16 *Planococcus minor* (Hemiptera: Pseudococcidae): Bioecology, Survey and Mitigation Strategies

Amy Roda,[1] Antonio Francis,[2] Moses T.K. Kairo[2] and Mark Culik[3]
[1]*USDA-APHIS-PPQ, Center for Plant Health Science and Technology, Miami, Florida 33158, USA;* [2]*Center for Biological Control, College of Engineering Sciences, Technology and Agriculture, Florida Agricultural and Mechanical University, Tallahassee, Florida, USA;* [3]*Instituto Capixaba de Pesquisa, Assistência Técnica e Extensão Rural – INCAPER, Vitória, Espírito Santo, Brazil*

16.1 Introduction: Host Range, Economic Impact and Pest Status

Planococcus minor (Hemiptera: Pseudococcidae) is commonly referred to as the passionvine mealybug, pacific mealybug or guava mealybug. *P. minor* is one of 35 species belonging to a genus that is native to the Old World (Cox, 1989), which includes many well-known pests of economic importance (Williams and Watson, 1988; Cox, 1989). As a phloem feeder, *P. minor* can cause stunting and defoliation that eventually leads to reduced yield and fruit quality. The pest also causes indirect or secondary damage due to the sooty mold growth on honeydew produced by the mealybug. *P. minor* is also likely to transmit plant viruses such as swollen shoot virus of cacao, *Theobroma cacao* L. (Cox, 1989). In addition, multiple *Planococcus* species can transmit the same virus. For example, the Grapevine leafroll-associated virus is transmitted by both *P. citri* and *P. ficus* (Tsai *et al.*, 2008; Cid *et al.*, 2010).

Worldwide, the reported host plant range includes >250 species in nearly 80 families, some of which include important agricultural crops such as banana and plantain, *Musa* groups AAA, AAB and ABB, *Citrus*, cocoa, coffee (*Coffea arabica* L.), corn (*Zea mays* L.), grape (*Vitis vinifera* L.), mango (*Mangifera indica* L.), potato (*Solanum tuberosum* L.) and soybean (*Glycine max*) (Venette and Davis, 2004; Ben-Dov *et al.*, 2011). Although *P. minor* has a very broad host range, not all host records are necessarily reliable. Recent literature suggests that earlier records may be erroneous due to misidentification of closely related and difficult to distinguish mealybug, namely *P. citri* (Batra *et al.*, 1987; Cox, 1989; Williams and Granara de Willink, 1992; Santa Cecilia *et al.*, 2002). In addition, *P. minor* has a similar host range and geographical distribution as other *Planococcus* mealybugs, and multiple species may occur on the same plant (Cox, 1989). Infestation levels can also fluctuate spatially, even on plants in close proximity, and can vary from one year to the next (Miller and Kosztarab, 1979). Because of these issues, it is difficult to estimate the economic impact of *P. minor* alone. For instance, *P. minor* (formerly *P. pacificus*, reported as *P. citri* in 1966) reportedly made up approximately 90% of a scale complex on coffee in New Guinea, and caused an estimated yield reduction of 70–75%. In Taiwan, *P. minor* was considered as a major pest of important crops, including banana, *Citrus*, mango, celery (*Apium* spp.), melon (*Benincasa* spp.), pumpkin (*Cucurbita* spp.), soybean, betel nut (*Areca catechu*), star fruit (*Averrhoa carambola*), guava (*Psidium* spp.) and passionvine (*Passiflora* spp.) (Ho *et al.*, 2007). Although the host-plant ranges of *P. citri* and *P. minor* overlap, *P. minor* may prefer cacao more than *P. citri*, and many records of *P. citri* on this plant should refer to *P. minor* (Cox and Freeston, 1985). Similarly, although both species have been reported on citrus, this is a preferred host plant for *P. citri* and is rarely frequented by *P. minor*.

The mealybug can also exert an indirect economic impact due to trade restrictions. At US ports of entry, *P. minor* was intercepted >1160 times from 2005–2010, with 49% of the infested commodities arriving from Asian countries, 29% from the Caribbean basin region and the remainder from South America, North America and Europe (USDA, 2010). A US commodity-based pest risk assessment concluded that the likelihood of this pest becoming established in the USA was high, and the consequences of its establishment would be severe (Venette and Davis, 2004). As a result, the mealybug was considered a regulated pest and if found the commodity was either destroyed, re-exported or fumigated. When exporting products from infested countries the producer is often required to include phytosanitary measures that minimize the risk of movement of the mealybug to the USA. Similarly, US states may prohibit the movement of material or require compliance agreements that outline treatment and inspection requirements from infested states.

16.2 Origin and Distribution

P. minor is thought to be one of six species with origins in the Old World, and likely was introduced into the Neotropics through trade (Cox, 1989). It is now widely distributed throughout the Oriental, Austro-Oriental, Australian, Polynesian, Nearctic, Afrotropical, Malagasian, and Neotropical regions (Cox and Freeston, 1985; Williams, 1985; Williams and Watson, 1988; Cox, 1989; Williams and Granara de Willink, 1992; Ben-Dov *et al.*, 2011). *P. minor* was originally described in 1897 as *Dactylopius calceolariae* var. *minor* Maskell from a specimen collected in Mauritius, and was synonymized with *P. citri* by Morrison (1925). Cox (1981) redescribed the species as *P. pacificus* from material collected from Western Samoa, which was later recognized to be a synonym of *P. minor* (Cox, 1989).

The identification of many species in the genus *Planococcus* using morphological characters has been challenging (Cox and Wetton, 1988). *P. minor* is particularly difficult to separate from *P. citri* (Williams, 2004). A matrix system was developed based on six diagnostic characters, which were scored using a point system to identify adult females. The system was based on pioneer work by Cox (1981, 1983), who reared *P. citri* (Risso) and *P. minor* (Maskell) as well as *P. ficus* (Signoret) under different environmental conditions, to determine the limits of morphological variation within each species. Specimens having a total score of 35 or below were determined to be *P. minor*, and those having a total score of 35 or more to be *P. citri*. Cox and Freeston (1985) stated that when there are >13 ducts on the head and more than seven adjacent to the 8th pair of cerarii, then the species is undoubtedly *P. citri*. If there are 0–3 ducts on the head and 0–2 ducts adjacent to the 8th pair of cerarii, then the species is *P. minor*. This system is still relied upon by mealybug taxonomists to separate the two species.

P. minor has been routinely misidentified due to similarity in appearance, host plant range and geographic distribution (Williams, 1985; Cox, 1989; Williams and Granara de Willink, 1992; Ben-Dov *et al.*, 2011). Several authors highlighted inaccuracies in past literature, where the species of *Planococcus* commonly occurring in the Austro-oriental, Polynesian and the Neotropics regions was *P. minor* and not *P. citri*, despite most published records listing the latter (Williams, 1982; Cox and Freeston, 1985; Williams and Watson, 1988). The currently reported global distribution of *P. minor* suggests that the pest may be most closely associated with biomes characterized as desert and xeric shrubland; temperate grassland, savannahs, and scrubland; and tropical and subtropical moist broadleaf forest (Venette and Davis, 2004).

16.2.1 Molecular identification

Because it is difficult to distinguish *P. minor* from *P. citri* based on morphological characteristics, alternatives such as molecular identification of *P. minor* have been investigated (Rung *et al.*, 2008, 2009; Malausa *et al.*, 2010). Rung *et al.* (2008) found that sequences of the mitochondrial cytochrome oxidase-1 (COI) gene and the nuclear protein-coding gene elongation factor 1α (EF-1α) revealed three distinct clades within the *P. citri/ P. minor* species complex. They found that '*P. citri*' and '*P. minor*' were clades, corresponding to morphologically identified species collected from various locations around the world and a 'Hawai'ian clade', which includes specimens morphologically indistinguishable from *P. citri* and occurring only in Hawai'i. In a few specimens, the results from COI conflicted in the placement, causing the authors to question if the gene would always give an accurate identification. If *P. minor* and *P. citri* hybridize under natural conditions, mitochondrion introgression could potentially occur, resulting in individuals that have the nuclear genome of *P. minor* and the mitochondrial genome of *P. citri* or vice versa (Rung *et al.*, 2008). Recently, Malausa *et al.* (2010) found a set of markers that could reliably characterize complexes of cryptic taxa within the family Pseudococcidae. They used five markers, two regions of the mitochondrial COI gene, 28S-D2, the entire internal transcriber space 2 locus and the rpS15-16S region of the primary mealybug endosymbiont *Tremblaya princeps*. These markers distinguished between the species identified on morphological examination, including the most closely related species, *P. citri* and *P. minor*. The genus *Planococcus* appeared monophyletic. *P. citri* and *P. minor* clustered together for all genes, but were separated from *P. ficus*. As molecular analysis can be time-consuming and relatively expensive, the protocols used by Rung *et al.* (2009) and Malausa *et al.* (2010) were designed for use in routine work, as they require no gene cloning and make use of rapid, cost-efficient PCR procedures.

16.3 Biology, Life History and Rearing Techniques

The adult female mealybug is pinkish in color, wingless, and has a dark line running down the dorsal median of the insect (Fig. 16.1). The body is covered with white, cottony wax, and has a fringe of elongated waxy filaments that extend about the periphery of the body. An adult female mealybug is about 3 mm long and 1.5 mm in width. The mature female lays pinkish eggs in an egg sac of white wax, usually in clusters on the base of leaves, the twigs or bark of the host plant. The pest forms colonies on the host plant. If left undisturbed, the colonies can grow into large masses of white, waxy deposits on branches, fruiting structures and leaves. The mealybug and eggs sacs are also commonly found on flowers and fruits of a host plant. Eggs hatch into nymphs called crawlers which are very mobile. They may disperse over the host, especially toward tender growing parts, or be carried away by wind, people or animals. Ants may also play a role in mealybug dispersal. However, long-distance movement of the mealybug is most likely as a result of the movement of infested nursery stock and agricultural commerce. Nymphs of both sexes resemble female adults. Nymphs undergo three and four successive molts prior to emergence of adult females and males, respectively (Sahoo and Ghosh, 2001). The male third instar is referred to as the 'prepupa', while the fourth instar from which the adult emerges is termed 'pupa'. These are relatively inactive stages that develop in white cocoon-like structures (Sahoo and Ghosh, 2001). Adult males are c. 1 mm long with three distinct body divisions (Fig. 16.2), three pairs of legs and one pair of wings (Gill, 2004). Mouthparts are absent, therefore they only live for a few days (Sahoo and Ghosh, 2001).

The few studies undertaken on the life history of *P. minor* were conducted at either a single

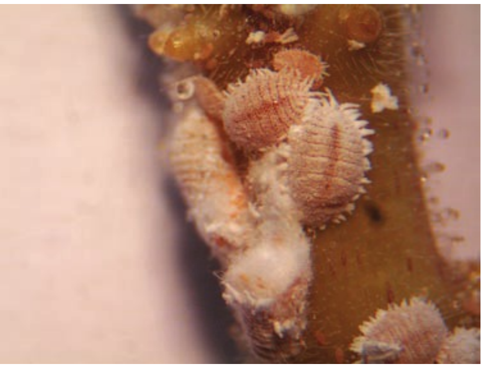

Fig. 16.1 *Planococcus minor,* adult females.

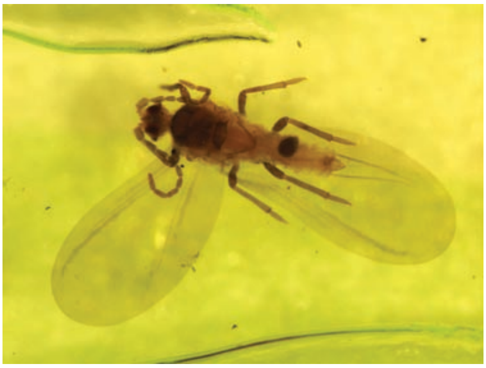

Fig. 16.2 *P. minor* adult male on sticky trap.

temperature (Martinez and Suris, 1998; Sahoo and Ghosh, 2001) or fluctuating temperature regimes (Maity *et al*., 1998; Biswas and Ghosh, 2000), and on different readily available host plants (Maity *et al*., 1998; Biswas and Ghosh, 2000). Eggs required as few as 2–5 days to hatch at 26°C and 69% RH (Martinez and Suris, 1998). The development time for males was longer than for females (Maity *et al*., 1998; Martinez and Suris, 1998), and the time to complete a single generation ranged from 31 to 50 days (Maity *et al*., 1998; Martinez and Suris, 1998; Biswas and Ghosh, 2000). Most mealybugs are biparental (Gullan and Kosztarab, 1997). However, several types of parthenogenesis have been described in coccoids, including obligate and facultative parthenogenesis (Gullan and Kosztarab, 1997). Facultative parthenogenesis has been reported in *P. citri* (Myers, 1932; Panis, 1969), but other studies found no reproduction with unmated females of *P. citri* (Borges da Silva *et al*., 2009). Studies have never been undertaken with *P. minor*, but both females and males occur in populations where males have been reported to be less numerous than females (Maity *et al*., 1998; Martinez and Suris, 1998; Sahoo *et al*., 1999; Sahoo and Ghosh, 2001). The preoviposition and oviposition periods of gravid females ranged from 6–11 and 8–14 days (Maity *et al*., 1998), and 6–8 and 8–9 days (Biswas and Ghosh, 2000). Female fecundity varied depending on the host plants. Biswas and Ghosh (2000) reported 66–159 eggs on *Ixora signaporensis*, soybean and *Acalypha wilkesiana*. However, Maity *et al*. (1998) reported as many as 266–426 eggs on taro (*Colocasia esculenta*), sprouted potato and pumpkin. In warm climates, *P. minor* stays active and reproduces throughout the year (Ben-Dov, 1994). Sahoo *et al*. (1999) reported as many as ten generations occurring per year in India. The low-temperature tolerance and overwintering mechanisms for *P. minor* are unknown. *P. citri* overwinters primarily as eggs on the upper roots, trunk and lower branches of the host plant. Other mealybug species are known to overwinter in the soil or on the host plant, particularly under the bark as late-instar nymphs or adult females.

16.3.1 Rearing

P. minor can be reared on potted host plants; however, propagating and maintaining these host plants requires considerable greenhouse space, special lighting and a sizable workforce. Often, a fruit or vegetable can be substituted as the host plant substrate of choice for an insectary operation for mass-producing mealybugs (Meyerdirk *et al*., 1998). *P. minor* has been successfully reared on squash and potatoes, using procedures adapted from those described by Meyerdirk *et al*. (1998). These plant materials have served as useful hosts for many different species of mealybugs, and are easy to maintain and manipulate. Mealybug cultures are typically maintained in closed, darkroom facilities. This reduces crawler movement and escape. Several alternative squash/pumpkin varieties can be used to rear the mealybug. The material should be purchased from an organic producer and should not be surface treated with wax or oil products. Potatoes should be grown in the dark to keep the sprouts from producing chlorophyll and turning green, which is undesirable for mealybug rearing. The mealybug crawlers and various instars will feed directly on the potato sprouts. Seed potatoes are preferred because they are not treated with sprouting inhibitors. Room humidity, and – most importantly – cage/cabinet humidity should be maintained above 50% RH. A crawler collection system consisting of a holding cabinet with a low-watt bulb modified with foil (so that a single beam of light projects downward onto a sheet of heavyweight paper) can be used to facilitate infestation of new plant material. Host material containing egg sacs that are about to hatch are placed around the periphery of the paper. Attracted by light, crawlers move from the old infested material unto the cardboard surface, and eventually to the paper surface under the beam of light. Crawlers can be collected daily by simply removing the paper and pouring them onto new host material.

16.4 Sampling and Monitoring Techniques

Surveys for live mealybugs require time-consuming and laborious examination of plant material (Millar *et al.*, 2002). There are no simple and effective visual methods to detect most species (Geiger and Daane, 2001). *P. minor* has cryptic habits, therefore plants need to be examined closely in good light to find them. They are rarely found in direct sunlight and are more often present on leaf undersides, inside the calyx of sepals, in axils or under bark. Typical signs indicating the presence of *P. minor* include plant areas with dieback, leaf loss, localized discoloring/yellowing of leaves, wet patches and sooty mold on the bark, stems, leaves and fruit. Other important indicators of a *P. minor* infestation are ants attending mealybug colonies, and masses of mealybug waxy material. Live insect specimens cannot be identified to genus or species with confidence, because their taxonomy is based on microscopic characters that are only visible in specimens prepared on microscope slides (Watson and Chandler, 2000). Watson and Chandler (2000) recommend placing a small piece of infested plant material in a vial with 80% ethanol to kill and preserve the specimens, and not dislodge an individual insect, as they are often very soft and can be damaged by instruments.

Recent developments in the identification (Ho *et al.*, 2007) and synthesis (Millar, 2008) of the female sex pheromone of *P. minor* may greatly aid in locating populations of the mealybug. Ho *et al.* (2008) isolated the sex pheromone by aeration of virgin females. The pheromone 2-isopropyl-5-methyl-2,4-hexadienyl acetate was identified, and the stereochemistry of the pheromone was assigned as (E) by comparison with synthetic standards of known geometry. The (E)-isomer was highly attractive to males in laboratory bioassays, whereas the (Z)-isomer appeared to antagonize attraction. In common with all of the scale and mealybug pheromones identified so far, this species produces unique pheromone chemicals, eliminating the possibility of competition for or interference with a particular pheromone channel (Millar, 2008). Because *P. minor* is strongly inhibited by the (Z)-stereoisomer form of its pheromone, the compound may be the pheromone of a related, sympatric species (Millar, 2008). A short and completely stereo-specific process to synthesize the pheromone was developed by Millar (2008). To produce the pheromone with high stereochemical purity is critically important, because the (Z)-isomer is a powerful behavioral antagonist. Solving the problem of synthesis provided a highly sensitive and effective method of detecting even small populations of *P. minor*. Although positive finds on a trap do not pinpoint the exact location of an infestation, they aid in defining the area where detailed field surveys need to be undertaken (Daane *et al.*, 2006). Within the genus *Planococcus*, sex pheromones have been identified and synthesized for *P. citri* (Bierl-Leonhardt *et al.*, 1981) and *P. ficus* (Hinkens *et al.*, 2001), and successfully used in monitoring programs (Hinkens *et al.*, 2001; Franco *et al.*, 2004). Recently, the synthetic pheromone was used to locate populations of *P. minor* in south Florida (Stocks and Roda, 2011). The US state and national regulatory agencies required adult *P. minor* females to morphologically confirm the presence of this species in a new area, as there is no morphological way to identify male *Planococcus* species. Although not yet commercially available, the synthetic pheromone may provide a means to locate new infestations, as well as monitor changes in population levels.

16.5 Damage: Evaluation of Damage and Economic Thresholds

Planococcus spp. have piercing-sucking mouthparts which they insert into the plant vascular tissue, and which can remain in place through several molts, ingesting plant sap (Arnett, 1993). Feeding activity causes reduced yield, lower plant or fruit quality, stunted growth, discoloration and leaf loss (Venette and Davis, 2004). If left unchecked, *Planococcus* spp. often reach high densities, even killing perennial plants (Krishnamoorthy and Singh, 1987; Ben-Dov, 1994; Walton *et al.*, 2006). Plant death may also be caused by viral diseases, because the mealybugs may also vector important viruses (Williams, 1985; Cox, 1989). In such cases, these mealybugs may be economic pests even at very low densities (Franco *et al.*, 2009).

Up to 90% of the ingested plant sap may be excreted as honeydew (Mittler and Douglas, 2003). Sooty molds grow on the honeydew and can build up on the leaves, shoots, fruits and other plant parts (Mittler and Douglas, 2003). These molds can cover so much of the plant that they interfere with the plant's normal photosynthetic activity (Williams and Granara de Willink, 1992). Honeydew and sooty mold cause cosmetic defects to plants and/or their fruits, affecting the produce.

Franco *et al.* (2009) noted that most of the economically important mealybug species are associated with long lists of hosts, yet under low pressure of natural enemies they spread into new areas and are observed on relatively large numbers of host plants. With this potentially wide host-plant range, it is reasonable to anticipate that *P. minor* will find and utilize additional new hosts as it expands its distribution to new habitats (Venette and Davis, 2004). *P. minor* is reported to show distinct host preferences, commonly occurring on cocoa throughout its geographic range (Cox, 1989). In addition, plant host susceptibility to *P. minor* can vary widely, and infestation levels can fluctuate spatially, even on plants in close proximity (Venette and Davis, 2004).

Since multiple species from the genus *Planococcus* may occur on the same host plant, it is often difficult to estimate the impact of *P. minor* alone (Cox, 1989). Although widely distributed, this mealybug is not reported to be an economic pest in many countries. Some earlier host records in certain regions might be erroneous through misidentification of it as *P. citri* (Cox, 1989; Williams and Granara de Willink, 1992; Santa Cecilia *et al.*, 2002). For example, *P. minor* as *P. citri* from Papua New Guinea where the mealybug comprised >90% of a mixed population with another pseudococcid and two different soft scales on coffee, and caused 70–75% reduction in crop yield (Szent-Ivany and Stevens, 1966). In India, this mealybug was reported as part of a *Planococcus* spp. complex or singly attacking custard apple (*Annona reticulata*) (Shukla and Tandon, 1984), grape (Batra *et al.*, 1987; Tandon and Verghese, 1987), ber (*Ziziphus* sp.), guava, mango (Tandon and Verghese, 1987) and coffee (Reddy and Seetharama, 1997).

16.6 Control Tactics

16.6.1 Chemical

Chemical control is a common management strategy for mealybugs. Because of the generally cryptic habits and due to the protection of the mealy cover, effective chemical control relies on application of materials using high-vapor pressure, or timed when vulnerable stages such as crawlers are present (Franco *et al.*, 2004). Major insecticides used against mealybugs include diazinon, dimethoate, azinfosmethyl, chlorpyrifos, parathion, pyrimifos-methyl and malathion, which are applied singly or in mixtures that include mineral oils (Franco *et al.*, 2004; Buss and Turner, 2006; Daane *et al.*, 2006). In India, *P. minor* has been shown to be resistant to several insecticides: organophosphates (Thirumurugan and Gautam, 2001), pyrethroids and organochlorines (Shukla and Tandon, 1984). Cultural practices such as pruning infested plant parts are used, to allow greater penetration of insecticides into the foliage (Franco *et al.*, 2004). Soil drenches of systemic insecticides also work as they reach all parts of the plant, and control of mealybugs has improved with the introduction of many new systemic (Daane *et al.*, 2006) neonicotinoids – acetamiprid, clothianidin, dinotefuran, imidacloprid, thiamethoxam – along with several insect growth regulators (IGR) (Buss and Turner, 2006).

16.6.2 Regulatory

A risk assessment by Venette and Davis (2004), developed under International Plant Protection Convention risk analysis standards, concluded that the economic consequences of *P. minor* introduction and establishment in the USA would be severe. Until April 2012 the mealybug was considered a high priority for exclusion by the US Department of Agriculture Animal and Plant Health Inspection Service (APHIS), Plant Protection and Quarantine (PPQ). In the USA *P. minor* was considered an 'actionable', quarantine-significant pest. If *P. minor* was found on imported products, the commodity was destroyed, re-exported or fumigated. Along with regulatory measures at ports of entry, the USA placed restrictions on the entry of plant products from countries known to have the pest. When exporting products from infested countries, the producer often is required to include pesticide or processing treatments that remove the mealybug from the commodity before exporting to the US. Irradiation treatments have been developed for *P. minor* as a potential phytosanitary measure that could be an alternative to current quarantine treatments (Ravuiwasa *et al.*, 2009). A dose of 150–250 Gy from a Cobalt 60 source decreased *P. minor* survival rate, percentage of adult reproduction, oviposition and fertility rate. The adult was the most tolerant life stage treated, and all treated life stages oviposited, but none of the F2 generation eggs hatched at the remanded dosage.

16.6.3 Biological

Mealybugs are amenable candidates for biological control, and this option has been deemed the best form of long-term control due to the reduction in costs associated with chemical control (Franco *et al.*, 2004; Buss and Turner, 2006). Very few natural enemies of *P. minor* were known (Ben-Dov *et al.*, 2011) until recent studies conducted in Trinidad (Francis, 2011). Despite the lack of historic knowledge of natural enemies of *P. minor*, several factors suggest that biological control plays an important role in regulating mealybug numbers. Ants have been observed feeding on the honeydew excretions of mealybugs (Kairo *et al.*, 2008). Although some ants may be predaceous, others are known to protect this important food source from predators. Mealybug populations closely associated with ants tend to be larger than non-tended populations of the same species (Lamb, 1974; Buckley and Gullan, 1991; Franco *et al.*, 2004). In studies of mealybugs – probably *P. minor* – infesting passion fruit, the destruction of natural enemies by pesticides increased mealybug numbers (Williams, 1991). As with other potential or secondary pests, problems with *P. minor* may be induced by pesticides. Table 16.1 lists known predators and parasitoids of *P. minor*.

Predators

As many as 47 mealybug predators are found in diverse insect orders and families such as Coleoptera (coccinellids), Diptera (cecidomyiids), Neuroptera (chrysopids and hemerobiids), Lepidoptera (lycanids) and Hemiptera (Moore, 1988). One of the most important predators of

Table 16.1. Reported natural enemies of *Planococcus minor.*

	Family	Species	Reference
Predators	Anthocoridae	*Calliodis* sp.	(Francis, 2011)
	Cecidomyiidae	*Diadiplosis coccidarum* Cockerell[3]	(Kairo *et al.*, 2008; Francis 2011; Stocks and Roda, 2011)
	Coccinellidae	*Brumoides suturalis* (Fabricius)	(Chandrababu *et al.*, 1997)
		Cryptolaemus affinis Crotch	(Szent-Ivany and Stevens, 1966)
		Cryptognatha nodiceps Marshall	(Francis, 2011)
		Tenuisvalvae bisquinquepustulata Fabricius	(Francis, 2011)
		Diomus sp.	(Francis, 2011)
		Diomus robert Gordon	(Francis, 2011)
	Syrphidae	*Ocyptamus stenogaster*	(Francis, 2011)
Parasitoids	Encyrtidae	*Leptomastix dactylopii* Howard	(Nagarkatti *et al.*, 1992; Kairo *et al.*, 2008; Francis, 2011)
		Aenasius advena Compere	(Bhuiya *et al.*, 2000)
		Coccidoxenoides perminutus Girault[1]	(Kairo *et al.*, 2008; Francis, 2011)
		Gahaniella tertia Kerrich[2]	(Kairo *et al.*, 2008; Francis, 2011)
		Coccidoctonus trinidadensis Crawford[2]	(Kairo *et al.*, 2008; Francis, 2011)
	Signiphoridae	*Signiphora* n. sp. (Woolley) mexicanus group	(Kairo *et al.*, 2008; Francis, 2011)

P. minor is *Cryptolaemus montrouzieri* Mulsant, a generalist feeder, which has been utilized extensively against many mealybugs and scale insects (Smith and Armitage, 1931; Reddy and Seetharama, 1997; Mani and Krishnamoorthy, 2008). *C. affinis* Crotch was also reported to be effective against *P. minor* in Papua New Guinea (Szent-Ivany and Stevens, 1966). *Brumoides suturalis* (Fabricius) has also been investigated in some detail as a potential control agent for a number of mealybug pests including *P. minor* (Chandrababu *et al*., 1997, 1999). In recent studies conducted in Trinidad, populations of *P. minor* were found to be very low and attacked by a complex of natural enemies including several Coccinellid species and the gall midge, *Diadiplosis coccidarum* (Cecidomyidae) (Kairo *et al*., 2008). Additionally, *D. coccidarum* was found attacking *P. minor* in South Florida (Stocks and Roda, 2011).

Parasitoids

Important hymenopteran parasitoids of *Planococcus* spp. belong to the family Encyrtidae and include the solitary endoparasitoids *Leptomastix dactylopii* Howard, *Leptomastidea abnormis* (Girault), *Anagyrus pseudococci* (Girault) and *Coccidoxenoides perminutus* Girault (Bartlett, 1961; Berlinger, 1977; Noyes and Hayat, 1994) (Fig 16.3). Other reported genera that have been reared from *Planococcus* spp. include *Aenasuis, Gyranusoidea, Pseudaphycus* and *Pativana* (Ben-Dov *et al*., 2011). However, in biological control programs against *P. citri* in particular, two of the most widely used of these encyrtid wasps have been *L. dactylopii* and *C. perminutus* (Noyes and Hayat, 1994).

16.6.4 Ant control

Ant species often engage in facultative mutualisms with pest Hemiptera. Large outbreaks of sometimes seemingly inconspicuous hemipterans are correlated to the presence of attendant ants likely because they can disrupt the activity of natural enemies (Buckley and Gullan, 1991; Franco *et al*., 2004; Daane *et al*., 2007; Mgocheki and Addison, 2009). Therefore, biological control could be enhanced by disrupting the activity of ants. Chemical tactics available to manage ant populations include insecticide-treated baits, ground, trunk or foliar treatments or placing insecticide-treated bands around trunks (Franco *et al*., 2004). Blocking the ants' path to the mealybugs can also be achieved by placing sticky bands around the tree trunk. Flood irrigation and soil disturbance such as plowing under cover crops can also be used to disrupt ant populations.

Fig. 16.3 *Coccidoxenoides perminutus* adult female parasitizing mealybugs.

16.6.5 Mating disruption, mass trapping, and lure and kill

The identification of the sex pheromone of *P. minor* combined with techniques to synthesize the active component to stereospecific purity has opened up new opportunities to improve monitoring techniques and control tactics (mass trapping, mating disruption, and lure and kill). The existence of facultative parthenogenesis *P. minor* would limit the use of pheromones for pest management. Studies would need to be conducted to verify if *P. minor* is an obligate amphimictic species, similar to what was found for *P. citri* (Borges da Silva *et al*., 2010). Additionally, little has been done on using mealybug pheromones as a management tactic (Franco *et al*., 2004; Daane *et al*., 2006; Walton *et al*., 2006). A 2-year study of mass trapping of *P. citri* males conducted in small citrus plots showed that mass trapping could significantly reduce the number of males; however, the male reduction obtained was not enough to significantly reduce fruit infestation. Therefore, the pheromone trapping system employed could not reduce the number of attracted males effectively, probably because many of the trapped males originated from outside the experimental plots. Therefore, more work is needed on the design of trapping systems before mass trapping can become a viable option for mealybug suppression (Howse *et al.*, 1998). Mating disruption was found not to affect *P. ficus* populations in heavily infested vineyards, possibly due to the fact that at high mealybug densities, adult males would emerge in close proximity to females (Daane *et al.*, 2006; Walton *et al.*, 2006). However, Daane *et al.* (2006) consistently found higher parasitism rates of the exposed mealybugs in the mating disruption plots, suggesting the encyrtid parasitoid *Anagyrus* may cue in on the mealybug pheromone, and either remain in the vineyard aggressively searching for mealybug hosts, or be pulled in from nearby vineyards.

16.6.6 Cultural, physical, mechanical

Specific cultural management practices for *P. minor* have not been reported. However, common strategies to manage other mealybugs would likely impact *P. minor*. Proper sanitation practices are very important in managing the spread of mealybugs that can be transported on farm equipment, plant parts and clothing of workers (Buss and Turner, 2006). To reduce the spread of these mealybugs, farm equipment and harvesting supplies should be cleaned of all plant parts prior to movement to an uninfested area. Plants should be inspected for signs of mealybug infestation before purchase or installation. All infested material should be destroyed, and the area thoroughly cleaned (especially important in greenhouses and nurseries). When infestations are low, mealybugs could be removed by rubbing, or picking them from affected plants. Additionally, mealybugs can be removed mechanically by spraying a steady stream of water at reasonably high pressure on the host plant. Once on the ground, the mealybugs will be vulnerable to ground predators. In citrus, pruning is used also to open ‘windows’ in the tree crown in order to expose cryptic mealybug populations inside the tree crown to light, thus changing the microclimate and ensuring greater exposure to natural enemies (Franco *et al.*, 2004). Mealybugs often thrive in warm, humid environments, so an increase in air flow or decrease in plant density in the area can make conditions less conducive. Soil fertility can play both a positive and a negative role in mealybug management. Scale insects often lay more eggs and survive better on plants receiving excess nitrogen, so avoiding over-fertilizing plants may help reduce the growth of mealybug populations. However, improved plant nutrition of cassava resulted in the production of larger cassava mealybugs, which in turn resulted in a higher proportion of female *Apoanagyrus lopezi* parasitic wasps with higher fertility levels (Schulthess *et al.*, 1997). Improved fertilization of cassava also enhanced the antibiotic properties of cassava against mealybug infestations (Neuenschwander, 2003).

16.6.7 Quarantine methods

Using quarantines to contain a pest such as *P. minor* would be difficult because the insect has a very large host range and could easily escape detection. In the USA, common quarantine action includes prohibiting movement of all host material from the infested area, unless an effective control treatment is available. The treatment for mealybugs usually entails a chemical spray or drench. The plant material will also normally require a phytosanitary certificate issued by a regulatory agency, saying that the material was treated according to the requirements, and based on visual inspection, has been found to be free of pests.

16.6.8 Host plant resistance

Host resistance has not been reported for *P. minor*. However, plant host susceptibility to *P. minor* varies widely (Venette and Davis, 2004) and the mealybug has shown distinct preferences to certain species (Cox, 1989). Additionally, there are highly susceptible citrus varieties for the similar species *P. citri* (Franco *et al.*, 2004). This suggests that there may be plant-resistant mechanisms available that could limit the impact of the pest.

16.7 Conclusions

P. minor has characteristics that indicate that the mealybug could become a serious economic pest. These include its wide host range, global distribution, potential for vectoring viruses and cryptic nature, which makes it possible for the pest to escape detection during inspections. Additionally, *P. minor*'s morphological similarity to other *Planococcus* species may allow the pest to escape detection during routine field surveys until the mealybug has become established. Fortunately, the recent developments in molecular markers and the identification and synthesis of the sex pheromone have provided tools to help with the timely and accurate detection of the pest, so that measures can be taken to mitigate economic damage. Once established, the vast host range of *P. minor* makes wide-scale chemical management unrealistic. However, the recent discovery of *Leptomastix dactylopii* and *Coccidoxenoides perminutus* attacking *P. minor, as* well as several predators, suggests that these natural enemies may suppress populations of the pest so that insecticide use maybe unnecessary in the landscape. Integrated pest management strategies developed for other pest *Planococcus* species will also help to reduce the impact of the pest in production systems, where management practices may disrupt the effectiveness of natural enemies. Note: Since the time of the orginal writing, P. minor was confirmed in the U.S. Populations were found not to have increased after 2 years of monitoring male numbers with pheromone traps and colonies with visual surveys. Natural enemies were also found attacking the pests. As a result, the U.S. down regulated the pest from "actionable" to "non-actionable" at ports of entry.

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