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Research Review Articles

Papaya mealybug (*Paracoccus marginatus*) (Hemiptera: Pseudococcidae): A new threat to agri-horticulture ecosystem

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ABSTRACT

The papaya mealybug, *Paracoccus marginatus* Williams and Granara de Willink (Hemiptera: Coccomorpha: Pseudococcidae) is an invasive insect pest of Central American origin that has become a serious threat to about 60 plant species belonging to more than 22 families across the globe. The average life cycle of *P. marginatus* lasts between 15–32 days depending on host plant species and it can complete about 11–13 generations per year, depending on the temperature and relative humidity. It is of considerable economic importance and causes major losses to both agricultural and horticultural crops. In India, papaya mealybug became a major pest in 2009 with a devastating outbreak in south India. Even though several control methods, such as cultural, chemical, legal and biological control, have been adopted to tackle the problem, only chemical and biological control methods have been widely practised for its management. About 17 predators and 8 host specific parasitoids have been reported to give effective control of *P. marginatus*. However, the parasitoid *Acerophagus papayae* Noyes and Schauff (Hymenoptera: Encyrtidae) has played a predominant role in suppressing *P. marginatus*, with percentage parasitism in several countries between 75–81%. Owing to papaya mealybugs' polyphagy, wide climatic adaptability and ecological plasticity, it clearly has the potential to invade new areas and host plants and is likely to cause much damage in the future. In this paper, the origin, distribution, taxonomy, bio-ecology, host range, natural enemies, management practices and the possible effects of climate change on *P. marginatus* are critically reviewed. The information gathered will guide the management of this difficult to control insect pest.

Key words: *Acerophagus papayae*, Biological control, Natural enemies, *Paracoccus marginatus*

The papaya mealybug, *Paracoccus marginatus* William and Granara de Willink (Hemiptera: Coccomorpha: Pseudococcidae), is a soft and tiny yellow insect that feeds by sucking plant sap. It is one of several invasive mealybug species that have ravaged most of the economically important agricultural and horticultural crops worldwide. This pest was initially described by Williams and Granara de Willink in 1992 and later re-described by Miller and Miller (2002). It is believed to be native to New Mexico, where it has not attained pest status, probably owing to the multiple primary parasitoids found there (Muniappan *et al.* 2009a).

Paracoccus marginatus has been reported to attack more than 60 plant species, including such economically important crops as papaya, cotton jackfruit, eggplant, mango, guava and jatropha (Miller *et al.* 2002). This mealybug is widely distributed throughout the world having been reported from more than 29 countries in Asia, Africa, North America, South America and Oceania (Williams and Granara de Willink 1992). Since 2008, *P. marginatus* has been a serious threat to many cultivated crops in India and it is likely to be found in other tropical and subtropical countries where it could threaten many economic crops. This review reports the global distribution, bio-ecology, host range, biocontrol agents and the management of *P. marginatus*, with particular reference to India.

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Origin and distribution

Paracoccus marginatus (PMB) is presumed to have originated from the Neotropical region consisting of Belize, Costa Rica, Guatemala and Mexico, *etc*. It was first recorded from Mexico in 1955 from cassava, *Manihot esculenta* Crantz**.** Later, Williams and Granara de Willink (1992) provided the first description, and was then re-described by Miller and Miller (2002). The first record of PMB as an economically important pest was in 1994 on the Caribbean island of St. Martin. Thereafter, the species has spread to 13 Caribbean countries (1994), USA (1998) and also to South America (Meyerdirk *et al.* 2004), Africa (Ghana-2009, Senegal-2013, Seychelles-2014) and Asia (India-2008, Bangladesh and Malaysia-2009, Philippines, Cambodia, Thailand and Taiwan-2010). Since then, the species has spread to Benin, Gabon, Nigeria and Togo in Africa. The latest new records are from Tanzania in 2015, Israel in 2016 and Kenya in 2017. Presently, it has been

reported from more than 29 countries worldwide. The pace at which it is expanding geographically poses a serious threat to agriculture.

P. marginatus was unknown in India prior to 2006. It was reported for the first time in India in July 2007 from papaya orchards in Tamil Nadu Agricultural University campus, Coimbatore. Later, it was found nearby and in the Tirupur, Erode, Salem, Namakkal and Karur districts of Tamil Nadu (Muniappan *et al.* 2009b). Subsequently, it has been reported from other states in India, such as Karnataka, Kerala, Andhra Pradesh, Assam, Rajasthan and Tripura. Of late, reports from West Bengal (August 2010) and Gujarat (December 2013 and January 2014) have also been seen (Table 1). It is clear that this mealybug will continue to colonize rest of India across the country under changing climatic conditions. However, classical biological control has been successful in the southern parts of India.

Biosystematics

Specimens of papaya mealybug were first collected in 1955 from Mexico, later it was described in 1992 based on the mealybug samples collected from Belize and Costa Rica (Williams and Granara de Willink 1992). The taxonomic status of *Paracoccus marginatus* Williams and Granara de Willink (Gimpel 1996):

Phylum:	Arthropoda
Class:	Insecta
Order:	Hemiptera
Suborder:	Sternorrhyncha
Family:	Pseudococcidae
Genus:	Paracoccus
Species:	Paracoccus marginatus Williams and Granara de Willink

Species description

In the field, infestation of PMB is evident as creamy-white cottony clumps adhering to the succulent parts of host plants. Adult males are 0.9 to 1.1 mm long and 0.2 to 0.3 mm wide across the thorax. Adult females are yellowish green and soft bodied and are 2.5–4 mm long. Diagnostic characters of slide mounted adult female are elongate oval-shaped body, eight segmented antenna, oral rim tubular ducts confined to the margin and sub-margin of dorsum, translucent pores present on hind coxa and each anal lobe with a ventral sclerotized anal bar (Williams and Granara de Willink 1992, Miller and Miller 2002). The white cottony ovisacs are dusted with mealy wax and a larger than the body and protrude from underneath the abdomen. The caudal filaments are about one fourth body length. Males are delicate, deep red in colour, and have: long 10-segmented antennae, legs each with a single claw, with a pair of membranous simple wings, and with two caudal filaments. Eggs are tiny and light green in colour and the first-instar nymphs emerge as active yellowish-green crawlers which disperse over the plant. Second-instar nymphs of both sexes are somewhat similar but male nymphs later turn a light pink colour, providing sex determination in this instar. The body of *Paracoccus* species often turns black in alcohol and dark-brown/black in potassium hydroxide (Watson and Chandler 1999). Identification of *P. marginatus* at the molecular level is possible using the mitochondrial cytochrome oxidase I

Table 1 Distribution and host plants of *P. marginatus* in India

Year of occurrence	State	Location (s)	Host plant	Reference
2007 (July)	Tamil Nadu	Coimbatore, Erode, Selam, Tirupur, Namakkal, Karur	Papaya	Muniappan *et al.* (2009a)
2009	Kerala	Agali, Sholayur and Puthur of Palghat	Mulberry, Papaya, *Acalypha*, Cassava,	Lyla and Philip (2010)
2009 (May)	Jammu and Kashmir	4 locations of Jammu	Papaya	Sarma (2013)
2009, 2010 (21 October)	Andhra Pradesh	Chittur Dist	Papaya, Mulberry	Shylesha *et al.* (2010)
2010	Tripura	-		Shylesha *et al.* (2010)
2010	Maharashtra	-		Shylesha *et al.* (2010)
2010	Odisha	-		Shylesha *et al.* (2010)
2010 (August)	West Bengal	Mohanpur, Nadia, North 24 Pargana, South 24 Pargana, Howrah, Hoogly, Bardhaman, Bankura	Papaya, Jackfruit, Eggplant, Cotton, Mango, Guava and Jatropha	Seni and Sahoo (2013)
2011-2012	Karnataka	Bengaluru, Mysore and other districts	Mulberry, Papaya, Guava, etc.	Gowda *et al.* (2014)
2012 (October)	Rajasthan	Udiapur	Papaya	Mani *et al.* (2012)
2012 (Winter season)	Assam	Dibrugarh	Papaya	Sharma *et al.* (2013)
2013 (December) 2014 (January)	Gujarat	Anand	Bt Cotton	Dhobi *et al.* (2014)

(CO-I) gene. Quick and accurate identification of this pest could help to boost our quarantine system in India**.**

Host plant species

PMB is highly polyphagous, damaging economically important plants belonging to over 22 families across the globe (Table 2). The host range of *P. marginatus* is large and includes field crops, vegetables, ornamentals, fruit trees and non-crop plants. The majority of host plants belong to the Malvaceae, Fabaceae, Euphorbiaceae, Rubiaceae, Solanaceae and Caricaceae. PMB is likely to inflict significant damage to papaya, tapioca, cotton, okra, brinjal, chilly and tomato. It is also known to cause severe losses to ornamental crops such as *Plumeria* and *Hibiscus* spp. PMB also colonizes such fruit crops as mango, *Annona*, avocado, *Citrus* and guava. Moreover, it is also reported to infest some non-crop plants, such as Indian nettle (*Acalypha indica*)*,* cotton buttons (*Tridax procumbens*) (Tanwar *et al.* 2010) and congress grass (*Parthenium hysterophorous*). These weeds support the carryover of the pest during the non-cropping season, when primary host plants are not available in the fields.

Bio-ecology

Extensive research on eco-biological aspects of papaya mealybug have been conducted by several researchers worldwide. Even though a year-round occurrence is noticed, the preferred condition for *P. marginatus* is warm dry weather. Prolonged drought with scanty rainfall favours rapid population growth (Ayyasamy and Regupathy 2010). Rainfall is a limiting factor to population growth as it washes the mealybug off the plants but does not kill them indeed. Temperature and relative humidity are also key abiotic factors which play a prime role in the insects' life cycle. A positive correlation (r= +0.756) has been reported between PMB population build up and temperature, whereas relative humidity (r= -0.162) and rainfall (r= -0.002) were found to have negative correlations (Seni and Sahoo 2015). PMB normally prefersa tropical climate and does not survive well in cold temperate conditions (CAB International 2001). Like other mealybug species, female *P. marginatus* have three nymphal stages before finally moulting into the apterous and less likely to move adult stage. Males have two nymphal stages followed by two non-feeding stages, the pre-pupa and pupa, before finally moulting into a delicate non-feeding, winged adult. Each adult female usually deposits 100-600 eggs (150-600 eggs – Tanwar *et al.* 2010, 100-500 eggs - Sharma 2013, 250 eggs-Amarasekare *et al.* 2008 and 299 eggs-Laneesha *et al.* 2018) in a white waxy ovisac which protrudes posteriorly to three to four times body length. Eggs usually hatch within 10 days and the emerging first-instar nymph is active and searches for a suitable site to settle. The details of the biology of *P. marginatus* have been studied by several workers.

Papaya mealybug completes its life cycle within 15-32 days depending on host plant species (Indra *et al.* 2008). It could complete around 11 generations per year with an influence of prevailing temperature and relative humidity. Time span of female ranged between 14-21 days, whereas male takes little longer time (16-23 days) for reaching sexual maturity owing to additional pre-pupal instar (Veeresh Kumar *et al.* 2014). Bisexual reproduction and parthenogenesis are the most preferred modes of reproduction.

Mutualistic association with ants

The prime reason for the mutualism of the mealybugs with ants is for transportation, even though the main dispersal of the crawlers is through wind. Ants enjoy the benefit of mutualism with mealybugs as they feed on the honeydew produced by mealybugs. It could be described as "farming" mealybugs. Because of this, the ants protect the mealybugs by attacking its predators and parasitoids. Even though ants' mutualism with mealybug is well documented, some species are famous for their predatory role in bio-control practices (Jahn *et al.* 2003). Ants benefit from the honeydew eliminated by mealybugs, which provides about half of the dietary requirement of many temperate wood ants (*Formica* sp.) and it accounts for the dominant part of subterranean ants' diet (Mittler and Douglas 2003). Ants may also utilize mealybugs as their protein source when the protein dietary requirements are not met from honeydew.

Ants' mutualistic relation with papaya mealybugs is quite general in most fields. Nearly eight ant species belonging to three subfamilies were found attending PMB on papaya, mulberry gardens and other hosts (Gowda *et al.* 2014).

Management

Effective management of mealybugs is often difficult to achieve due to their wax coating and their cottony ovisac, which provide some protection against adverse environmental conditions and pesticides. Therefore, management of mealybugs should involve an integrative approach, comprising cultural, legal, biological and chemical strategies in a compatible manner.

Legal strategies: Free movement of infested fruits, vegetables and other material within and between countries is one of the main reasons for the rapid spread of PMB. Enforcement of strict quarantine measures is essential in preventing entry of mealybug species into new areas. Containment of pests within a country should be achieved by domestic quarantine measures, whilst the strengthening international quarantine laws is essential for preventing long-distance movement of pest species (Tanwar *et al.* 2010).

Cultural management: Availability of alternative hosts including non-crop plants such as weeds in and around fields, movement of crawlers through irrigation water and on farm equipment etc., are some of the factors responsible for the spread of PMB within and between the fields. By adopting simple cultural practices such as pruning and burning of infested branches, removal of alternate host plants such as *Hibiscus* spp. and *Parthenium*, avoiding flood irrigation, sanitation of farm equipment before and after use, and using pest-free planting materials, etc. would help in containing

Table 2 Plant species recorded as hosts of *P. marginatus*

Family	Host plant	Reference
Acanthaceae	Wild bergamot, *Fistulosa* sp. golden shrimp plant, *Pachystachys lutea*	Miller and Miller (2002)
Aizoaceae	Black pig weed, *Trianthema portulacastrum* L.	Tanwar *et al.* (2010)
Amaranthaceae	Devil's horsewhip, *Achyranthus aspera* L	Miller and Miller (2002)
Annonaceae	Sweetsops, *Annona squamosa* L. Ramphal, *A .reticulata* L. Soarsops, *A. muricata* L.	Tanwar *et al.* (2010) Miller and Miller (2002)
Capridaceae	Asian spider flower, *Cleome viscose*	Tanwar *et al.* (2010)
Commelinaceae	Tropical spiderwort, *Commelina bengalensis* L.	Tanwar *et al.* (2010)
Convolvulaceae	Field bindweed, *Convolvulus arvensis* L. Morning glory, *Ipomoea carnea* Jacq.	Tanwar *et al.* (2010), Miller and Miller (2002)
Euphorbiaceae	Copper leaf, *Acalypha* spp. *A. wilkesiana* Muell. Asthma plant, *Euphobia hirta* L. Barbados nut, *Jatropha curcus* L. Spicy jatropha, *J. Integerrima* Jacq. Cassava, *Manihot esculenta* Crantz. Gale of the wind, *Phyllanthus nirruri* L. Castor, *Ricinus communis* L.	Tanwar *et al.* (2010), Miller and Miller (2002), Williams and Granara de Willink (1992)
Fabaceae	Wattles, *Acacia* spp. Orchid tree, *Bauhinia* sp. Pigeon pea, *Cajanus cajan* (L) Millsp. Lucky bean tree, *Erythrinaa byssinica* Lam. Quick stick, *Gliricidia sepium* Jacq. Catclaw mimosa, *Mimosa pigra* L. Rabbit vine, *Tetramnus labialis* L.	Miller and Miller (2002), Matile-Ferrero and Etienne (1998), Williams and Granara De Willink (1992)
Lamiaceae	Thumbai, *Leucas aspera* (Willd.) Holy basil, *Ocimum sanctum* L. Pagoda flower, *Clerodendrum paniculatum* L. Teak, *Tectona grandis* L.	Tanwar *et al.* (2010) Miller and Miller (2002)
Lauraceae	Avocado, *Persea americana* Mill.	Miller and Miller (2002)
Malvaceae	Indian mallow, *Abutilon indicum* (L.) Sweet Capoktree, *Ceiba pentandra* (L.) Gaertn. Cotton, *Gossypium hirsutum* L. China rose, *Hibiscus rosa-sinensis* L. Lipstick hibiscus, *Malvavis cusarboreus* (DC.) Common wire weed, *Sida* sp.	Tanwar *et al.* (2010), Williams and Granara de Willink (1992)
Moraceae	Mulberry, *Morus alba* L.	Tanwar *et al.* (2010)
Myrtaceae	Guava, *Psidium guajava* L.	Tanwar *et al.* (2010)
Phyllanthaceae	Amla, *Phyllanthus emblica* L.	Mani Chellappan *et al.* (2013)
Poaceae	Sea oats, *Uniola paniculata* L. Maize, *Zea mays* L.	Miller and Miller (2002)
Polygonaceae	Buckwheat, *Coccoloba* sp.	Miller and Miller (2002)
Rosaceae	Indian hawthorn, *Raphiolepis umbellata* (Thunb.) Rose, *Rosa* sp.	Miller and Miller (2002)
Rubiaceae	Turkey berry, *Canthium inerme* L. Scarlet bush, *Hamelia* sp. Prophet's Tears, *Mussaenda* sp.	Tanwar *et al.* (2010)
Rutaceae	Grape fruit, *Citrus paradisi* MCfad.	Miller and Miller (2002)
Solanaceae	Night blooming jasmine, *Cestrum nocturnum* L., Tomato, *Solanum lycopersicum* Mill.	Tanwar *et al.* (2010), Miller and Miller (2002)

this pest within the infected area (Tanwar *et al.* 2010, Ayyasamy and Regupathy 2010).

Chemical management: Papaya mealybugs are very hard to kill owing to the waxy coatings all over the body in all stages of mealybugs, which provide some protection against the action of insecticides limiting the effectiveness of chemical insecticides as management strategy. However, with the high fecundity, short life cycle, rapid rate of development and high survival rate coupled with favourable environmental conditions, *P. marginatus* does cause serious outbreaks. In such situations, the use of insecticides is the only effective control measure.

In India, there are about 32 insecticides and eight combination products registered with the Central Insecticide Board and Registration Committee (CIB and RC) for sucking pest management in cotton, tomato, brinjal and papaya. Conventional insecticides, such as methyl demeton, quinalphos, fenthion, acephate, dimethoate, malathion, and white mineral oils were the earlier preferred chemicals for bringing down population levels. Newer insecticides, such as buprofezin, imidacloprid, thiomethoxam, spirotetramat have been found to be very effective (Seni and Sahoo 2015). Bio-efficacy trials of various pesticides on PMB have been conducted in different parts of the world (Seni and Sahoo 2015). However, the resistant nature of the waxy coating, the toxicity against natural enemies and the need for frequent applications of pesticides, renders insecticidal treatments effective only for the short period.

Effect of insecticides on natural enemies

Classical biological control was considered as an important component in the management of *P. marginatus*. The main contributors of PMB control are the three species of parasitoids belonging to the family Encyrtidae, viz. *Acerophagus papayae* Noyes and Schauff, *Anagyrus loecki* Noyes and Menezes and *Pseudoleptomastix mexicana* Noyes and Schauff. Even though the chemical pesticides are being used as a last resort to manage papaya mealybug outbreaks, they give only temporary relief and often farmers have to spray repeatedly resulting in toxicity, pollution and high mortality of beneficial insects. Sakthivel *et al.* (2012) studied the effect of some recommended insecticides, viz. thiamethoxam, chlorpyriphos, dichlorvos, fish oil rosin soap (FORS) and neem oil on *A. papayae*. Selected insecticides caused 100% mortality of adults within 3 h of treatment. Fish Oil Rosin Soap (FORS) and Neem oil were less detrimental and resulted in a very low mortality 24 h after treatment. The residual toxicity of the most persistent insecticide thiamethoxam was 27% mortality of *A. papayae* 28 days post treatment. Neem oil and Fish Oil Rosin Soap became less or non-toxic to adults of *A. papayae* at 3 days post treatment. Same workers also studied the effect of dichlorvos and dimethoate on parasitism rate of *A. papayae* on PMB. A pronounced reduction in per cent parasitism by *A. papayae* adults were noticed in the plots treated with the two sprays of dimethoate (81%), dimethoate after dichlorvos (74%), dichlorvos after dimethoate (68%), followed by two sprays of dichlorvos (62%) at 10 day intervals, which owed to remarkable increase in the population of PMB in the treated plots (27.8–42.5%) over the control (Sakthivel *et al.* 2015). Chlorpyriphos and malathion have been reported as highly toxic to female mealybugs, whereas chlorpyriphos and dichlorovos caused low mortality to *Cryptolaemus montrouzieri* Mulsant, a predator of both *P. marginatus* and *P. solenopsis* (Suroshe 2011). This all indicates that the choice of pesticide for chemical control requires utmost care.

Role of natural enemies in management of P. marginatus

Biological control through the use of entomopathogens, predators and parasitoids can provide excellent control of mealybugs, i.e. pink mealybug, *Maconellicoccus hirsutus* (Green) in the Caribbean (Kairo *et al.* 2000), cassava mealybug, *Phenacoccus manihoti* Matile-Ferrero in Africa (Herren *et al.* 1987), cotton mealybug, *P. solenopsis* in Pakistan (Solangi *et al.* 2012) and India (Fand and Suroshe 2015), citrus mealybug, *Planococcus citri* (Risso) in India (Singh *et al.* 2004), *etc.* A handful of predators and parasitoids associated with *P. marginatus* have been recorded from different agro-ecosystems, such as coccinellid beetles (Ladybirds), chrysopids (lacewings), syrphid flies and lepidopteran predatory caterpillars (Table 3 and 4). Research on *P. solenopsis* (Suroshe *et al.* 2013) has found that coccinellids and chrysopids are the major predators and this is probably true for PMB as well.

A number of hymenopteran parasitoids belonging to the family Encyrtidae were reported as indigenous to the origin of mealybug, viz. *A. loecki, Apoanagyrus californicus* Compere, *A. papayae, Pseudophycus* sp. and *P. mexicana*, from other countries as part of classical biological control programmes. Since parasitoids were proven to be an effective means of PMB control, three exotic Encyrtid parasitoids, viz. *A. loecki, A. papayae* and *P. mexicana* were introduced to India from USDA-APHIS, Puerto Rico, on 15 July 2010, by NBAIR, Bengaluru, India. After testing their safety under quarantine facilities, the parasitoids were released in several states, such as Tamil Nadu, Karnataka, Andhra Pradesh, etc. The effectiveness of these three exotic parasitoids against *P. marginatus* was studied on PMB-infested mulberry in six locations, three each in Thirunelveli and Virudanagar districts of Tamil Nadu (Muniappan *et al.* 2006). An average of 10.4% parasitism and 9.7% reduction in papaya mealybug population was noticed within a month of release and thereafter, a gradual decrease in mealybug population and an increase in percentage parasitism was noted. Among the parasitoids released, the highest population and greatest field activity was observed in the case of *A. papayae*, which accounted for 75.6–81.7% parasitism, followed by *P. mexicana* (9.3-24.4%), whereas *A. loecki* was comparatively very poor with 0.7–9.0% and was not recovered in the field four months after release.

Other alternative control measures

Biopesticides are environmentally safe but still remain less used for PMB than other chemicals. Fish oil rosin soap,

Table 3 Predators recorded as associated with *P. marginatus*

Species name	Order: Family	Host plants	Country	Reference
Brumoides suturalis (Fabricius)	Coleoptera: Coccinellidae	Cotton, Papaya	India	Tanwar *et al.* (2010)
Cheilomenes sexmaculata (Fabricius)	Coleoptera: Coccinellidae	Papaya	India	Tanwar *et al.* (2010)
Coccinella septempunctata L.	Coleoptera: Coccinellidae	Papaya	India	Tanwar *et al.* (2010)
Nephus regularis Sicard	Coleoptera: Coccinellidae	Papaya	India	Tanwar *et al.* (2010)
Scymnus coccivora Ayyar	Coleoptera: Coccinellidae	Papaya, Plumaria	India Thailand	Tanwar *et al.* (2010)
Cryptogonus Orbiculus (Gyllenhal)	Coleoptera: Coccinellidae	Papaya, Plumaria	Thailand	Saengyot and Burikam (2011)
Scymnus quadrillum Motschulsky	Coleoptera:Coccinellidae	Papaya, Plumaria	Thailand	Saengyot and Burikam (2011)
Cryptolaemus montrouzieri (Mulsant)	Coleoptera: Coccinellidae	Cotton, Papaya	India Malaysia Hawaii	Tanwar *et al.* (2010), Mastoi *et al.* (2015)
Sasajiscymnus quinquepunctatus (Weise)	Coleoptera: Coccinellidae	Papaya, Plumaria	Thailand	Saengyot and Burikam (2011)
Chrysoperla pallia sp. nov. Henry	Neuroptera: Chrysopidae	Papaya, Plumaria, Cotton	India Thailand	Tanwar *et al.* (2010), Ayyasamy and Ragupathy (2010)
Mallada basalis (Walker)	Neuroptera: Chrysopidae	Papaya, Plumaria	India Thailand	Tanwar *et al.* (2010)
Apertochrysa sp.	Neuroptera: Chrysopidae	Papaya	Malaysia	Mastoi *et al.* (2015)
Orius sp.	Hemiptera: Anthocoridae	Papaya	India	Tanwar *et al.* (2010)
Spalgius epius (Westwood)	Lepidoptera, Lycaenidae	Papaya	India Thailand	Tanwar *et al.* (2010)
Stethorus sp.	Lepidoptera: Lycaenidae	Papaya, Plumaria	Thailand	Saengyot and Burikam (2011)

Table 4 Parasitoids reported as associated with *P. marginatus*

Species name	Order: Family	Host plants	Country	Reference
Acerophagus papayae (Noyes and Schauff)	Hymenoptera: Encyrtidae	Papaya, Plumaria Cassava Cotton	India Indonesia Sri Lanka	Tanwar *et al.* (2010) Ayyasamy and Ragupathy (2010) Muniappan *et al.* (2009a)
Anagyrus loecki (Noyes)	Hymenoptera: Encyrtidae	Papaya, Plumaria Cassava	India Indonesia Sri Lanka Malaysia	Tanwar *et al.* (2010) Muniappan *et al.* (2009a) Matsoi *et al.* (2011)
Pseudleptomastrix mexicana (Noyes and Schauff)	Hymenoptera: Encyrtidae	Papaya, Plumaria Cassava Cotton	India Indonesia Sri Lanka Malaysia Florida	Tanwar *et al.* (2010) Muniappan *et al.* (2009a) Matsoi *et al.* (2011) Amarasekare *et al.* (2010)
Apoanagyrus californicus Compere	Hymenoptera: Encyrtidae		Mexico Puerto Rico	Meyerdirk and Kauffman (2001)
Pseudophycus sp.	Hymenoptera: Encyrtidae	Papaya	Mexico	Meyerdirk and Kauffman (2001)
Marietta leopardina	Hymenoptera: Aphelinidae	Papaya	Malaysia	Matsoi *et al.* (2011)
Chartocerus sp.	Hymenoptera: Signophoridae	Papaya	Malaysia	Matsoi *et al.* (2011)
Cheiloneurus sp.	Hymenoptera: Encyrtidae	Papaya	Malaysia	Matsoi *et al.* (2011)

azadirachtin and white mineral oils have been found to be partially effective against PMB. Surfactants have also been recommended for the removal of the waxy coating. The insecticidal formulations based on *Datura stramonium* L, *Azadiracta indica* A. Juss and *Nicotiana tabacum* L are in common use, along with suitable surfactants (Krishnan *et al.* 2016). The fungal pathogens, *Verticillium lecanii* (Zimm.), *Beauvaria bassiana* (Bals.) *Paecilomyces pictus*, *Neozygytes* and *Metarhizium anisopliae* (Metsch.) are known to cause 40-50% mortality of *P. marginatus* (Ayyasamy and Ragupathy 2010).

Conclusion

The papaya mealybug, *P. marginatus,* an invasive pest of Central American origin, has become a nuisance since recent years. It is highly polyphagous and reported to have host range up to 60 plant species belonging to more than 22 families across the globe. Within a short span of time, papaya mealybug has caused havoc in many developing countries especially in Asian continent. It has assumed major pest status in India since 2009, when there was a devastating outbreak in south India. Since most of the homopteran pests are highly preferred by generalist predator as well as host specific parasitoids, the application of insecticide should be restricted to conserve these bio-agents. Emphasis must be given on the augmentation of most potent hymenopteran parasitoid, *A. papayae*. This parasitoid has already played a predominant role in suppressing the papaya mealybug in several countries in the range of 75–81%. We must work on reducing the greenhouse gases by adopting conservation agricultural practices like crop residue management, cultural practices to minimize pest infestation, following region specific cropping systems which are more vulnerable to climate change and by developing robust varieties that are resilient to biotic and abiotic stress factors. All the available tactics of management has to percolate down to each and every segment of the stakeholders for managing the quarantine sucking insect pests of national importance.

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