may no longer serve us as well.

As I look back on the last two decades and reflect on those businesses that have continued to thrive and grow they all share common characteristics. They are agile, know who and what they are, giving them a strong core which allows them to flex easily as adversity and opportunity finds them and to take profitable advantage of whatever the future may offer.

●●

Mealybug in Persimmon

By Lara Senior, Entomologist, Department of Employment, Economic Development and Innovation (DEEDI)
Email: lara.senior@deedi.qld.gov.au Phone: 07 5466 2250

General
A number of different mealybug species can infest persimmon in Australia. In the southern states and inland, the more important pests are citrophilous mealybug, Pseudococcus calceolariae and longtailed mealybug, Pseudococcus longispinus. These two species can be distinguished by the presence of distinctive long, anal filaments (at least as long as the body) in the longtailed mealybug. In Queensland, the dominant pest species is the citrus mealybug, Plannococcus citri.

Lifecycle
Most species of mealybug have several generations per year, often overlapping so that immature and adult stages are present at the same time. Optimum conditions for development are temperatures of about 25°C, with high relative humidity, so populations often peak in spring and autumn.

Citrophilous and citrus mealybugs produce eggs in an egg sac, whereas in longtailed mealybugs the eggs are laid directly beneath the female's body, often hatching very quickly. Females can produce several hundred eggs in their lifetime. After hatching, the juveniles (termed crawlers) move away to look for a sheltered feeding site. Soon after beginning to feed they develop the distinctive white, waxy/mealy coating that gives them their name. The crawlers moult several times before becoming adult.

Male and female mealybug adults look very different. In the case of males, the last crawler stage pupates in a silk cocoon, emerging as a small, winged adult male. The males are short-lived, their only purpose being to mate with the females. In comparison, adult females change little as they develop, resembling larger versions of the crawlers.

Current control methods
Current insecticide registrations and permits for mealybug in fruit trees (including persimmon) are:
Buprofezin (e.g. Applaud)
Fenthion (e.g. Lebaycid)
Methidathion (e.g. Supracide)
Fatty acids
In addition, oils and pyrethrins, which are registered for use in fruit trees against other pests, may help to control mealybug.

For most effective control, insecticide sprays must be targeted against the younger stages, and good coverage is required. Fenthion and methidathion are toxic to natural enemies.

Good control can be achieved by releasing natural enemies such as the mealybug ladybird (Cryptolaemus montrouzieri) and parasitic wasps (Leptomastix dactylopii and Anagyrus fusciventris). These biological controls are available from a number of companies (see www.goodbugs.org.au for a list of suppliers).

Mealybug in Persimmon

By Lara Senior, Department of Agriculture, Fisheries and Forestry (DAFF) QLD
Email lara.senior@daff.qld.gov.au Phone 0427 600744

A HAL funded project, led by DAFF (QLD) entomologist Lara Senior, is currently underway to review management options for mealybug in persimmon. Mealybug contamination is responsible for losses in persimmon export revenue due to phytosanitary failure, and represents a major hurdle for access to profitable export markets. Management options are currently constrained due to the limited number of registered insecticides. The project aims to review worldwide research into management strategies for mealybug in persimmon and other cropping systems, including: potential new pesticides, methods of optimising spray application, feasibility of biological control, and developing better monitoring techniques. Management strategies will be evaluated in order to identify those techniques with the most potential for practical use in the Australian persimmon industry.

As part of the project, Lara recently met with researchers at Plant & Food Research New Zealand (Auckland and Hawke's Bay). A report on these meetings has been submitted to HAL. Some key findings are summarised below:

Chemical control

- Broad spectrum insecticide use has been almost completely phased out in several crops, including apple: mealybugs are no longer considered an issue in this crop.
- An IPM system has been developed for persimmon (Green and Gold®), however broad spectrum organophosphates and synthetic pyrethroids are still heavily used.
- Trials by Plant & Food Research Hawke's Bay have demonstrated the efficacy of Calypso (thiacloprid), Confidor (imidacloprid) and Movento (spirotetramat) for control of mealybug in grape. A HAL funded project led by Grant Bignell (DAFF QLD) is underway to trial some of these chemicals for mealybug control in Australian persimmons.
- Timing of insecticide application is crucial for effective control.

Monitoring

- Visual monitoring is time consuming and often unreliable. Mealybugs are very difficult to spot early in the season, which is when insecticide applications may be most effective.
- Pheromone traps attract male mealybugs. They are a simple and effective method of monitoring mealybug populations.
- Plant & Food Research NZ also plan to evaluate pheromone traps for mating disruption.
- The citrus mealybug pheromone is commercially available in Australia and is currently being assessed by DAFF (QLD). The longtailed mealybug pheromone is available in the USA, however trials in Australia (Stewart Learmonth, Department of Agriculture and Food WA) and New Zealand (Plant & Food Research) have had mixed success. The citrophilous pheromone is currently being commercialised by Plant & Food NZ.

Post harvest disinfestation

- In New Zealand, exported persimmons are harvested, put into modified atmosphere bags, subjected to cold storage (-0.8°C for 8-10 weeks), then exported via sea freight.
- Some growers use a hot water dip (20 minutes at 51°C). This is primarily for phytosanitary purposes, but is claimed to also kill mealybug.

A grower survey appeared in the December edition of Persimmon Press. **We would like to encourage growers who have not already done so to complete and return this survey, even if not all questions can be answered** – it will give us an understanding of the impact and significance of mealybug in different growing regions, as well as the control measures currently employed and environmental factors that may influence infestations. The survey can be completed as a paper copy and returned via fax/post/ email, or online using the following link: http://www.surveymonkey.com/s/VW3FNK8

If growers have any questions regarding the survey they are very welcome to contact Lara directly on 0427 600744.

Know-how for Horticulture™

Appendix C Unpublished reports produced for related projects

Reports were produced by Robert Nissen as part of related projects on management of mealybug in persimmons:

Nissen, RJ, Khanh, LD, Kai, LQ, Hang, DT (2012) Short report on mealybug on persimmon in Vietnam. Unpublished report produced as part of ACIAR Project AGB 2006/066 "Improving productivity and fruit quality of sweet persimmon in Vietnam and Australia"

Nissen, RJ (2012) Tree phenology and physiology of persimmons with particular reference to the use of chemicals for control of mealybug. Unpublished report produced as part of HAL funded project PR09000, "Australian sweet persimmon industry development – phase 2", Queensland Department of Agriculture, Fisheries and Forestry.

Short report on mealybug on persimmon in Vietnam

By R.J. Nissen[1], Dr Le Duc Khanh[2], Mr Le Quang Kai[2] and Mrs Do Thi Hang[2].

[1]Ag-Hort International Pty. Ltd. 86 – S 26 Nguyen Thong, Phuong 9, Quan 3, Ho Chi Minh, Vietnam.
[2]Plant Protection Research Institute (PPRI) Dong Ngac, Tu Liem, Hanoi, Vietnam.

The main species of mealybug found on persimmon in northern Vietnam was Citrus mealybug, *Planococcus citri* (Risso) (Plate 1 and 2). Due to the scattering of the persimmon production areas across Northern Vietnam this mealybug is wide spread (Table1 and Plate 3).

Plate 1. Citrus mealybug *Planococcus citri* (Risso)
Luc Ngang District, Bac Giang Province, Northern Vietnam.

Plate2. Citrus mealybug *Planococcus citri* (Risso) being attended by an ant on a new persimmon shoot. Location Da Bac District, Hoa Binh Province, Northern Vietnam.

During the winter months in northern Vietnam mealybugs are found sheltering in the top layer of soil at the trunk base (Plate 3 and 4).

Plate 3. Trunk of persimmon tree with mealybug just under the soil surface.

Plate 4. Mealybug attached to a sucker removed from the base of the trunk of a persimmon tree.

When spring arrives they move up onto the new developing shoots, where they settle and feed (Plates 5, 6 and 7).

Plate 5. Circle indicates where citrus mealybug is located on the trunk of a persimmon tree.

Plate 6. Citrus mealybug gathering around a new persimmon shoot.

Plate 7. Circle indicates where Citrus mealybug are at the base of a new persimmon shoot.

Plate 8. Vietnamese cultivar Nhanh Hau severely infested with mealybug.

Fruit are also infested with mealybug causing significant marketing problems due to sooty mould build up and death of calyx when infestation levels are high (Plate 8).

Control measures

When trees were dormant, the trunks were sprayed once using a knapsack sprayer to the point of runoff with a mixture of D-C- Tron Plus ® (Ampol oil) and Suparcide 400 EC ® at the manufactures rates in Vietnam. The following growing season, no mealybugs could be located in the soil near the trunks, on the bark or in crevices, on new shoot or fruit. This mixture provided excellent control and the mealybugs have not returned for three years.

Table 1. Persimmon production areas in Vietnam

No	Provinces	Regions	Concentrated Districts	Persimmon Varieties	Area (ha)	Ref need to include in ref list
1	Lang Son	Northeast of Northern Vietnam	Can Loc, Huu Lung, Chi Lang, Loc Binh, Lang Son	Bao Lam, Thach That, Nhan Hau	2,086.9	Lang Son, 2005
2	Bac Giang	Midland of Northern Vietnam	Luc Ngan	Thach That, Nhan Hau	1,600	Luc Ngan, 2006
3	Ha Giang	North of Northern Vietnam	Quan Ba	Quan Ba	250	Ha Giang, 2006
4	Son La	Northwest of Northern Vietnam	Moc Chau	Thach That, Nhan Hau	200	Moc Chau, 2006
5	Lao Cai	Northwest of Northern Vietnam	Bat Xat, Simacai, Sa Pa, Van Ban	Nhan Hau, Bao Luong	251	Lao Cai, 2005
6	Vinh Phuc	Red River delta	Tam Dao	Thach That, Nhan Hau, Hac Tri	150	Vinh Phuc, 2006
7	Phu Tho	Northwest of Northern Vietnam	Doan Hung, Phu Ninh, Thanh Ba	Thach That, Nhan Hau, Hac Tri, Son Duong	220	Phu Tho, 2006
8	Hoa Binh	Midland of the Northern Vietnam	Da Bac	Yen Thon, Nhan Hau	566.9	Da Bac, 2006
9	Lam Dong	Central highland of Vietnam	Da Lat	Local	700	Lam Dong, 2005
10	Yen Bai	Northwest of Northern Vietnam	Luc Yen	Vinh Lac	100	Yen Bai 2006

(See Figures 1 and 2 above for regions and provinces in Vietnam).

Figure 1. Major persimmon production areas in Vietnam in 2008.

Tree phenology and physiology of persimmons with particular reference to the use of chemicals for control of mealybug.

By R. J. Nissen[1]

[1]Ag-Hort International Pty Ltd., 3 Maheno Court, Tin Can Bay, Queensland Australia, 4580 or 86 - S26 Nguyen Thong, Phuong 9, Quan 3, TP Ho Chi Minh, Vietnam.

The plant growth cycle of persimmon affects the success of various chemicals to control mealybug. Understanding these plant systems is critical to developing and implementing effective control measures. The phenological sequence of development can be specific to a particular cultivar, the environmental conditions in which it is grown, tree condition and management practices. All play a major part in developing a successful integrated pest management (IPM) system for control of mealybug. Described below are some of the physiological, phenological environmental factors to consider.

Plant sap movement effects

Passively mobile chemicals; are chemicals that are transported around the plant in the xylem and phloem tissue by plant liquids. For example, in the xylem tissue, these chemicals are transported along with water and nutrients from the soil to the leaves. Evaporation from the leaves is the driving force behind this movement in the xylem tissue.

In the phloem tissue, chemicals are passively transported along with photosynthate from leaves and storage regions to the actively growing regions of the plant. Mass flow gradients, changes in turgor pressure, due to accumulation of sugars and potassium phosphate occurs in the phloem tissue driving this movement.

These two pathways; in the xylem and phloem tissue, are also connected via parenchyma rays. These rays are located along the entire length of the plant stem enabling exchange and transport of plant sap and chemicals.

Leaf absorption

The absorption of chemicals through leaf surface into the moderately thick lamina of persimmon is difficult. This is due to the epicuticular wax. Persimmon leaves are lustrous and dark green in colour; having an abundance of stomata and one celled hairs on the abaxial surface. The upper surface has very few hairs and stomata if any.

Studies on the leaf nutrient absorption by persimmon; showed higher amounts of phosphorus was absorbed through the aqueous pores on the lower surface, because it contains a large number of stomata (*Hossain and Ryu,* 2009). Therefore, sprays have to target the abaxial surface of the leaf but the abundance of hairs hinders and prevents good coverage and peneteration down to the cuticle surface of the leaf. Furthermore, due to the lustrous epicuticular wax on the upper surface it is also difficult to achieve good coverage of the leaf surface. Therefore the use of a non-ionic surfactant or sticker has to be carefully considered in conjunction with the chemical to obtain good coverage of the leaf surface for maximum absorption.

Phenological sequence

Understanding the phenological sequence is critical for the effective use of chemicals to control mealybug. In subtropical Australia, bud break normally begins in late August to early September.

When bud burst occurs, trunk and cambium development begins and continues for approximately 24 weeks (*Archer and Cameron,* 1939).

Shoot extension growth (vegetative flush) in late spring is rapid and is normally completed within six weeks of bud break. In some regions with favourable conditions and with younger trees, a second vegetative flush may occur in early summer.

Flowering normally occurs about 35 days after bud break. Flowering is usually concentrated, occurring over a 7–10 day period, but under cooler conditions flowering may be more protracted. Flowering dates can differ by one to two weeks between cultivars. Full bloom usually occurs at the cessation of the first vegetative growth flush.

Fruit set occurs from late October to early November. Fruit development is a sigmoid or double sigmoid growth pattern and growth is divided into three phases (stage I, stage II and stage III) and last for 120 to 190 days. Harvesting usually occurs from early to late Autumn and is highly dependent upon cultivar, environment, crop load, plant reserves, and management practices.

Root growth occurs in one or two flushes over the growing season (*Mowat and George*, 1994). Root flushing occurs in late spring and early summer and appears to be influenced by shoot and fruit growth cycles (*Nakamura,* 1935; *George, Collins, and Nissen,* 1992). Peak root growth tends to occur between spring vegetative flush and fruit growth.

Therefore applications of systemic chemicals (Xylem-mobile, Amphimobile, Translaminar) have to be timed when maximum uptake can be achieved by the plant. Once the first leaves start to mature on the new shoots and the first root flush begins, water and nutrients uptake dramatically increases. Systemic chemicals that are soil applied or foliar applied and translocated via the xylem and phloem tissue are best applied at this time, but possible concentrations of chemicals in the fruit at harvest can occur.

The application of fertiliser, especially nitrogen, facilitates vegetative growth and the uptake of water and other nutrients and these are timed at bud break and late December. Flowering normally occurs 35 days after budbreak with fruit set occurring in late October early November. Therefore, chemicals applications before flowering are best, especially when young mealybugs are hatching and moving on to the new leaves.

Environmental conditions

Temperature

Temperature effects on the plant transport system are significant. For example; the optimum leaf temperature for photosynthesis in persimmon is 20°C (*Amano, et al.,* 1972). Persimmon leaves shut down once leaf temperature passes 32°C (*Kobayashi,* 1960). Once leaf evaporation stops, the movement of water, nutrient and chemicals in the xylem ceases. Root temperatures also affect the conversion of starch to sugars and subsequently the rate of water uptake. Root temperatures above 23°C delay plant growth and stop uptake of water and nutrients (*Mowat & George,* 1994).

Drought stress

Drought stress is also another significant factor. The rate of water loss by a plant is influenced by soil moisture, leaf area and environmental conditions (temperatures and humidity). Persimmons have a greater sensitivity to water stress than apple, peach, or grape. The greatest proportions, of persimmon roots, are located in the top 200-300 mm of the surface. Changes in soil moisture at a depth of 100-150 mm affect these roots and have a major influence of water uptake, tree growth and development.

The transportation (evaporation) rate of persimmon is low to moderate compared to other fruit crops, with stomatal conductance falling rapidly with a slight increase in in leaf water potential from 0.2-0.6 MPa (*Mowat & George*, 1994).

Climatic conditions

Climatic conditions in southeast Queensland during spring and early summer are favourable for tree growth and also for mealybug egg laying, hatching and nymph movement. This is due to increasing temperatures during spring and early summer storms rains providing moisture.

Early and late spring is also optimal for plant growth as high summer temperatures (during December) cause vegetative growth to cease. Studies by *Hossaina and Ryub*, 2009, found that persimmon stomata remain shut from 2-10 hours per day due to high temperatures (leaf temperatures >32°c). Leaves shutting their stomata, stops evaporation or leaf transpiration and halts xylem sap movement and water and nutrient uptake.

The incidence of drought stress during spring and early summer is also high and regular irrigation is critical to obtain optimal vegetative growth. Plant sap movement during spring for nutrient uptake is also critical for fruit set and early fruit development.

Mealybug lifecycle

In Southeast Queensland, mealybug populations increase significantly during spring on infected persimmon trees. This is due to increases in temperature, moisture availability, food and sheltered living sites (due increased vegetative growth). During this period, young mealybug nymphs move onto leaves and newly set fruit to feed on and under the calyx. They are particularly attracted to trees that have high nitrogen content. They excrete honeydew on which sooty mould grows, causing fruit to be unmarketable domestically and internationally. Mealybug infested fruit cannot be exported due to the plant quarantine regulations imposed by other countries.

Conclusions

The spring period is when significant sap movement occurs and the effectiveness of systemic chemicals should be trialled. An IPM systems approach (combining several control measures) needs to be developed urgently for this pest of persimmon.

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Appendix D Report on a visit to Plant & Food Research New Zealand

As a component of this project, a trip to New Zealand took place between 9th and 13th July 2012 in order to meet with researchers at Plant and Food Research and with persimmon growers.

Report on a visit to Plant & Food Research New Zealand July 2012

Being Milestone 103 of Project PR11000
(Scoping study: management options for mealybug in persimmon)

Lara Senior
Queensland Department of Agriculture, Fisheries and Forestry

The purpose of this document is to report on the trip associated with HAL project PR11000 in July 2012.

This project has been funded by HAL using the persimmon industry levy and matched funds from the Australian Government.

Date of report 23rd July 2012

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Media summary

Mealybug contamination is a major issue for the persimmon industry, resulting in losses in export revenue due to phytosanitary failure. Management options are currently limited, with very few registered insecticides. Project PR11000 was initiated to review worldwide research into management strategies for mealybug in persimmon and other cropping systems, in order to identify techniques with the most potential for application in Australian persimmons. As a component of this project, meetings were held with researchers at Plant and Food New Zealand, identified as conducting leading research in mealybug management. The objective was to discuss recent advances in mealybug control techniques with potential for application in Australian persimmons. Visits were also made to two New Zealand persimmon growers.

Access to new information regarding management of mealybug in persimmon and related crops was gained as a result of discussions with researchers and growers. Several areas of research were identified as directly applicable to the Australian persimmon industry:

- There is documented evidence that a reduction in broad spectrum chemical use is strongly correlated with an increase in natural enemy populations and a decrease in mealybug populations. Many of the key mealybug natural enemies are common to Australia and New Zealand.
- Efficient and accurate monitoring of mealybug populations using pheromone baited traps is viewed as critical for the successful development of an integrated pest management program for this pest. The citrophilous mealybug sex pheromone is currently being commercialised by Plant and Food Research.
- Several neonicotinyls and spirotetramat have shown good efficacy for control of mealybug. However, timing and coverage are critical for successful control.
- Research on the impact of ants on mealybug populations is ongoing.
- Hot water dips and cold storage treatments are used as phytosanitary treatments.

New professional relationships were developed with researchers at Plant and Food Research New Zealand, as well as links with New Zealand persimmon growers.

Introduction

Mealybug contamination is a major issue for the persimmon industry, contaminating product for export and contributing to post-harvest issues such as shelf life and downgrade due to blemish. Phytosanitary failure due to mealybug infestation results in loss of export revenue. Currently the industry relies on a very limited number of mostly broad spectrum, contact chemical sprays for management of this pest. Project PR11000 was initiated to review worldwide research into management strategies for mealybug in persimmon and other cropping systems, in order to identify techniques with the most potential for application in Australian persimmons.

Plant and Food Research (New Zealand) is recognised as conducting leading research in the area of pest management in summerfruit, including persimmon, and management of mealybug in a variety of crops including winegrapes and pome fruit. Their recent research has included the used of mealybug sex pheromones (for monitoring and mass trapping), insecticidal control (including spray coverage, adjuvants and timing), biocontrol (including natural enemy surveys and the impact of ants on mealybug biocontrol) and postharvest disinfestation techniques. Of the three key mealybug pests in Australian persimmon, two (longtailed and citrophilus mealybug) are important in New Zealand. Furthermore, many of the natural enemies in New Zealand were accidentally imported from Australia. Therefore much of the research is very applicable to Australia.

Two Plant and Food research centres were identified as conducting relevant research: Mt Albert (Auckland) and Hawkes Bay (Havelock North), each with different areas of expertise. Accordingly, meetings were arranged with key researchers at each of these locations. The objective of these meetings was to discuss past research and recent advances in mealybug management techniques, with potential for application in Australian persimmon.

In order to obtain maximum value from the trip, visits were also arranged to persimmon growers within travelling distance of Auckland, with the aim of viewing first hand the pest management practices employed in New Zealand persimmon. Visits were made to two growers, in the Auckland and Northland regions of North Island.

Expected outcomes and how they were achieved

Meetings were held with researchers at Plant and Food Research Mt Albert and Plant and Food Research Hawkes Bay, with the aim of discussing their research in the area of mealybug management. Much of the groups' work is published in the form of confidential reports to industry. However, they were able to share some of their relevant research and key findings. In addition, visits were made to two persimmon growers, with the aim of learning how management techniques had been adopted by industry.

Mealybug management in New Zealand – general information

Mealybug species and their distribution

Three mealybug species are important pests in tree fruit crops (including persimmon) and grapevines in New Zealand: the longtailed mealybug, *Pseudococcus longispinus*, the citrophilous mealybug, *P. calceolariae* and the obscure mealybug, *P. viburni*.

Currently, the longtailed and citrophilous mealybugs are the most prevalent species. Both are found throughout the North Island and the northernmost part of the South Island. The citrophilous mealybug is generally the dominant pest, with a wide distribution, whereas the longtailed mealybug is more localised, preferring a mild, wet climate. The obscure mealybug was an important pest historically, but in recent years organophosphate use has dramatically declined in certain crops (e.g. apple), and in these situations the obscure mealybug has become relatively inconsequential. However, it may still be the dominant pest in crops where pest management is reliant on organophosphates.

The distribution of mealybug species is thought to have implications for biocontrol, as the natural enemy distribution also varies in a similar manner to the pest. However it is unknown whether this is due to host availability, climate or other factors.

The number of generations of mealybug per year is temperature dependant. In New Zealand there are generally two or three.

Management of mealybug

Management of mealybug varies according to crop type:

- Apples: broad spectrum insecticide use has been almost completely phased out. One to two more selective insecticides are applied early in the season to control any overwintering mealybug and scale. Mealybugs are now largely a phytosanitary issue in this crop.
- Kiwi fruit: mealybug is a contaminant pest only, drifting into the crop from surrounding vegetation, such as windbreak (shelter belt) trees.
- Grapes: mealybug is a serious pest in grapes as it vectors leaf roll virus. However, research has largely been focussed on managing the disease rather than the vector, for instance through local eradication by removal of infested vines. There has

been some research to investigate the immigration pattern of mealybug into grapes, and management of mealybug populations in areas outside of the crop.

- Persimmon: management of mealybug and other pests is based on the Green and Gold® IPM Manual. This IPM system was developed between 1995 and 1998, based on life-cycle studies and field trials. However, broad spectrum organophosphate and synthetic pyrethroid insecticides currently form the basis of pest control in persimmons as these insecticides are cheap and viewed as reliable. No work has been carried out on mealybug management in persimmon since the 1990s.

Augmentative or inundative releases of natural enemies for control of mealybug are not made as existing natural enemies are thought to be sufficient for control.

Plant and Food Research Mt Albert (Auckland)

Key personnel

John Charles (Science Leader)
Lisa Jamieson (Scientist)
Allan Woolf (Team Leader)
Graham Walker (Research Entomologist – Team Leader: IPM for Outdoor Vegetables)

Areas of expertise

The Mt Albert team does not have any active work in persimmon. However, much of the historical research is applicable, and their current research in other crops (e.g. apples, kiwi fruit and grapes) is also highly relevant. John Charles and his team have worked extensively on mealybug biocontrol programs, and Lisa Jamieson has expertise in the area of post-harvest disinfestation in persimmon. A brief meeting was also held with Graham Walker to discuss potential collaboration in the area of vegetable IPM.

Outcomes of meetings

1. John Charles - biocontrol

- A variety of natural enemies of mealybug have been documented. The main natural enemies of mealybug in persimmon are: *Coccophagus gurneyi*, *Tetracnemoidea brevicornis*, *T. sydneyensis*, *Anagyrus fusciventris*, *Ophelosia* spp and *Parectromoides varipes*. *Alamella mira* is an important parasitoid of citrophilous mealybug. These parasitoids were probably accidentally introduced to New Zealand from Australia.
- It is assumed that these natural enemies are effective for suppression of mealybug in New Zealand, however there has been little attempt to quantify the impact of the different predators and parasitoids on the pest. Existing information is based largely on observation and supposition. It is not known whether there are additional natural enemies present in Australia which would be more effective than those currently present in New Zealand.
- Generalist predators can be particularly useful for mealybug control as they are able to eradicate a point source: mealybugs generally have a highly patchy distribution.
- The patchy distribution of mealybug means that it is a difficult pest to work with. Design of trials to compare treatments can be problematic. This partially explains the lack of research into the impact of natural enemies on this pest.
- The crop type has a large impact on mealybug and beneficial populations. Mealybug populations are often higher in vineyards (a two dimensional structure) than tree crops (a three dimensional structure), which John believes may be at least partially linked with differing levels of natural enemy activity in these two crop types.

- There is a link between pesticide use and beneficial activity. In research carried out in 1992-93 the team found more mealybugs were parasitised in unsprayed persimmon orchards (20 – 44% parasitism, n = 5) than in sprayed orchards (6 – 7% parasitism, n = 2). Similar results were reported from citrus. (Industry report)
- Wind break trees (shelter belts) can act as sources of pests as well as beneficials. For instance, willow, poplar and *Leylandi* cypress are known to be high risk species for scale insects. However, there has been very little work on the link between shelter belt species, pests and beneficials: most work on shelter belts has concentrated on their agronomic impacts (e.g. impact of their root system on the crop; efficacy as a wind break).
- Likewise, other crops and weeds are known to harbour pests, e.g. kiwifruit harbour scale. The Green and Gold IPM Manual notes that common mealybug hosts are flax, passion fruit and grapes.
- Mealybug development has been found to differ in different crops. Studies found differences in development time, longevity and fecundity when reared on pear, apple and persimmon. (Industry report)

2. Lisa Jamieson and Allan Woolf – post harvest disinfestation

Techniques currently used in persimmon to target mealybug and other pests are:

- Hot water dip: this treatment is used currently although sporadically. According to Lisa Jamieson it is effective (however refer to the comments of persimmon grower Lance Walters). The recommendation is to dip fruit for 20 minutes at 51°C. The hot water drench also reduces disease and aids in storage of the fruit. According to Allan Woolf, persimmons are very tolerant of high temperatures compared to many other fruits.
- Cold storage: protocols for export are currently being negotiated with China for market access; cold storage will form one component. Similar protocols were recently approved for the USA.
- Currently, exported persimmons are harvested, put into modified atmosphere (MA) bags, subjected to cold storage (-0.8°C for 8 – 10 weeks), then exported via sea freight.

Potential treatments highlighted in a report to industry include:

- Low temperature phosphine fumigation: not practical according to Lisa.
- Ethyl formate: available in New Zealand and Australia as Vapormate.
- Anoxia: persimmons can withstand low oxygen.
- Pesticide dip or drench including an organosilicone surfactant.
- Radio-frequency (RF): not practical for persimmon due to the large investment required.
- Irradiation: not feasible in New Zealand, but may be worthy of investigation in Australia.

Recent work with persimmon examined the combination of cold storage with a number of additional treatments such as modified atmosphere bags (low oxygen); however the additional treatments were no more effective than cold storage alone.

Currently there are no plans for further research on post-harvest disinfestation techniques for persimmon.

3. Graham Walker – IPM in vegetables

Graham shared his experiences in developing IPM systems for tomato, brassica and lettuce. In all cases, replicated small plot trials were performed to establish action thresholds, based on numbers of pests and beneficials. Crops were monitored for at least three seasons to establish pest and beneficial activity under the IPM system. Once an IPM system had been established and its efficacy proven, Graham's team provided intensive training to grower representatives.

Graham believes that predators are very important for pest suppression. For instance, lacewings (the brown Tasman lacewing), hoverflies (a native New Zealand species) and coccinellids are key generalist predators in lettuce and other vegetable crops. Spiders are also thought to be important. However, Graham stressed the importance of understanding intraguild predatory behaviour: for instance, coccinellids can have an adverse impact on many other predators.

Plant and Food Research Hawkes Bay

Key personnel

Jim Walker (Team Leader Apple and Winegrape Entomology)
Peter Lo (Senior Scientist)
Vaughn Bell (Scientist)
Lyn Cole (Technician)

Areas of expertise

The Hawkes Bay team has activity in apples and winegrapes. They work with pheromone based monitoring systems for the three key mealybug species (obscure, longtailed and citrophilus mealybug). They have activity in insecticidal control and have worked extensively with spirotetramat and with neonicotinyls as both soil and foliar treatments. They have also worked on spray coverage, timing and adjuvants. They have had some activity in mealybug biocontrol and in particular the impact of ants on mealybugs and natural enemies.

General information

IPM of mealybugs should be based on a good understanding of which species are important in which growing regions, and their phenology in these regions. This should be based on monitoring using sex pheromones, as this method is more efficient and accurate than monitoring pest levels on trees. Similarly, an understanding of the key natural enemies is necessary. This knowledge is a prerequisite to developing an IPM system.

Accurate timing of insecticide applications is critical to successful mealybug management. During the early season (spring) the mealybug population densities are at their lowest point, following their over-wintering period. Furthermore, lack of foliage means that good coverage can be achieved during this time. However, insecticides can be ineffective if applied too soon after the dormant period as there may be insufficient mealybug activity. Hence there is a very brief window during which optimum control can be achieved: as little as two weeks can make the difference between good or poor control.

Good spray coverage is also very important. For instance the team have found a direct link between the density of burr knots (the main mealybug overwintering habitat) and infestation at harvest. High water rates and effective spray equipment are critical.

There is a strong association between the use of organophosphates, natural enemies and mealybug populations. The team have found that when the use of organophosphates is discontinued, mealybug numbers generally show a marked decline, often in the same season. For instance, in a trial which aimed to compare a number of insecticide treatments for mealybug, the lowest numbers were found in the untreated control whereas the chlorpyrifos treatment had the highest numbers. The previous season approximately 40% of plants were infested. The team are therefore of the opinion that mealybugs are an induced pest. Likewise, trials have demonstrated that use of Lorsban can result in high populations of other pests (e.g. leaf hoppers), due to suppression of natural enemies.

Many weed species host mealybugs, however the relationship between mealybugs, the crop and alternative hosts is complex. For example, alternative hosts may act as a source of the pest, but they can also act as a sink if the alternative hosts are preferred. It has been observed that in certain vineyards under organic pest management programs, mealybug do not cause a problem on the crop even when large populations are present on inter-row weeds.

Outcomes of meetings

1. Jim Walker – general overview of mealybug management in apple

Jim provided a general overview of the development of mealybug management in apple:

- In Hawkes Bay, obscure mealybug generally has two generations per year. They overwinter in bark crevices on trees and on other host plants, developing slowly. In New Zealand, overwintering mortality is very high. In October/November eggs hatch and low numbers of crawlers disperse onto foliage. Adults occur from January. Eggs of the second generation are found from February onwards.
- Prior to the availability of pheromones for monitoring, crawler sampling was carried out in spring, through inspections of fruitlets, shoots, burr knots and/or sticky bands on trunks. However, it was found that these inspections were only a reliable indicator of mealybug infestation at harvest at high populations (more than 10% of fruit infested).
- The history of control of the obscure mealybug is linked to use of organophosphates. Parathion resistance was first detected in this species in the late 1970s. In the 1980s new products such as Tokuthion (prothiofos) and Lorsban (chlorpyrifos) first became available, and management programs based on these insecticides plus oil continued into the 1990s. In 1995 Lorsban resistant mealybugs were found to be present at 62% of sampled sites in the Hawke's Bay region; by 1996 there was a control crisis. As a result, softer chemicals were introduced, such as Applaud (buprofezin).
- Currently, control is based almost entirely on selective insecticides, with almost no use of organophosphates, and the obscure mealybug is now no longer an issue in apple.
- Cold storage is part of the mealybug control strategy in apple: 30 days storage results in 100% mortality.
- Spray coverage has been investigated:
    - Burr knots (the main mealybug overwintering habitat) are linked to high infestations at harvest
    - Sprayer technology
    - Adjuvants – oil; organosilicones (water); alkylsilicones (oil). Different types are most effective with different insecticides, e.g. alkylsilicones (oil

surfactants) are most effective with Applaud. Oils can only be applied during dormancy as they are phytotoxic.

- Insecticides and timing of application have been trialled, and the following found to be effective:
    - Applaud (buprofezin)
    - Calypso (thiacloprid)
    - Movento (spirotetramat)
- Until 1998 there was thought to be an additional mealybug species: *P. similans*. However, use of rDNA and work by John Charles proved that *P. calceolariae* and *P. similans* were actually different temperature-dependent forms of the same species.
- Apple washers were developed for market access (2000 onwards). These can result in removal of 91-100% of mealybugs.
- Natural enemies include the brown lacewing (*Micromus tasmaniae*), mealybug destructor ladybird (*Cryptolaemus montrouzieri*), hoverfly (*Melanostoma fasciatum*), dusky lacewing (*Cryptoscenea australiensis*), a predatory midge (*Diadiplosis koebelei*) and the aphelinid parasitoids *Coccophagus gurnei* and *Alamella mira*. The predators have a variable contribution to mealybug control, e.g. *Cryptolaemus* requires high host densities to be effective.
- Predatory mites (Bdellid mites and Anystid/Whirligig mites) are associated with mealybug overwintering in burr knots.
- A new imported parasitoid (*Pseudaphycus maculipennis*) was released for control of obscure mealybug from 2000. It has since been recovered at up to 78% of release sites, but its effectiveness is as yet unknown.

2. Peter Lo – insecticidal control of mealybug

- The current chemical options in grape are:
    - Oils
    - Tokuthion (prothiofos) and other organophosphates (under review)
    - Attack (permethrin and pirimiphos-methyl)
    - Lannate (methomyl)
    - Applaud (buprofezin)
    - Confidor (imidacloprid) – applied (as a drench) to non-bearing vines only due to residue concerns.
- An application of Tokuthion and oil is generally made when the vines are dormant in August (pre leaf/bud break), followed by two applications of buprofezin, made as late as the withholding period will allow, up until flowering (late November). Thereafter the broad spectrum chemicals are the only control options available.
- Movento (spirotetramat) is close to registration for grapes. This chemical has just been registered for apples and has been available for control of scale in kiwi fruit for several years.
- With regard to Confidor, autumn applications give better control than spring applications, as this insecticide takes time to take effect. Moisture in the soil is important for uptake. Likewise, imidacloprid can become bound up in organic matter; hence this is a factor in its efficacy.
- The following insecticides have been trialled for efficacy and timing of application:

    - Applaud (buprofezin)
    - Calypso (thiacloprid)
    - Movento (spirotetramat)
    - Admiral (pyriproxyfen) – not found to be effective
- Applications made later in the season (i.e. December) are better than those made earlier. This is because there is more activity of juveniles later in the season. However, late applications are limited by the withholding period (residues).
- In the case of Movento and Applaud, two applications are more effective than a single application.
- Adjuvants may enhance performance:
    - Boost adjuvant (ammonium sulphate) enhances performance of Movento and the neonicotinoid insecticides, dependent on timing. Two applications of Movento plus Boost in November and/or December result in highly effective control.
    - Organosilicone adjuvants enhance the performance of systemic insecticides, but not contact insecticides.
- Water rates are critical in order to achieve good coverage. However, there has been some resistance from growers who prefer to use low water rates, in order to reduce labour. Although adjuvants can improve insecticide performance, this does not obviate the need for a high water rate.
- Resistance was a problem in the obscure mealybug. Recent sampling from the Nelson area has revealed some tolerance to Lorsban in the longtailed mealybug. However, there is no current resistance monitoring scheme as there are no indications of resistance developing elsewhere at present.

3. Vaughn Bell – sex pheromones / ants

Mealybug sex pheromones

- The Hawkes Bay team has the sex pheromones for the three key mealybug species in New Zealand (citrophilous, longtailed and obscure mealybug). The pheromone of the citrophilous mealybug was identified by Plant & Food scientists (Lincoln) about three years ago, and they are currently involved in commercialising and patenting the synthetic pheromone. The details of the Business Manager dealing with this commercialisation were provided (Dr Claire Hall).
- The pheromone of the longtailed mealybug was developed by Jocelyn Millar (University of California), who made the synthetic pheromone freely available to researchers in New Zealand and also Australia (Stewart Learmonth, Department of Agriculture and Food, WA). However, it has proven to be less effective in New Zealand than in California: there is speculation that the longtailed mealybug is part of a species complex, with difference between the populations in New Zealand (and most likely Australia) and those in the USA, where the pheromone was developed.
- The citrophilous mealybug sex pheromone exhibits a dose response up to 10 mg (the highest dose tested). A dose of 1 mg is frequently used in trials in Hawkes Bay. It is thought that this remains effective for an extended period of time; however the release rate is related to temperature, hence the dose rate would need to be tailored to location of use.

- The team have carried out field trials to establish the distance over which pheromone-baited traps are effective, in order to determine optimum trap spacings.
- They are currently attempting to develop pheromone trap treatment thresholds in winegrapes.
- Work is planned to trial pheromone based mass trapping (lure and kill) for citrophilous mealybug.

Impact of ants on biocontrol of mealybug

- Ants can disturb the biocontrol of mealybug and other pests. Overseas, invasive ant species such as the Argentine ant have been shown to be particularly disruptive to mealybug management. The fire ant (present in Australia) is also thought to be of concern.
- The Argentine ant was first recorded in New Zealand in 1990, and is generally found in urban or disturbed environments. It has rarely been found in horticultural crops in New Zealand and therefore its potential impact on mealybug controls is unknown at present. Research is ongoing.
- Argentine ants can be associated with permanent irrigation.
- Native New Zealand ants do not appear to impact on biocontrol.

4. Lyn Cole – mealybug colonies

Two mealybug colonies are maintained at Hawkes Bay research centre: citrophilous and longtailed. The citrophilous prefers a cooler temperature than the longtailed mealybug. The mealybugs are reared on sprouting seed potatoes.

Grower visits

Visits were made to two persimmon growers in the Auckland and Northland regions of North Island: Jeremy Noakes, Hawkes Nest Orchard and Vineyard (Warkworth) and Lindsay Wells, Valley View Orchard (Kamo).

Both growers rely heavily on insecticides for control of the majority of the insect pests. As the domestic market for persimmon in New Zealand is very small, fruit is primarily grown for export: 80 to 90% in the case of Jeremy; Lindsay aims to export 100%, with fruit which fail to meet the export grade going to the domestic market. Lindsay is also investigating alternatives for the non-export fruit. Both orchards grow Fuyu as the sole variety.

New Zealand growers use a range of windbreak trees, as strong winds are common and damaging. Both growers visited on this trip were concerned that the windbreaks could act as a source of pest insects.

Jeremy Noakes, Hawkes Nest Orchard and Vineyard

Jeremy has been working at the orchard for approximately 20 years, but has recently taken over its management. It is a relatively small operation, comprising approximately 1100 established persimmon trees, 400 recently planted persimmon trees, and various other crops (limes, avocados, wine grapes and cherimoya). Older trees are trained to a closed V-trellis, and new trees to a vertical (palmette) trellis. According to Jeremy, the vertical trellis system produces slightly less fruit; however he has found it easier to achieve good spray penetration.

Mealybug are considered a major pest, along with leafrolling caterpillar and light brown apple moth; all are quarantine pests. Other pests include scale, thrips, green vegetable bug, ants and lemon tree borer (a native beetle). Mynah birds can also be very damaging: a toxic bait has proven effective for their control.

Mealybugs are mainly seen during harvest (April and May). Jeremy does not monitor specifically for mealybug or other pests, however the trees are inspected during summer pruning (January and February). During this time they normally encounter only very low numbers of mealybug. This is also the case for leafroller caterpillars.

Jeremy does not practice IPM, but follows a pest management program developed over many years. The same program is followed every year with some variations:

- An organophosphate with oil is applied at the green tip stage
- Two weeks later two applications of buprofezin are made, before flowering
- Calypso (thiacloprid) is applied at flowering for control of thrips
- Later in the season (around New Year), one application is made of Prodigy (methoxyfenozide) and Proclaim (emamectin benzoate) (short withholding), both for control of leafroller
- Bt may also applied be applied for leafroller control

Applications are made at 2000 L/canopy ha. No post-harvest controls are used. Jeremy has previously tried pheromone traps for the caterpillar pests, but without success, as he was not able to correlate trap catch with damage.

The above system has been in use for some time; however it has recently become much less effective for management of mealybug. Jeremy is concerned that there may be resistance to the insecticides and that the system may not be effective for much longer. He also agreed that it is possible that the use of organophosphates has resulted in low numbers of beneficials (he has not specifically monitored for beneficials). He was interested in trialling other methods of managing mealybug and leafroller.

Jeremy noted that mealybug were much less of a problem in the wine grapes grown at his property compared with the persimmon. The use of organophosphates in the grapes was generally limited to a single application per year: a low level of infestation is tolerated in this crop as mealybugs are not a contamination issue, as they are in persimmon. Jeremy had also observed that there were very few earthworms in the blocks containing the established persimmon, where organophosphate use was high. In comparison, there were many worms in the block where new persimmon trees were recently planted.

Jeremy was planning to remove the lichen and moss which grew heavily on some of the persimmon trees, as he was concerned that this may be sheltering the mealybug. Likewise he thought that certain of the other fruit crops (cherimoya in particular) could be harbouring mealybug. He thought that the recent overcast, cool weather may have contributed to higher than usual mealybug populations, and that thrips were associated with humid weather.

Persimmon at Hawkes Nest Orchard and Vineyard

Lindsay Wells / Lance Walters, Valley View Orchard

Valley View Orchard is managed by Lindsay and Duane Wells. Lindsay Wells has been involved in the New Zealand persimmon industry for many years, only recently retiring as chairman of the Persimmon Industry Council in New Zealand. As such he has been very proactive in developing improvements to production, including in the area of pest management. Lance Walters has been working at the orchard for several years and is now responsible for spray operations, in association with his wife (Bronwyn Walters), who is responsible for pest monitoring. As Lindsay was unavailable I met with Lance.


Persimmon at Valley View Orchard

Valley View Orchard is a large operation, focussing solely on persimmons. There are 3385 established trees, 4 young (but producing) blocks comprising a further 2000 trees, and several more (1000 +) of recently planted trees. The current area under production is approximately 9 ha, with plans to expand further in the near future. Trees are trained to a closed V-trellis. This style was preferred due to the better production compared with alternative training systems. Unlike Jeremy, Lance did not experience any problems with achieving good spray coverage.

Mealybug, leafroller caterpillar and scale are the major pests. Other pests include mynah birds, mites, green vegetable bug, thrips, light brown apple moth, lemon tree borer, cicada and bronze beetle (the latter originating from the windbreak trees). Mealybug are present all year round, however they are mainly seen under the calyx.

Monitoring is carried out on a regular basis. During these inspections they randomly check a number of areas of the orchard, for weeds, pruning requirements, etc as well as pests. Pheromone traps are used to monitor light brown apple moth and have been found to be very useful for predicting flights of these pests.

Lance is very reliant on the Green and Gold IPM manual for information on pests and control methods. He also referred regularly to a spray manual and a wall chart (produced by the Persimmon Industry Council) (appendix). They have an established spray programme for mealybug and other pests, based on the wall chart. However, Lance made clear that this was not a calendar spraying system, but was based on a knowledge of which chemicals are most effective at which times of the pests' lifecycle, and subject to withholding periods.

- Lime sulphur is applied when trees are dormant (before August), to remove excessive lichen, which shelters mealybug
- Tokuthion (prothiofos) and oil (1%) is applied approximately 21 days after the lime sulphur application and before the end of September
- Diazinon and Attack (pirimiphos-methyl and permethrin) are applied in November (Attack at preflower)
- From then on sprays are applied for control of a variety of pests, dependent on populations:
    - Lorsban (chlorpyrifos) in February for mealybug and other pests
    - Dew (diazinon) in March for leafroller and scale
    - Delfin (Bt) in April to clean up any caterpillar pests still remaining (this application is viewed as a last resort)
    - Proclaim (emamectin benzoate) just before harvest for leafrollers (also a last resort)

In addition, Ovation (buprofezin) is applied for control of mealybug, however diazinon is viewed as the main control for this pest. Lorsban is very effective against mealybug, however they try to avoid using it if possible.

All spray applications are made using a fan propelled sprayer with a high water volume to achieve good coverage. A spray application is often also made to the windbreak trees as these harbour pests such as scale, which can cause problems if not controlled.

According to Lance, this spray programme is very effective for managing all persimmon pests. They are proud of being able to export the majority of their fruit. However, Lance also stated that timing of insecticide application is very important to achieve good control.

Lichen and moss growing on the trees can provide shelter for mealybugs, and is removed during the winter clean-up. They generally use lime sulphur. An alternative, softer product is available (Graphic, benzalkonium chloride and copper sulphate), but is not reliably effective. This year they plan to trial manual scrubbing in some blocks to determine whether this is more effective compared with the standard treatment.

They do not take any measures to actively promote natural enemies, but have observed them in the orchard (e.g. ladybirds, spiders), particularly when the trees are in leaf and fruit develop the calyx.

A hot water dip is used on the fruit before packing: 52.5°C for a maximum of 20 minutes. They have carried out extensive trial work using different temperatures and immersion times in order to achieve an optimum result. The hot water dip is a phytosanitary measure to get rid of contamination pests such as spiders and slaters. Lance felt this treatment was not very effective against mealybug as few of these pests were observed (dead) in the water. Until recently they have been dipping approximately 200 of the 650 crates packed per day, but next year will aim to dip all fruit. The fruit are then stored in the pack house under a controlled climate.

Implications for Australian persimmon industry

Research outcomes (Plant & Food)	Relevance to Australian persimmon
Mealybugs as pests Three mealybug species are important in New Zealand tree crops (longtailed, citrophilous and obscure mealybug), with distribution related to climate and pesticide use. There are generally two to three generations per year.	Two of these species (longtailed and citrophilous mealybug) are key pests in Australian persimmon, with differences in distribution in the different growing regions. There can be up to six generations per year (QLD).
Biocontrol The key natural enemies of mealybug in New Zealand have been documented. Evidence suggests that a reduction in broad spectrum pesticide use is strongly correlated with an increase in natural enemy populations and a decrease in mealybug populations.	Many of the key natural enemies present in New Zealand are common to Australia. Currently many Australian persimmon growers rely heavily on chemical control using broad spectrum insecticides that are incompatible with biocontrol. Monitoring in an organic orchard compared with an orchard with heavy use of broad spectrum chemistries would give an indication of the contribution of natural enemies to suppression of mealybugs.
Post-harvest disinfestation Hot water dips are used as a phytosanitary treatment, although there are differences of opinion as to their efficacy for removal of mealybug. Cold storage is reportedly effective.	Hot water dips have potential for use by the Australian persimmon industry. Long-term cold storage is not considered a viable option in Australia.
Mealybug sex pheromones Plant and Food Research have the pheromones for longtailed and citrophilous mealybug. Monitoring using pheromone baited traps is viewed as the basis for developing an IPM system and critical for optimal timing of insecticide applications.	The citrophilous mealybug pheromone is being commercialised by Plant and Food Research. The longtailed mealybug pheromone is freely available, but may not be effective for Australian mealybug populations. Preliminary work would be required to determine the optimum dose rates and thresholds appropriate for Australian conditions. Pheromone traps could be used to confirm the distribution of mealybug species and their phenology in the different persimmon growing regions in Australia. This information is critical to the development of a successful IPM program.

Chemical control Several neonicotinyls and spirotetramat have shown good efficacy for mealybug control. However, timing and coverage are critical. Timing: applications are most effective when there is high activity of the crawler stage but before large populations of mealybug develop. This is generally in late spring to early summer, but is dependent on the insecticide and the phenology of the mealybug species. Coverage: high water rates are critical; several types of adjuvant have been shown to improve efficacy.	Trials are currently in development to assess spirotetramat and three neonicotinyl insecticides in a commercial persimmon property (HAL project proposal PR12000 Australian Sweet Persimmon Industry Development – Phase 3). The New Zealand research results will be valuable in developing the Australian trial work. Use of pheromone traps is critical to determine optimal timing of applications.
Ants Exotic ant species (e.g. Argentine ant) are thought to be particularly disruptive to mealybug management.	Effective control of ants is necessary for successful management of mealybug. Likewise, an understanding of the spread of Argentine and fire ants and their potential impact on mealybug control is required.

Recommendations

- Obtain the sex pheromones for citrus, longtailed and citrophilous mealybug.
- Monitor mealybugs in a variety of locations in order to confirm the key species and the phenology in different growing regions.
- Expand the selective chemistry available to persimmon growers (a recently approved HAL project led by Grant Bignell will trial several chemistries for efficacy against mealybug and clearwing moth).
- Determine the most effective timing of application of chemical controls.
- Confirm the natural enemies present in the different growing regions and their potential impact on mealybug populations.
- Investigate hot water dipping as a post-harvest disinfestation technique.

Itinerary

Monday 9th July	Travel to Auckland
Tuesday 10th July	Visits to persimmon growers: Hawkes Nest Orchard and Vineyard (Warkworth) and Valley View Orchard (Kamo)
Wednesday 11th July	Meetings with Plant and Food Research Mt Albert personnel: John Charles, Lisa Jamieson, Allan Woolf, Graham Walker
Thursday 12th July	Meetings with Plant and Food Research Hawkes Bay personnel: Jim Walker, Peter Lo, Vaughn Bell, Lyn Cole
Friday 13th July	Meetings with Plant and Food Research Hawkes Bay personnel as above Depart New Zealand

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Appendix: Persimmon Industry Council Crop Protection Programme (2007/2008)

Products and Application Rates for use in the Crop Protection Programme: Summary Only

Active ingredient	Products	Rate /100L	Comments
benzalkonium chloride + copper*	Graphic Biocide	750 ml	Lichen removal, general clean-up. Fully dormant use only.
lime sulphur*	FIL, Gro-Chem, Orion and SSL Lime Sulphur brands Key Lime Sulphur	3.5 L 2.5 L	
copper compounds*	Blue Shield DF, Champ WP, Champ Flo, Copper Oxychloride, Agpro Cupric Hydroxide, Cuprofix Disperss, Headland Choice, Kocide 2000 DS, Kocide 2000 LF, Nordox Oleo 40, Nordox 75 WG	various, see full CPP	At budburst for blast, also later if needed.
carbendazim*	Addstem, Carbendazim, Chief, Goldazim 500 SC, MBC 500 Flo, Prolific Protek MBC 800 WDG	50 ml 50 g 30 g	To control *Botrytis* petal blight during flowering. For use after flowering, see Notes in full programme.
thiophanate-methyl*	Topsin M-4A	100 ml	
iprodione*	Rovral Gold Defence 500, Hawk, Ippon 500 SC, Rapid 500 Rovral Flo	50 g 75 ml 150 ml	
pyrimethanil*	Scala, Pyrus 400 SC	200 ml	
cyprodinil + fludioxonil*	Switch	80 g	
biological fungicides*	Botry-Zen, Serenade Max, Sentinel	see full CPP	
mancozeb*	Dithane Rainshield NeoTec, Mancozeb 80 W, Manco 75, Manzate 200, Penncozeb Manex II	200 g 330 ml	To control persimmon bud mite. Apply 1 spray 1-4 weeks before flowering.
Bt	Agree Bactur 48 LC, BMP 48 LC Delfin WG, **Dipel DF**, Bactur WDG, Bio-Bit **Dipel ES**	100 g 150 ml 50 g 75 ml	To control leafrollers from flowering to harvest. Selective.
buprofezin	Applaud 40 SC, Mortar, Buprimax Ovation 50 WDG Pilan	30 ml 25 g 50 g	Pre-flowering and 1 spray before Xmas.
chlorpyrifos*	Lorsban 50 EC, Nufarm Chlorpyrifos 48 EC, Hortcare Chlorpyrifos 480 EC & 50 EC, Chlor-P 480 EC, Defend, Pychlorex 48 EC, Pyrinex, Toppel Lorsban 750 WG	50 ml 50 ml 33 g	Broad spectrum. Some mealybugs in Hawkes Bay are resistant to chlorpyrifos.
diazinon	**Diazinon 50 W**, DEW 500, Diazol, Hortcare Diazinon 500 EW DEW 600, Diazonyl 60 EC Diazinon 800 EC, Digrub, Diazamax 800	100 g / ml 80 ml 60 ml	Only the WP formulation is registered for use.
emamectin*	Proclaim	2 g	To control leafrollers, short residual, selective.
fipronil*	Ascend	10 ml	To control thrips, very toxic to bees.
methoxyfenozide*	Prodigy	15-25 ml	Use before February, see below.
mineral oil*	D-C Tron Plus, Excel Oil, Sunspray *all-purpose oils* BP Crop Oil, D-C Tron, Excel Spring Oil *intermediate oils*	1 litre	Often used with other insecticides to improve control of mealybugs and scales.
permethrin + pirimiphos-methyl	Attack	100 ml	Very broad spectrum.
prothiofos*	Tokuthion 500 EC	100 ml	Pre-flowering against mealybugs and scales.
tebufenozide*	Mimic 700 WP, Approve 70 WP, Echo, Comic, Islandzide Approve 240 SC	8.6 g 25 ml	Use before February, see below.
thiacloprid*	Calypso	20 ml	**Scales,** pre-flowering. Systemic.
dichlorvos	Divap, Nuvos 1000 EC	90 - 100 ml	Maximum of 3 sprays, short residual.
pyrethrins*	Key Pyrethrum, Earthwise Garlic and Pyrethrum, GreenSeals Pyrethrum, PyGanic	100 - 500 ml	Very short residual.

* = material not registered for use on persimmons

Crop Protection Programme for Export Persimmons 2007/2008

The Wallchart summarises the full CPP given in the manual insert. Materials mentioned that are not registered for use on persimmons are shown by *, these can only be used at the grower's risk and in a way that will leave no unacceptable residues at harvest. Growers wanting to use a chemical not listed in the CPP must advise the Quality Manager (06 356 5730) before spraying. Otherwise they may be liable for special residue testing costs.

Fruit from all growers will be residue tested before export.

The first part of the Programme below lists the active ingredients that are effective against particular pests and diseases and the timings of sprays, and the second gives activity and Pre-harvest Intervals for insecticides used after flowering. Above is a list of products and rates of use for the main active ingredients.

Timing	Pest or disease	Actions	Materials	Product names
Dormant	lichen	1 spray at fully dormant only if lichens are excessive. Water blasting is a non-spray alternative.	benzalkonium / copper* lime sulphur*	Graphic Biocide various lime sulphur brands
Bud movement to start of flowering	bacterial blast	1 spray at bud movement (green tip), if a problem previously.	copper sprays*	various, see above
	mealybug armoured scales	Up to 3 sprays depending on severity of mealybug problem, generally 1 or 2. Mealybug sprays also affect scales. Adding 1% mineral oil improves control, and is recommended for at least the first spray. Sprays except buprofezin also kill leafrollers, although this is not necessary until fruit set.	buprofezin	Applaud, Mortar, Ovation, Pilan, Buprimax
			chlorpyrifos*	Lorsban, Chlorpyrifos, Chlor-P, Defend, Pychlorex, Pyrinex, Toppel
			diazinon	DEW, Diazinon, Diazol, Diazonyl, Digrub, Diazamax
			prothiofos*	Tokuthion
			OP-SP mix	Attack
	bud mite	1 or 2 sprays 2-4 weeks before flowering begins.	mancozeb*	Dithane, Manco, Mancozeb, Manex, Manzate, Penncozeb
Flowering	*Botrytis* petal blight	Apply if *Botrytis* has been a problem previously, and rain is expected. First two materials are same chemical group. See Notes.	carbendazim*	various, see above
			thiophanate-methyl*	Topsin M-4A
			cyprodinil / fludioxonil*	Switch
			iprodione*	Rovral, Defence, Fortify, Hawk, Ippon, Rapid
			pyrimethanil*	Scala, Pyrus
			biological products*	Botry-Zen, Serenade Max, Sentinel
	leafrollers	If damage is noted during flowering.	Bt	**Dipel**, Agree, Bactur, BMP, Bio-Bit, Delfin
Fruit set to harvest	mealybugs / armoured scales	Spray at fruit set and repeat at about 3 weekly intervals or when pests noted.	Choose sprays depending on your target markets for fruit; **see above and Notes following.**	
	leafrollers	Spray at fruit set and repeat as needed.	Choose sprays carefully, **see Notes following.**	
	greenhouse thrips	Populations are higher when autumn is warm and moist.	Attack: fipronil*: diazinon	Attack: Ascend: DEW, Diazol and other diazinons
Harvest	leafrollers	If preharvest check or early harvest indicates a need.	Bt	**Dipel**, Agree, Bactur, BMP, Bio-Bit, Delfin
			dichlorvos	Nuvos, Divap
	other contaminants	Leafrollers are a major quarantine problem at harvest.	pyrethrins*	various, see above

* = material not registered for use on persimmons

Insecticides after flowering, and the intervals from last use to harvest for various markets.

Pests	buprofezin[2]	Attack	diazinon	carbaryl	chlorpyrifos*	Ascend*	tebufenozide*[3]	Prodigy*[3]	Proclaim*	Bt	oil*	dichlorvos[4]	pyrethrins*[4]
	Spray materials (see above for product names and rates)												
mealybugs	✔	✔	✔	✔	✔	-	-	-	-	-	✔	✔?	✔?
armoured scales	✔	✔	✔	-	✔	-	-	-	-	-	✔	✔?	-
leafrollers	-	✔	✔	✔	✔	✔	✔	✔	✔	✔	-	✔	✔?
thrips	-	✔	✔	✔	✔	✔	-	-	-	-	✔	✔	✔
tydeid mites	-	?	-	-	-	?	-	-	-	-	✔	-	-
Market	**Days from last spray to harvest (PHI) for each material and market**												
New Zealand	84[1]	7	7	7	56[1]	21[1]	56	56[1]	3	1	1	3	1
Australia	84[1]	7	7	7	56	21[1]	56	56[1]	3	1	1	3	1
Indonesia	nd	70[1]	7	nd	100[1]	21[1]	nd	nd	3	1	1	3	3
Singapore	nd	70[1]	7	nd	100[1]	21[1]	nd	nd	3	1	1	3	1
Malaysia	nd	70[1]	nd	nd	100[1]	21[1]	nd	nd	3	1	1	3	1
Thailand	nd	70[1]	nd	nd	100[1]	21[1]	nd	nd	3	1	1	3	3
Hong Kong	nd	70[1]	nd	nd	100[1]	21[1]	nd	nd	3	1	1	3	3
China (PRC)	nd	56	nd	nd	100[1]	21[1]	nd	nd	3	1	1	3	3
Korea	56	56	28	nd	56	21[1]	56	28[1]	3	1	1	3	1
Japan	nd	7	28	28	100	21[1]	28[1]	14[1]	3	1	1	3	1
Taiwan	nd	56	7	28	28	21[1]	56	nd	3	1	1	3	3
Canada	84[1]	28	28	56[1]	100	21[1]	56	56[1]	3	1	1	3	3
EU	nd	35[1]	nd[5]	28	100	21[1]	nd	nd	3	1	1	3	1

* = material not registered for use on persimmons. **nd** = not detectable, used when there is insufficient data to estimate the PHI. See also [2] & [3] below.

[1] = estimated time to get to undetectable residues or a set MRL from limited data.

[2] = Applaud / Buprimax / Mortar / Ovation / Pilan are registered for use before flowering. Data suggest non-detectable residues if 1 more spray is used before Christmas.

[3] = Data on Mimic / Approve / Comic / Echo / Islandzide suggest 2 sprays before February will give non-detectable residues. Prodigy is similar, possibly slightly less residual.

[4] = dichlorvos and pyrethrins are short-lived materials for use close to harvest, not for use throughout the crop cycle.

[5] = The EU will reduce the diazinon MRL from 0.02 to 0.01 ppm, the Limit of Detection, in December 2007.

These pre-harvest intervals (PHIs) are the estimated minimum times from last spray to harvest that is reasonably sure of reaching an MRL; they are not a guarantee of reaching this. Sprays closer to harvest may only be used **provided** a residue test before the crop is harvested shows that any residues present are below the appropriate MRL. **Always consult your exporter before using sprays that could affect harvest dates.**

Disclaimer

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