



Review Article

Paracoccus marginatus, an invasive mealybug of papaya and its biological control – An overview

M. MANI, C. SHIVARAJU and A. N. SHYLESHA*

Division of Entomology & Nematology

Indian Institute of Horticultural Research, Hessaraghatta, Bangalore 560 089, Karnataka, India

*National Bureau of Agriculturally Important Insects, Bangalore 560 024, Karnataka, India

*Corresponding author: E-mail: anshylesha@gmail.com

ABSTRACT: The papaya mealybug, *Paracoccus marginatus* Williams and Granara de Willink (Hemiptera: Pseudococcidae) is native of Mexico and /or Central and North America. Since its description in 1992, it has invaded several Caribbean Islands, Florida, Sri Lanka, Indonesia, Taiwan, India, Bangladesh, West Africa, and it is likely to spread many other countries. It is highly polyphagous attacking more than 70 plant species causing severe loss. Insecticides failed to give adequate control of *P. marginatus*. On the other hand, natural enemies particularly, *Acerophagus papayae* Noyes and Schauff were highly useful to suppress the papaya mealybug. Its origin, distribution, taxonomy, biology, ecology, host range, natural enemies and methods of control particularly classical biological control are reviewed here.

KEY WORDS: *Paracoccus marginatus*, invasive mealybug, *Acerophagus papayae*, biology, distribution, host range, natural enemies, taxonomy, classical biological control.

(Article chronicle: Received: 30-05-2012 Revised: 16-06-2012 Accepted: 18-06-2012)

INTRODUCTION

Mealybugs throughout the world cause various economic problems. *Paracoccus marginatus* Williams and Granara de Willink, popularly known as papaya mealybug (PMB) has invaded several countries and damaged many economically important crop plants (Muniappan *et al.*, 2008; Shylesha *et al.*, 2011a). It is 'hard to kill pest' with conventional insecticides because of cryptic habit and waxy coating over the body. This review provides information on the biosystematics, origin, distribution, biology, host range, ecology, natural enemies, management options with particular emphasis on biological control which will be ultimately useful for the successful management of papaya mealybug.

ORIGIN AND DISTRIBUTION

Paracoccus marginatus is native to Mexico and/or Central and North America (Miller *et al.*, 1999; Watson and Chandler, 1999). Since its first description in 1992 from new tropical region, *P. marginatus* has spread to several Caribbean islands and central and south America (Miller *et al.*, 1999; Matile-Ferro *et al.*, 2000; Kauffman *et al.*, 2001a; Watson and Chandler, 1999; Miller and Miller, 1999), Mexico (Williams & Granara de Willink, 1992); U.S. Virgin Islands (CABI/EPPO, 2000); The

Dominican Republic (CABI/EPPO, 2000) and Grenada in 1994, Antigua and Barbuda (CABI/EPPO, 2000), Saint Martin (Pollard, 1999) and The British Virgin Islands in 1996 (CABI/EPPO, 2000); USA (Florida) (Pollard, 1999; Miller and Miller, 2002; Walker *et al.*, 2006), Haiti, St. Kitts and Nevis (CABI/EPPO, 2000); St Barthélemy (Ben Dov, 2008) Guatemala (Ben Dov, 2008), Haiti (CABI/EPPO, 2000) and Guadeloupe (Ben Dov, 2008) in 1998; French Guyana (Ben Dov, 2008), Guiana (Ben Dov, 2008), Guadeloupe (Matile-Ferrero and Etienne, 1998), Cuba (CABI/EPPO, 2000), and Puerto Rico in 1999 (CABI/EPPO, 2000); Barbados (CABI/EPPO, 2000); Belize (Ben Dov, 2010), the Cayman Islands (CABI/EPPO, 2000), Costa Rica (Ben Dov, 2010), Cayman and Montserrat in 2000 (CABI/EPPO, 2000), Netherlands Antilles (CABI/EPPO, 2000), the Bahamas and Guam in 2002-03 ((Meyerdirk *et al.*, 2004); Palau in 2003 (Anonymous, 2003; Muniappan *et al.*, 2006) and neighboring islands in the Pacific (Meyerdirk *et al.*, 2004).; Hawaii-Maui and Oahu in 2004 (Heu and Fukada, 2005; Heu *et al.*, 2007), the Northern Marianas (Tinian) in 2005 and the Northern Marianas (Tinian) in 2005.

In Africa, it was reported in Ghana in 2009 (Cham *et al.*, 2011). In South and South East Asian region it was noticed in during 2008-09. In May 2008, it was recorded in Java, Indonesia and later spread to Bali and Sulawesi

Islands (Muniappan *et al.*, 2008 & 2009). It was also reported in July 2008 in Colombo and Gampaha districts in Sri Lanka (Galanihe *et al.*, 2010), Joyedpur in Bangladesh; Phnom Penh in Cambodia in 2010, Manila in Philippines in 2008; Thailand in 2010 (Muniappan *et al.*, 2009). In Malaysia, *P. marginatus* was first reported from Negeri Sembilan and Selangor in February, 2009 (Muniappan *et al.*, 2008; Mastoi *et al.*, 2011) and Taiwan in 2010 (Chen *et al.*, 2011) and Maldives very recently.

In India, it was first reported from Coimbatore in Tamil Nadu in July, 2008 (Muniappan *et al.*, 2008 & 2009; Regupathy and Ayyasamy, 2009; Suresh *et al.*, 2010). Since July 2008, it has spread subsequently to neighboring states such as Karnataka, Andhra Pradesh, Maharashtra, Kerala and to distant states like Tripura, Assam and Orissa in India (Shylesha *et al.*, 2011c; Rabindra, 2010; Krishnamurthy and Mani 2011; Sajeev, 2011; Jacob Mathew, 2011; Mani Chellappan, 2011a; Chandele *et al.*, 2011; Lyla and Philip, 2010; Krishnakumar and Rajan, 2009; Mahalingam *et al.*, 2010; Suresh *et al.*, 2010).

SYSTEMATICS

Paracoccus marginatus specimens were collected first in 1955 in Mexico, but it was described in 1992 from the specimen collected in neotropical region (Belize, Costa Rica, Guatemala and Mexico) by Williams & Granara de Willink (1992) and later redescribed by

Miller and Miller (2002) and Angeles Martinez and De Los Suris (2005). Miller and Miller (2002) gave a complete description of all the stages of the papaya mealybug.

Adult male *P. marginatus* has a distinct aedeagus with ventral lobes that are broad and cylindrical in dorsal ventral view, lateral pore clusters, a heavily sclerotised thorax and head and well developed wings. Antenna is 10 segmented with bristle shaped and fleshy setae. Eight abdominal tergite usually without setae Adult males are approximately 1.0 mm long, with an elongate oval body and the thorax is 0.3 mm wide. 17 numbers of cerari, presence of oral rims on margins of coxae, a heavily sclerotized thorax and head, and well-developed wings (Watson and Chandler, 1999).

Adult female body is greenish yellow, dusted with mealywax not thick enough to hide body colour, without discrete bare areas on dorsum, with many short waxy filaments around the body margin. Caudal filaments are about one fourth of the body length. Adult females are wingless, 2-3 mm long; and 1.4mm wide. The species epithet is derived from a Latin word, meaning enclosed with a border and refers to the border of oral rim tubular ducts (Williams & Granara de Willink, 1992).

BIOLOGY

Details on the biology of *P. marginatus* were given by Amarasekare *et al.* (2008 a & b), Wallker *et al.* (2006)

Table 1. Development of *Paracoccus marginatus* at different temperature (Amarasekare *et al.*, 2008a)

Temp (± °C)	Life history stage								
	Egg	First	Second		Third		Fourth	Cumulative	
			Male	Female	Male	Female		Male	Female
15	27.5±0.2 ^a								
18	23.1±0.2 ^b	25.3±0.5 ^a	21.1±1.6 ^a	13.5±1.3 ^a	7.0±1.8 ^a	13.2±0.9 ^a	11.7± 1.8 ^a	85.2±1.8 ^a	74.4±1.4 ^a
20	14.4±0.2 ^c	14.6±0.5 ^b	13.6±0.8 ^b	9.3±0.7 ^b	4.5±0.7 ^{ab}	8.9±0.9 ^b	8.9± 0.7 ^a	53.4±0.7 ^b	45.9±0.9 ^b
25	8.7±0.1 ^d	6.5± 0.1 ^c	6.6± 0.5 ^c	5.5±0.5 ^c	2.4±0.5 ^b	5.2±0.2 ^c	4.1± 0.5 ^b	28.5±0.3 ^c	25.9±0.2 ^c
30	7.3±0.2 ^c	6.1± 0.2 ^c	6.3± 0.4 ^c	5.7±0.4 ^c	4.4± 0.3 ^c	4.4±0.3 ^c	3.6± 0.4 ^b	24.9±0.6 ^c	23.2± 0.3 ^c
34	5.9±0.1 ^f	–	–	–	–	–	–	–	–
35	5.5±0.1 ^f	–	–	–	–	–	–	–	–
37	0.0	–	–	–	–	–	–	–	–
F	1922.10	100.59	57.41	17.09	5.35	15.31	15.66	725.42	521.23
df	6.212	3.132	3.97	3.104	3.94	3.95	3.91	3.84	3.90
p	<0.0001	<0.0001	<0.0001	<0.0001	<0.0020	<0.0001	<0.0001	<0.0001	<0.0001

Means within a column followed by the same letters are not significantly different at $\alpha = 0.05$ (Tukey's test n = 35)

and Thangamalar *et al.* (2010). There were differences in the developmental times of *P. marginatus* when reared on different host plants and also at different temperatures.

A single female lays about 230 eggs (Amarasekare *et al.*, 2008a) and 300-400 eggs (Mahalingam *et al.*, 2010) in an ovisac. The ovisac, developed ventrally, is three to four times the body length and entirely covered with white wax ((Pantoja *et al.*, 2007).

Females undergo only three instars and no sexual dimorphism between male and female instars. However the duration of I, II and III instar nymph in mealybug was 6.5, 5.5 and 5.2 day respectively at 25°C (Amarasekare *et al.*, 2008a). The species is known to reproduce both sexually and parthenogenitically (CAB International, 2001). Adult female mealybug secretes large amounts of white wax. When specimens are placed in alcohol, they turned into blue black (Pantoja *et al.*, 2007).

Males have longer development time (27-30 days) than females (24-26 days) at 25±1°C, 65±2% RH and 12:12 (L:D) photoperiod (CAB International, 2001). Mean longevity of adult males and females was 2.3 and 21.2 days respectively (Amarasekare *et al.*, 2008a).

The ovipositional period is usually one to two weeks. Eggs are greenish yellow and egg hatching occurs in about 10 days.

Males undergo four instars, the first instar nymphs are called as crawlers, and the duration of I, II, III and IV instar male nymph was 6.5, 6.6, 2.4 and 41 days respectively at 25°C (Table 1). The fourth instar, referred as pupa stays in the cocoon. Adult males are yellow in the first and second instar and later turn pink during the pre-pupal and pupal stages (Amarasekare *et al.*, 2008 a).

DAMAGE

Papaya mealybug infestations are typically observed as clusters of cotton-like masses on the above-ground portion of plants. *Paracoccus marginatus* damages various parts of the host plant including the leaves, stems, flowers and fruits. *P. marginatus* may show very similar symptoms to pink hibiscus mealybug, *Maconellicoccus hirsutus* (Green) (Pollard, 1999). The insect sucks the sap by inserting its stylets into the epidermis of the leaf, fruit and stem. While feeding, it injects a toxic substance into the leaves resulting in curling, crinkling, rosetting, twisting and general leaf distortion (Miller *et al.*, 1999; Walker *et al.*, 2003; Heu and Fukada, 2005; Pantoja *et al.*, 2007). Heavy mealybug infestations render fruit

inedible. Due to the build-up of thick white waxy coating and sooty mould development on the honeydew excreted by mealybug, infested fruits get reduced market value. Fruits may fail to develop normally and may be unusually small. Such fruits eventually shrivel and drop (Tanwar *et al.*, 2010; Heu *et al.*, 2007). Some economically important crops such as papaya, mulberry, cotton, cassava, citrus, sweet potato, peas and beans, okra, eggplant, guava and ornamentals such as hibiscus, *Jathropha*, *Allamanda*, *Acalypha* McComie, 2000b; Meyerdirk *et al.*, 2000; Shylesha *et al.*, 2011b).

ECOLOGY

The incidence of *P. marginatus* was noticed throughout the year, but active in warm dry weather. Prolonged drought with scanty rain fall and less number of rainy days favour the faster multiplication (Ayyasamy and Regupahy, 2010). During the rainy season, population of *P. marginatus* especially the crawlers decreased drastically because heavy rain washed the insects off the plants. However, mealybugs sheltered within unopened leaves and other hiding places survived and built up their numbers again during the warm, dry weather. The climatic preferences of *P. marginatus* have been documented well, but its occurrence in countries located 30°C from the Equator suggest that probably does not tolerate cold conditions (CAB International, 2001).

HOST PLANTS

It is a highly polyphagous insect pest that can damage large number of tropical and subtropical fruits, vegetables and ornamental plants (Miller and Miller, 2002). According to Muniyappan *et al.* (2008), it was known to infest plants belonging to 22 families from Asia. Galanihe *et al.*, (2010) recorded more than 40 plant species in Sri Lanka compared to 55 plants species recorded in Florida (Walker *et al.*, 2003). *P. araccois marginatus* attacks over 60 species of plants including field crops, fruit trees ornamentals, weed and scrub vegetation in India (Shylesha *et al.*, 2011b).

NATURAL ENEMIES

It has never gained the status as a pest in the native home of Mexico, Central and North America probably, due to presence of endemic natural enemy complex (Walker *et al.*, 2003). The *P. marginatus* papaya mealybug became pest when it invaded the Caribbean region mainly due to the absence of natural enemies. *Spalgius epeius* Westwood was the predominant natural

enemy on *P. marginatus* on papaya mealybug damaging several host plants in South India (Thangamalar *et al.*, 2010). *Cryptolaemus montrouzieri* Mulsant, a general predator of mealybug was also recorded occasionally on *P. marginatus* papaya mealybug in India and elsewhere. Parasitoids of *P. marginatus* from Mexico and Caribbean are listed by Schauff (2000). Four species of chalcidoid parasitoids and two predators were found attacking *P. marginatus* in Malaysia (Mastoi *et al.*, 2011).

A total of 22 natural enemies occurring either naturally /introduced were reported on papaya mealybug in different countries (Table 2).

Table 2. List of host plants for papaya mealybug, *Paracoccus marginatus*

Family and Species	Country	References
Caricaceae		
<i>Carica papaya</i>	Ghana,	Cham <i>et al.</i> (2011)
	India	Shylesha <i>et al.</i> (2011d) Tanwar <i>et al.</i> (2010) Mani Chellappan (2011a) Muniappan <i>et al.</i> (2008) Jacob Mathew (2011)
	Florida	Walker <i>et al.</i> (2003) Miller and Miller (2002)
	Sri Lanka	Galanihe <i>et al.</i> (2010)
	Malaysia	Mastoi <i>et al.</i> (2011)
	Puerto Rico	Pantoja <i>et al.</i> (2007)
	Indonesia	Muniappan <i>et al.</i> (2008)
	Hawaii	Ronald <i>et al.</i> (2007)
	Palau	Muniappan <i>et al.</i> (2006)
	Anacardiaceae	Ghana
<i>Mangifera indica</i>	Florida	Walker <i>et al.</i> (2003)
	Sri Lanka	Galanihe <i>et al.</i> (2010)
	Palau	Anonymous (2003)
	India	Muniappan <i>et al.</i> (2008) Jacob Mathew (2011) Shylesha <i>et al.</i> (2011d)
Indonesia	Muniappan <i>et al.</i> (2008)	
	Hawaii	Ronald <i>et al.</i> (2007)
Apocynaceae		
<i>Plumeria alba</i>	Ghana	Cham <i>et al.</i> (2011)
	Ghana	Cham <i>et al.</i> (2011)
<i>Plumeria rubra</i>	Palau	Muniappan <i>et al.</i> (2006)
	Florida	Miller and Miller (2002)
	India	Muniappan <i>et al.</i> (2008) Mani Chellappan, (2011a) Jacob Mathew (2011) Shylesha <i>et al.</i> (2011d)

Family and Species	Country	References	
	Indonesia	Muniappan <i>et al.</i> (2008)	
	Hawaii	Ronald <i>et al.</i> (2007)	
	Guam	Meyerdirka <i>et al.</i> (2004)	
Euphorbiaceae <i>Manihot esculenta</i>	Ghana	Cham <i>et al.</i> (2011)	
	India	Mani Chellappan (2011a) Jacob Mathew (2011) Muniappan <i>et al.</i> (2008) Tanwar <i>et al.</i> (2010) Shylesha <i>et al.</i> (2011d)	
	Sri Lanka	Galanihe <i>et al.</i> (2010)	
	Palau	Muniappan <i>et al.</i> (2006)	
	Puerto Rico	Pantoja <i>et al.</i> (2007)	
	Florida	Miller and Miller (2002)	
	Indonesia	Muniappan <i>et al.</i> (2008)	
	Malaysia	Mastoi <i>et al.</i> (2011)	
	<i>Euphorbia hirta</i>	Ghana	Cham <i>et al.</i> (2011)
		India	Tanwar <i>et al.</i> (2010) Shylesha <i>et al.</i> (2011d)
<i>Euphorbia heterophylla</i>	Ghana	Cham <i>et al.</i> (2011)	
<i>Hura crepitans</i>	Ghana	Cham <i>et al.</i> (2011)	
	India	Tanwar <i>et al.</i> (2010)	
<i>Phyllanthus niruri</i>	India	Tanwar <i>et al.</i> (2010)	
	Florida	Miller and Miller (2002)	
<i>Acalypha</i> sp	Ghana	Cham <i>et al.</i> (2011)	
	Puerto Rico	Pantoja <i>et al.</i> (2007)	
Convolvulaceae <i>Ipomoea batatas</i>	India	Muniappan <i>et al.</i> (2008)	
	Indonesia	Muniappan <i>et al.</i> (2008)	
	Hawaii	Ronald <i>et al.</i> (2007)	
Leguminaceae /Fabaceae <i>Cajanus cajan</i>	Ghana	Cham <i>et al.</i> (2011)	
	India	Tanwar <i>et al.</i> (2010) Shylesha <i>et al.</i> (2011d) Muniappan <i>et al.</i> (2008)	
<i>Glyricidia sepium</i>	Ghana	Cham <i>et al.</i> (2011)	
<i>Phaseolus vulgaris</i>	Ghana	Cham <i>et al.</i> (2011)	
	Florida	Walker <i>et al.</i> (2003)	
	Sri Lanka	Galanihe <i>et al.</i> (2010)	
	Palau	Muniappan <i>et al.</i> (2006)	
	Hawaii	Ronald <i>et al.</i> (2007)	
<i>Vigna unguiculata</i>	Ghana	Cham <i>et al.</i> (2011)	
	India	Mani Chellappan (2011a) Shylesha <i>et al.</i> (2011d)	

Family and Species	Country	References	Family and Species	Country	References
<i>Arachis hypogaea</i>	Ghana	Cham <i>et al.</i> (2011)	<i>Lycopersicon esculentum</i>	Ghana India	Cham <i>et al.</i> (2011) Tanwar <i>et al.</i> (2010)
<i>Phaseolus atropurpureus</i>	Ghana	Cham <i>et al.</i> (2011)		Florida	Mani Chellappan (2011a) Walker <i>et al.</i> (2003)
<i>Gliricidia sepium</i>	Sri Lanka	Galanihe <i>et al.</i> (2010)		Palau Hawaii	Galanihe <i>et al.</i> (2010) Muniappan <i>et al.</i> (2006) Ronald <i>et al.</i> (2007)
<i>Mimosa nigra</i>	Florida	Miller and Miller (2002)	<i>Solanum melongena</i>	Ghana India	Cham <i>et al.</i> (2011) Tanwar <i>et al.</i> (2010)
Acacia	Florida	Miller and Miller (2002)		Florida	Mani Chellappan (2011a) Walker <i>et al.</i> (2003)
Malvaceae				Sri Lanka Palau Hawaii	Galanihe <i>et al.</i> (2010) Muniappan <i>et al.</i> (2006) Ronald <i>et al.</i> (2007)
<i>Abelmoschus esculentus</i>	Ghana	Cham <i>et al.</i> (2011)		Malaysia Puerto Rico	Mastoi <i>et al.</i> (2011) Pantoja <i>et al.</i> (2007)
<i>Abutilon indicum</i>	Ghana India	Cham <i>et al.</i> (2011) Tanwar <i>et al.</i> (2010)	<i>Solanaum torvum</i>	India	Tanwar <i>et al.</i> (2010)
<i>Sida sp</i>	Ghana Florida	Cham <i>et al.</i> (2011) Miller and Miller (2002)	Compositae		
<i>Ceiba pentandra</i>	Ghana	Cham <i>et al.</i> (2011)	<i>Tridax procumbens</i>	Ghana India	Cham <i>et al.</i> (2011) Tanwar <i>et al.</i> (2010)
<i>Gossypium hirsutum</i>	India Florida	Tanwar <i>et al.</i> (2010) Walker <i>et al.</i> (2003)	<i>Launaea taraxacifolia</i>	Ghana	Cham <i>et al.</i> (2011)
<i>Hibiscus rosa sinensis</i>	India	Shylesha <i>et al.</i> (2011d) Tanwar <i>et al.</i> (2010) Mani Chellappan (2011a) Muniappan, <i>et al.</i> (2008) Jacob Mathew (2011)	Cucurbitaceae		
	Florida	Walker <i>et al.</i> (2003) Miller and Miller (2002)	<i>Luffa cylindrical</i>	Ghana	Cham <i>et al.</i> (2011)
	Sri Lanka	Galanihe <i>et al.</i> (2010)	<i>Curcubita sp</i>	Ghana Palau	Cham <i>et al.</i> (2011) Muniappan <i>et al.</i> (2006)
	Malaysia	Mastoi <i>et al.</i> (2011)	<i>Benincasa hispida</i>	India	Mani Chellappan (2011a)
	Puerto Rico	Pantoja <i>et al.</i> (2007)	Rutaceae		
	Indonesia	Muniappan <i>et al.</i> (2008)	<i>Citrus sp.</i>	Ghana Palau Florida Sri Lanka	Cham <i>et al.</i> (2011) Muniappan <i>et al.</i> (2006) Walker <i>et al.</i> (2003) Galanihe <i>et al.</i> (2010)
	Hawaii	Ronald <i>et al.</i> (2007)	<i>Murraya koenigii</i>	India	Mani Chellappan (2011a)
	Palau	Muniappan <i>et al.</i> (2006)	Sterculiaceae		
	Guam	Meyerdirka <i>et al.</i> (2004)	<i>Theobroma cacao</i>	Ghana	Cham <i>et al.</i> (2011)
Solanaceae			Lauraceae		
<i>Capsicum annum</i>	Ghana Hawaii India Sri Lanka	Cham <i>et al.</i> (2011) Ronald <i>et al.</i> (2007) Mani Chellappan (2011a) Galanihe <i>et al.</i> (2010)	<i>Persea americana</i>	Ghana Florida Puerto Rico Florida	Cham <i>et al.</i> (2011) Walker <i>et al.</i> (2003) Pantoja <i>et al.</i> (2007) Miller and Miller (2002)
<i>Capsicum frutescens</i>	Ghana Florida Palau	Cham <i>et al.</i> (2011) Walker <i>et al.</i> (2003) Muniappan <i>et al.</i> (2006)			

Family and Species	Country	References	Family and Species	Country	References
	India	Muniappan <i>et al.</i> (2008)	<i>Wedelia</i>	Ghana	Cham <i>et al.</i> (2011)
	Indonesia	Muniappan <i>et al.</i> (2008)	<i>trilobata</i>	Florida	Miller and Miller (2002)
Bombacaceae			<i>Hevea</i>	Sri Lanka	Galanihe <i>et al.</i> (2010)
<i>Adansonia</i>			<i>brasiliensi</i>	India	Mani Chellappan (2011a)
<i>digitata</i>	Ghana	Cham <i>et al.</i> (2011)			Jacob Mathew (2011)
Plumbagi- naceae			<i>Tagetes</i>		
<i>Plumbago</i>			<i>erecta</i>	Sri Lanka	Galanihe <i>et al.</i> (2010)
<i>auriculata</i>	Ghana	Cham <i>et al.</i> (2011)	<i>Helianthus</i>		
Moraceae			<i>annuus</i>	Sri Lanka	Galanihe <i>et al.</i> (2010)
<i>Morus alba</i>	India	Tanwar <i>et al.</i> (2010)	Aizoaceae		
Myrtaceae			<i>Trianthema</i>		
<i>Psidium</i>	India	Tanwar <i>et al.</i> (2010)	<i>portulacastrum</i>	India	Tanwar <i>et al.</i> (2010)
<i>guajava</i>	Sri Lanka	Mani Chellappan (2011a) Galanihe <i>et al.</i> 2010	Rubiaceae		
Verbenaceae			<i>Canthium</i>		
<i>Tectona</i>			<i>inerme</i>	India	Tanwar <i>et al.</i> (2010)
<i>grandis</i>	India	Tanwar <i>et al.</i> (2010)	Moraceae		
Amarantha- ceae			<i>Artocarpus</i>		
<i>Achyranthus</i>			<i>integrifolia</i>	Sri Lanka	Galanihe <i>et al.</i> (2010)
<i>aspera</i>	India	Tanwar <i>et al.</i> (2010)		Malaysia	Mastoi <i>et al.</i> (2011)
<i>Amaranthus</i>				India	Mani Chellappan (2011a)
<i>cruentus</i>	India	Mani Chellappan (2011a)	Punicaceae		
Capridaceae			<i>Punica</i>	Florida	Walker <i>et al.</i> (2003)
<i>Cleome</i>			<i>granatum</i>	Sri Lanka	Galanihe <i>et al.</i> (2010)
<i>viscosa</i>	India	Tanwar <i>et al.</i> (2010)	Oleaceae		
Commeli- naceae			<i>Jasminum</i> spp	Sri Lanka	Galanihe <i>et al.</i> (2010)
<i>Commelina</i>			Sapindaceae		
<i>benghalensis</i>	India	Tanwar <i>et al.</i> (2010)	<i>Nephelium</i>	Sri Lanka	Galanihe <i>et al.</i> (2010)
Convolvu- laceae			<i>lappesium</i>	Malaysia	Mastoi <i>et al.</i> (2011)
<i>Convolvulus</i>			Musaceae		
<i>arvensis</i>	India	Tanwar <i>et al.</i> 2010	<i>Musa</i>		
<i>Ipomoea</i>			<i>sapientum</i>	Sri Lanka	Galanihe <i>et al.</i> (2010)
<i>batatas</i>	Ghana Florida Palau	Cham <i>et al.</i> (2011) Walker <i>et al.</i> (2003) Muniappan <i>et al.</i> (2006)	Arecaceae		
Lamiaceae			<i>Cocos nucifera</i>	Sri Lanka	Galanihe <i>et al.</i> (2010)
<i>Leucas</i>			Oxalidaceae		
<i>aspera</i>	India	Tanwar <i>et al.</i> (2010)	<i>Annona</i> spp	Florida	Miller and Miller (2002)
<i>Ocimum</i>	India	Tanwar <i>et al.</i> (2010)	Poaceae		
<i>sanctum</i>	Ghana	Cham <i>et al.</i> (2011)	<i>Zea mays</i>	Florida	Miller and Miller (2002)
Asteraceae			Phyllantha- ceae		
<i>Parthenium</i>			<i>Phyllanthus</i>		
<i>hysterophorus</i>	India	Tanwar <i>et al.</i> (2010)	<i>emblica</i>	India	Mani Chellappan (2011a)

MANAGEMENT

Mealybugs are difficult to control because they live in protected areas such as cracks, crevices and under the bark of their host plants. Most of the stages including eggs of mealybug are covered with waxy secretions that protect them. An integrated pest management (IPM) approach involving cultural practices, legal, chemical and biological control is advisable.

(1) Legal

Strict quarantine measures are needed to prevent the entry of mealybug infested planting materials/fruits/flowers from other countries. Domestic quarantine measures are to be strengthened to prevent the movement from one state to other states within the country (Tanwar *et al.*, 2010).

(2) Cultural Control

Planting material free from mealybugs is to be used. In the initial stages of appearance of mealybug, collection and destruction of infested plant parts are to be carried out (Ayyasamy and Regupathy, 2010; Tanwar *et al.*, 2010).

(3) Chemical Control

Chemicals were used desperately when there was outbreak of mealybugs, and other methods were not available immediately. A number of insecticides like monocrotophos, methyl demeton, dimethoate, acephate, methomyl, fenthion, imidacloprid, thiomethoxam, dichlorovos, quinalphos, profenophos, fenitrothion, carbaryl, chlorpyrifos, diazinon, malathion, buprofezin were used against papaya mealybug (Tanwar *et al.*, 2010; Regupathy and Ayyasamy, 2009; Mahalingam *et al.*, 2010; Banu *et al.*, 2010; Suresh *et al.*, 2010). They give short-term control but chemical control is difficult and requires repeated application of the insecticides (Tanwar *et al.*, 2010; Ayyasamy and Regupathy, 2010; Galanihe *et al.*, 2010)). The chemicals were recommended for the control of the mealybug until the biological control agents could be introduced.

(4) Biopesticides

Fish oil rosin soap, azadirachtin and white mineral oils were found partially effective against papaya mealybug. The three fungal pathogens *Verticillium lecanii* (Zimm.), *Beauria bessiana* (Bals.) and *Metarhium anisopliae* (Metsch.) were known to cause 40-50% mortality of *P. marginatus* (Banu *et al.*, 2010).

(5) Biological Control

Though several methods were available, excellent control of mealybug was obtained with use of biocontrol agent throughout the World (Myerdirk, 2000). In case of PMB also, outstanding control was achieved with use of parasitoids in several countries (Mani and Shivaraju, 2012; Shylesha *et al.*, 2011c).

Guam

P. marginatus was reported in April 2002; Survey of *P. marginatus* in Guam before the release of the parasitoids showed that there were no local parasitoids recorded on this mealybug. A few coccinellids such as *C. montrouzieri* and *Chilocorus nigrita* (Fabricius) were however, found feeding on it. They were not capable of suppressing the populations of *P. marginatus*. The parasitoids, *Acerophagus papayae*, *Anagyrus loecki* and *Pseudleptomastix mexicana* totaling 46, 200 individuals were introduced from Puerto Rico, and released in Guam from June to October, 2002. Establishment of the parasitoids was confirmed within a month of release at the sample sites and releases were continued at other geographical locations across the Island. A reduction of over 99% of PMB was observed about a year of introduction of these parasitoids. By August 2003, the population of PMB declined to a level which was hard to find in the field. Almost all papaya, *Plumeria* spp. and *Hibiscus* spp. plants recovered and no symptoms of damage were noted at that time (Meyerdirk *et al.*, 2004).

Palau

The pest was reported in March 2003, and was causing serious damage to papaya plumeria, Hibiscus and many other plants. Very few *C. montrouzieri* larvae and adults were encountered on *P. marginatus* in the survey. The parasitoids *A. loecki*, *P. mexicana* and *A. papayae* totaling 24, 586 were imported from Puerto Rico, and released in Palau from August 2003 to June 2004. Establishment of parasitoids was confirmed within a month. *A. loecki* and *A. papayae* appeared to be promising biological control agents of PMB in Palau. No field recovery of *P. mexicana* was made in spite of several field releases. The reduction of the papaya mealybug population density levels below detectable levels was observed in a six-month period following the introduction of these exotic parasitoids. Following the successful implementation of a classical biological control program, the risk of this mealybug spreading to other islands in the Republic of Palau and to neighboring Micronesian Islands has been considerably reduced (Muniyappan *et al.*, 2006).

Sri Lanka

The PMB was reported on a large number of plant species in Columbo and Gampha district in Sri Lanka for the first time in 2008. It has caused worst damage in papaya growing districts of Sri Lanka. A classical biological control work was initiated in 2009. Three parasitoids *A. loecki* (2000), *P. Mexicana* (3200) and *Acerophagus papayae* (4800) was released in October, 2009. After two to three months, *A. papayae* established in all the sites and subsequently PMB was controlled to level of 90-100 per cent by December, 2009 (Wahundenya *et al.* 2009 Personal Communication, 2009).

Mexico

Biological control appears to be the main factor keeping the species under control in Mexico. The most important natural enemies were the encyrtids, *Anagyrus* spp., *Acerophagus* spp. and *Apoanagyrus* spp. The general predators such as *Chrysopa* spp. and *Chilocorus* spp. were also encountered in low densities on PMB (Gonzalez *et al.*, 1999).

Puerto Rico and Dominican Republic

Paracoccus marginatus was first intercepted from Puerto Rico in 1995, and by 1998 it was found to be distributed throughout Puerto Rico with a higher density on the west side of the Island (Saez, 2000). During 2001-2002, severe infestation of papaya mealybug required several insecticides applications to control pest (Pantoja *et al.*, 2007).

USDA-APHIS found that the five parasitoid species, *Anagyrus loecki*, *Apoanagyrus californicus*, *Acerophagus* sp. and *Pseudophycus* sp and *Pseudleptomastix mexicana* brought about a 99.7% reduction in papaya mealybug populations in the Dominican Republic, and a 97% reduction in Puerto Rico, with parasitism levels of 35.5-58.3% (Kauffman *et al.*, 2001a; Meyerdirk and Kauffman, 2001). However, *Acerophagus* sp. emerged as the dominant parasitoid species in both Puerto Rico and the Dominican Republic (Meyerdirk and Kauffman, 2001; Ramirez and Saez, 2002; Walker *et al.*, 2003; Arnold, 2001; Kauffman *et al.*, 2001b).

Florida

Paracoccus marginatus was discovered in Florida 1998, the USDA Animal and Plant Health Inspection Service (APHIS) and USDA Agricultural Research Service (ARS) initiated a classical biological control programme for the papaya mealybug (Ngyen, 2000). Four genera of encyrtid endoparasitoid wasps specific to the

mealybug were collected in Mexico by USDA and ARS researchers and Mexican cooperators as potential biological control agents: *Acerophagus papayae*, *Anagyrus loecki*, *Anagyrus californicus* and *Pseudaphycus* sp. (USDA 1999, 2000; Meyerdirk and Kauffman 2001). A fifth collected species was later reared and identified as *Pseudleptomastix mexicana* (Noyes and Schauff 2003). The first releases of these four parasitoids were made in Florida in October 2000 (Walker *et al.*, 2003) and again released in 2003 (Meyerdirk, 2003). Although it is believed that these parasitoids are established in the released areas, *Acerophagus papayae* had higher per cent parasitism than *A. loecki* and there is no recovery of *P. mexicana* (Kaushalya *et al.*, 2008).

India

Paracoccus marginatus invaded India in 2008 and has become severe on several agricultural and horticultural crops. The potential economic loss due to this pest ranges from 60-80% in papaya. The parasitoids *Acerophagus papayae*, *Pseudleptomastix mexicana* and *Anagyrus loecki* from USDA-APHIS Puerto Rico were shipped to India. A total of 3429 of *A. papayae*, 1485 of *P. mexicana* and 516 of *A. loecki* were received by National Bureau of Agriculturally Important Insects, Bangalore during July- October, 2010. After ascertaining the safety in quarantine, these three parasitoids were distributed to different states in India.

During October 2010, *Acerophagus papayae* was released on jatropha and plumeria in Bangalore, on papaya in Jakkur, Mysore, Chamaraj nagar, and Nelamangala and on mulberry in Mandya district and. *A. papayae* was observed in few numbers on 20 days after release and the spread of the parasitoid was very good on 40 and 60th day of observation. After a span of 3 months, there was a reduction of 80-90% in the pest population, and new shoots developing were not found to harbor any mealybug (Shylesha *et al.*, 2010; Shylesha *et al.*, 2011c; Krishnamurthy *et al.*, 2011; Qadri *et al.*, 2011).

Paracoccus marginatus was reported in Pune region of Western Maharashtra on July, 2010. It assumed the status of major pest of papaya in Pune, Nandurbar and Jalgaon districts of Maharashtra. The parasitoid *Acerophagus papayae* was found parasitizing for the first time in August, 2010. Subsequently a release rate of 1000-1500/ac was recommended for several papaya gardens in Maharashtra. There was 85-92% decline in the mealybug population within three months (Pokharkar *et al.*, 2011; Mundale and Nakat, 2011; Chandale *et al.*, 2011; Nakat *et al.*, 2011).

Table 3. List of natural enemies on *Paracoccus marginatus*

Family and Species	Country	References
Hymenoptera Encyrtidae <i>Acerophagus papayae</i> Noyes and Schauff	India	Shylesha <i>et al.</i> (2011d) Tanwar <i>et al.</i> (2010) Jothi <i>et al.</i> (2011) Ayyasamy and Ragupathy (2010) Chandale <i>et al.</i> (2011) Qadri (2011) Nakata <i>et al.</i> (2011) Kalyanasundaram <i>et al.</i> (2011) Muniappan <i>et al.</i> (2008) Jacob Mathew (2011)
	Indonesia	Muniappan <i>et al.</i> (2008)
	Sri Lanka	Galanihe <i>et al.</i> (2010)
	Malaysia	Mastoi <i>et al.</i> (2011)
	Puerto Rico	Pantoja <i>et al.</i> (2007)
	Indonesia	Muniappan <i>et al.</i> (2008)
	Hawaii	Ronald <i>et al.</i> (2007)
	Palau	Muniappan <i>et al.</i> (2006)
	Florida	Kaushalya <i>et al.</i> (2010) Miller and Miller (2002)
	Mexico	Meyerdirka and Kauffman (2011)
<i>Anagyrus loecki</i> Noyes	India	Shylesha <i>et al.</i> (2011d) Tanwar <i>et al.</i> (2010) Jothi <i>et al.</i> (2011) Ayyasamy and Ragupathy (2010) Chandale <i>et al.</i> (2011) Qadri (2011) Nakata <i>et al.</i> (2011) Kalyanasundaram <i>et al.</i> (2011) Muniappan, <i>et al.</i> (2008) Jacob Mathew (2011)
	Indonesia	Muniappan <i>et al.</i> (2008)
	Sri Lanka	Galanihe <i>et al.</i> (2010)
	Malaysia	Mastoi <i>et al.</i> (2011)
	Puerto Rico	Pantoja <i>et al.</i> (2007)
	Indonesia	Muniappan <i>et al.</i> (2008)
	Hawaii	Ronald <i>et al.</i> (2007)
	Palau	Muniappan <i>et al.</i> (2006)
	Florida	Kaushalya <i>et al.</i> (2010) Miller and Miller (2002)
	Mexico	Meyerdirka and Kauffman (2001)

Family and Species	Country	References
<i>Apoanagyrus californicus</i> Compere	Mexico Puerto Rico	Meyerdirka and Kauffman (2001) Pantoja <i>et al.</i> (2007)
<i>Pseudleptomastrix mexicana</i> Noyes and Schauff	India	Shylesha <i>et al.</i> (2011d) Tanwar <i>et al.</i> (2010) Ayyasamy and Ragupathy (2010) Chandale <i>et al.</i> (2011) Qadri (2011) Nakata <i>et al.</i> (2011) Muniappan, <i>et al.</i> (2008) Kalyanasundaram <i>et al.</i> (2011)
	Indonesia	Muniappan <i>et al.</i> (2008)
	Sri Lanka	Galanihe <i>et al.</i> (2010)
	Malaysia	Mastoi <i>et al.</i> (2011)
	Puerto Rico	Pantoja <i>et al.</i> (2007)
	Florida	Miller and Miller (2002)
	Indonesia	Muniappan <i>et al.</i> (2008)
	Hawaii	Ronald <i>et al.</i> (2007)
	Palau	Muniappan <i>et al.</i> (2006)
	Florida	Kaushalya <i>et al.</i> (2010)
	Mexico	Meyerdirka and Kauffman (2001)
	Guam	Meyerdirka <i>et al.</i> (2004)
<i>Pseudaphycus</i> sp.	Mexico	Meyerdirka and Kauffman (2001)
Lepidoptera: Lycaenidae <i>Spalgis epius</i> (Westwood)	India	Shylesha <i>et al.</i> (2011d) Tanwar <i>et al.</i> (2010) Jothi <i>et al.</i> (2011) Jonathan <i>et al.</i> (2011) Thangamalar <i>et al.</i> (2010) Krishnamurthy and Mani (2011) Chandale <i>et al.</i> (2011) Nakat <i>et al.</i> (2011)
Coleoptera: Coccinellidae <i>Cryptolaemus montrouzieri</i> Mulsant	India	Shylesha <i>et al.</i> (2011d) Tanwar <i>et al.</i> (2010) Nakata <i>et al.</i> (2011) Jothi <i>et al.</i> (2011) Ayyasamy and Ragupathy (2010) Jonathan <i>et al.</i> (2011) Mastoi <i>et al.</i> (2011)
	Malaysia	Mastoi <i>et al.</i> (2011)
	Palau	Muniappan <i>et al.</i> (2008)
	Hawaii	Ronald <i>et al.</i> (2007)

Family and Species	Country	References	Family and Species	Country	References
	Florida	Walker <i>et al.</i> (2011)			Ayyasamy and Ragupathy (2010)
	Guam	Anon (2010)			
	British Virgin Island	Meyerdirka <i>et al.</i> (2004) CAB International (2011)	<i>Apertochrysa</i> sp.	Malaysia	Mastoi <i>et al.</i> (2011)
<i>Nephus bilucernarius</i> (Mulsant)	Hawaii	Ronald <i>et al.</i> (2007)	Diptera: Syrphidae <i>Ischiodon scutellaris</i> F.	India	Shylesha <i>et al.</i> (2011d) Tanwar <i>et al.</i> (2010) Jonathan <i>et al.</i> (2011)
<i>Scymnus taiwanus</i> (Ohta)	India	Shylesha <i>et al.</i> (2011d) Tanwar <i>et al.</i> (2010) Nakata <i>et al.</i> (2011) Chandele <i>et al.</i> (2011) Jonathan <i>et al.</i> (2011)	Entomopathogenic fungi <i>Metarrhizium anisopliae</i> (Metsch.)	India	Shylesha <i>et al.</i> (2011d) Ayyasamy and Ragupathy (2010)
<i>Brumoides suturalis</i> Fabricius	Hawaii	Ronald <i>et al.</i> (2007)	<i>Verticillium lecanii</i> (Zimm.)	India	Shylesha <i>et al.</i> (2011d) Ayyasamy and Ragupathy (2010) Jonathan <i>et al.</i> (2011) Mani Chellappan (2011b)
<i>Hyperaspis silvestrii</i> Weise	Hawaii	Ronald <i>et al.</i> (2007)	<i>Paecilomyces pictus</i>	India	Ayyasamy and Ragupathy (2010)
<i>Curinus coeruleus</i> Mulsant	Hawaii	Ronald <i>et al.</i> (2007)	<i>Beauveria bassiana</i> (Bals.)	India	Shylesha <i>et al.</i> (2011d)
<i>Cheilomenus sexmaculatus</i> (F.)	India	Jonathan <i>et al.</i> (2011)	<i>Neozygites Chilocorus nigrita</i> Fab	India	Shylesha <i>et al.</i> (2011d)
<i>Coccinella transversalis</i> Fabricius	India	Jonathan <i>et al.</i> (2011)		Guam	Meayerdirk <i>et al.</i> (2004)
Neuroptera: Chrysopidae <i>Chrysoperla carnea</i> (Stephens)	India	Shylesha <i>et al.</i> (2011d) Tanwar <i>et al.</i> (2010)		Mexico	Gonzalez <i>et al.</i> (1999)

In Tamil Nadu, *P. marginatus* was first observed during July 2008 in Coimbatore district and subsequently spread to neighboring districts of Tamil nadu. Initially several chemicals were used for the control of PMB. During the October 2010, the parasitoids, *Acerophagus papayae*, *Pseudleptomastix mexicana* and *Anagyrus loeckii* were obtained from NBAII and reared initially. *A. papayae* was subsequently multiplied on large scale and released in the farmer's field of papaya in several districts in Tamil nadu. There was substantial reduction of PMB density to very low level with three month of

after its introduction (Kalyanasundaram *et al.*, 2011; Jonathan *et al.*, 2011; Regupathy and Ayyasamy, 2011).

P. marginatus is a serious pest on rubber, several forest trees, vegetables, fruits, plantation crops, flower crops and other weed plants in Kerala. Biological control programme was initiated in 2011 with the release of *A. papayae* in Kerala (Mani Challappan 2011b; Jacob Methew, 2011; Sajeev, 2011).

In eastern state of Odisha, *P. marginatus* is a serious pest on several agriculture and horticultural crops in

2011. Biological control programme was initiated in 2011 itself with the release of *A. papayae* (Shylesha *et al.*, 2011a). Similarly in north eastern state of Tripura, more than 60% of papaya plants were infested with *P. marginatus* during 2009-10 in four districts of Tripura. Biological control programme was initiated in 2011 with the release of *A. papayae* (Agarawala, 2011).

Caribbean Islands

As an exotic introduction to the Caribbean islands, there were good prospects for control of *P. marginatus* by hymenopteran parasitoids originating from its area of origin in Central America (Pollard, 1999).

Malaysia

Paracoccus marginatus was reported for the first time in Malaysia on papaya, cassava, eggplant, jatropha and hibiscus plants. Four species of chalcidoid parasitoids were observed parasitizing the PMB. *Acerophagus papayae* was the major parasitoid of PMB. Two common predators namely *Apertochrysa* sp. and *Cryptolaemus montouzieri* were also found feeding on PMB (Mastoi *et al.*, 2011).

Taiwan

P. marginatus was found damaging papaya in Taiwan for the first time in 2011. *A. papayae* was useful in controlling the papaya mealybug in Taiwan. Bio-control is to be initiated for the control of PMB (Chen Shu Pei *et al.*, 2011).

Indonesia

The papaya mealybug, *Paracoccus marginatus* was recorded in Indonesia (Java) in 2008. Introduction of parasitoid, *A. papayae* is to be carried out in controlling the papaya mealybug in Indonesia (Herlina, 2011).

CONCLUSION

The papaya mealybug *Paracoccus marginatus* is likely to invade several countries in the World. Several methods like cultural, chemical, legal and biological have been adopted to tackle the mealybug problem. However only chemical and biological control methods have been widely practiced for the management of mealybugs. Only the host specific parasitoids have given control of *P. marginatus*. More specifically the hymenopteran parasitoid *Acerophagus papayae* played a predominant role in suppressing the papaya mealybug in several countries. It is advisable to obtain *A. papayae* from the other countries and release the same whenever the invasion of *P. marginatus* was observed in the countries.

REFERENCES

- Agarwala BK. 2011. A preliminary report of the papaya mealy bug *Paracoccus marginatus* (Hemiptera: Pseudococcidae) in Tripura. Proceedings of the National consultation meeting on strategies for deployment and impact of the imported parasitoids of papaya mealybug, Classical biological control of papaya mealybug (*Paracoccus marginatus*) in India, pp.45-46
- Amarasekare KG, Chong JH, Epsky ND, Mannion CM. 2008a. Effect of temperature on the life history of the mealybug *Paracoccus marginatus* (Hemiptera: Pseudococcidae). *J Econ Entomol.* **101**: 1798–1804.
- Amarasekare KG, Mannion CM, Osborne LS, Epsky ND. 2008b. Life history of *Paracoccus marginatus* (Hemiptera: Pseudococcidae) on four host plant species under laboratory conditions. *Env Entomol.* **37**(3): 630–635.
- Angeles Martinez MDE, Los Suris M. 2005. Morphological comparison of *Paracoccus marginatus* (Hemiptera: Pseudococcidae) presents in cassava and papaya Cuban field. [Spanish] Comparacion morfologica de *Paracoccus marginatus* (Hemiptera: Pseudococcidae) presentes en plantaciones Cubanas de yuca y frutabomba. *Rev Prot Vegetal.* **20**(3): 165–168.
- Anonymous 2003. Papaya mealybug, *Paracoccus marginatus* in Palau, Pest Alert, Plant Protection Service, Secretariat of the Pacific Community, Fiji, No. 31. 1 p.
- Arnold J. 2001. Parasitic wasp could curb mealybug. *ARS News and Information*, United States Department of Agriculture, August 2001.
- Ayyasamy, R, Regupathy A. 2010. Need and scope for insecticide resistance management for the invasive papaya mealy bug *Paracoccus marginatus* Williams and Granara de Willink in small scale papaya farming system in Tamil Nadu, India. *Res Pest Mgmt Newslet.* **19**: 2, 23–28.
- Banu JG, Suruliveru T, Amutha M, Gapal Krishnan N. 2010. Susceptibility of cotton mealy bug, *Paracoccus marginatus* to entomopathogenic fungi. *Ann Pl Prot Sci.* **18**: 247–248.
- Ben Dov, Y. 2008. Scale Net, *Paracoccus marginatus*. 17 September 2008. <http://www.sel.barc.usda.gov/catalogs/pseudoco/Paracoccusmarginatus.htm>.
- Ben Dov, Y. 2010. ScaleNet, *Paracoccus marginatus*. Accessed online 22 July 2010 at, <http://www.sel.barc.usda.gov/catalogs/pseudoco/Paracoccusmarginatus.htm>.

- CAB International, 2001. *Crop Protection Compendium*. (Wallingford, UK; CAB International).
- CABI/EPPO. 2000. *Paracoccus marginatus*. Distribution Maps of Plant Pests, MapNo. 614. CAB International with EPPO. 2 p.
- Cham D, Henry Davis, Daniel Obeng Ofori, Ebenezer Owusu. 2011. Host Range of the newly invasive mealybug species *Paracoccus Marginatus* Williams and Granara De Willink (Hemiptera: Pseudococcidae) in two ecological zones of Ghana *Res Zoology*. **1**(1): 1–7.
- Chandele AG, Nakat RV, Pokharkar DS, Dhane AS, Tamboli ND. 2011. Status of papaya mealybug, *Paracoccus marginatus* W & G (Hemiptera: Pseudococcidae) in Maharashtra, Proceedings of the National consultation meeting on strategies for deployment and impact of the imported parasitoids of papaya mealybug, Classical biological control of papaya mealybug (*Paracoccus marginatus*) in India, pp. 43–44.
- Chen Shupe, Wong Jenyu, Wu Wenjen. 2011. Preliminary report on the occurrence of papaya mealybug, *Paracoccus marginatus* Williams and Granara de Willink, in Taiwan. *J Taiwan Agric Res*. **60** (10): 72–76.
- Galanihe LD, Jayasundera MUP, Vithana A, Asselaarachchi N, Watson GW. 2010. Occurrence, distribution and control of papaya mealybug, *Paracoccus marginatus* (Hemiptera: Pseudococcidae), an invasive alien pest in Sri Lanka. *Tropical Agric Res Ext*. **13**(3): 81–86.
- Gonzalez HJ, Villanueva A, Millar DR. 1999. Parasitoides del piojo harinoso del papaya, *Paracoccus marginatus* Williams y Granara de Willink (Homoptera: Pseudococcidae), en Mexico. Memorias del XXII Congreso Nacional de Control Bio-lógico, October 1999, Montecillo, Mexico.
- Herlina L. 2011. Introduction of parasitoid, a new concept in controlling papaya mealybugs *Paracoccus marginatus* in Indonesia. (Indonesian) Introduksi parasitoid, sebuah wacana baru dalam pengendalian hama kutu putih pepaya *Paracoccus marginatus* di Indonesia. *Jurnal Penelitian dan Pengembangan Pertanian*. **30**: 87–97.
- Heu RA, Fukada MT, Conant P. 2007. Papaya mealybug, *Paracoccus marginatus* Williams and Granara de Willink (Hemiptera: Pseudococ-cidae). State of Hawaii New Pest Advisory. De-partment of Agriculture No. 04–03 March 2007.
- Heu RA, Fukada MT. 2005. Papaya Mealybug, *Paracoccus marginatus* Williams and Granara de Willink (Homoptera: Pseudococcidae), State of Hawaii, Department of Agriculture, New Pest Advisory No. 04–03, 2 p.
- Jacob Mathew. 2011. Status of papaya mealy bug on rubber in Kerala. Proceedings of the National consultation meeting on strategies for deployment and impact of the imported parasitoids of papaya mealybug, Classical biological control of papaya mealybug (*Paracoccus marginatus*) in India, p. 60.
- Jonathan EI, Karuppuchamy P, Kalyanasundaram M, Suresh S, Mahalingam CA. 2011. Status of papaya mealybug in Tamil Nadu and its management. Proceedings of the National consultation meeting on strategies for deployment and impact of the imported parasitoids of papaya mealybug, Classical biological control of papaya mealybug (*Paracoccus marginatus*) in India, pp. 24–33.
- Jothi BD, Surulivelu T, Rajan TS, Valarmathi R. 2011. First record on the establishment of the parasitoid (*Acerophagus papayae* Noyes and Schauff) of papaya mealybug (*Paracoccus marginatus* Williams and Granara de Willink) on cotton. *Karnataka J Agric Sci*. **24**: 536–537.
- Kalyanasundaram M, Karuppuchamy P, Divya S, Sakthivel P, Rabindra RJ, Shylesha AN. 2011. Impact on release of the imported parasitoid *Acerophagus papayae* for the management of papaya mealybug *Paracoccus marginatus* in Tamil nadu. Proceedings of the National consultation meeting on strategies for deployment and impact of the imported parasitoids of papaya mealybug, Classical biological control of papaya mealybug (*Paracoccus marginatus*) in India, pp. 68–72.
- Kauffman WC, Meyerdirk DE, Warkentin R, Alvarez P, Abud A. 2001a. Biological control of papaya mealybug in the Caribbean safeguarding the US Poster Presentation. International Organization for Biological Control, August 2–5, 2001, Bozeman, Montana.
- Kauffman WC, Myerdirk DE, Miller D, Schauff M, Hernandez HG, Jimenez JAV. 2001b. Papaya mealybug biological control in Puerto Rico and Dominican Republic. *ESA Annual Meeting –2001: An Entomological Odyssey of ESA*.
- Kaushalya G, Amarasekare Catharine M, Mannion, Epsky ND. 2008. Host instar susceptibility and selection and interspecific competition of three introduced parasitoids of the mealybug *Paracoccus marginatus*

- (Hemiptera: Pseudococcidae). *Env Entomol.* **39**: 1506–1512.
- Krishnamoorthy A, Mani M. 2011, Occurrence of papaya mealybug, *Paracoccus marginatus* in Karnataka: IIHR perspective Proceedings of the National consultation meeting on strategies for deployment and impact of the imported parasitoids of papaya mealybug, Classical biological control of papaya mealybug (*Paracoccus marginatus*) in India, p. 37–39.
- Krishnakumar R, Rajan V. P. 2009, Record of papaya mealybug, *Paracoccus marginatus* infesting mulberry in Kerala. *Insect Env.* **15**(3): 142.
- Krishnamurthy A, Mani M, Gangavisalkshi PN, Gopalakrishna Pillai K. 2011. Classical biological control of papaya mealybug, *Paracoccus marginatus* using exotic parasitoid, *Acerophagus papayae*. Proceedings of national symposium on Harnessing biodiversity for biological control of crop pest, abstract. May 25-26, 2011, NBAII, Bangalore, p. 101.
- Lyla KR, Philip BM., 2010. Incidence of papaya mealybug *Paracoccus marginatus* Williams and Granara de Willink (Hemiptera: Pseudococcidae) in Kerala. *Insect Env.* **15**(4): 156.
- Mahalingam CA, Suresh S, Subramanian S, Murugesha KA, Mohanraj P, Shanmugam R. 2010. Papaya mealybug, *Paracoccus marginatus* – a new pest on mulberry, *Morus* spp. *Karnataka J Agric Sci.* **23**: 182–183.
- Mani M, Shivaraju C. 2012. Classical approach for papaya mealybug management. *Indian Hort.*, In press.
- Mani Chellappan. 2011a. Impact of *Acerophagus papayae* Noyes and Schaufon *Paracoccus marginatus* Williams and Granara de Willink in Kerala. Proceedings of the National consultation meeting on strategies for deployment and impact of the imported parasitoids of papaya mealybug, Classical biological control of papaya mealybug (*Paracoccus marginatus*) in India, pp. 82–83.
- Mani Chellappan, 2011b. Status of papaya mealybug, *Paracoccus marginatus* Williams and Granara de Willink in Kerala. Proceedings of the National consultation meeting on strategies for deployment and impact of the imported parasitoids of papaya mealybug, Classical biological control of papaya mealybug (*Paracoccus marginatus*) in India, pp. 40–42.
- Mastoi MI, Azura AN, Muhammad R, Idris AB, Ibrahim Y. 2011. First report of papaya mealybug *Paracoccus marginatus* (Hemiptera: Pseudococcidae) from Malaysia. *Australian J Basic and Applied Sciences.* **5**: 7, 1247–1250.
- Matile-Ferrero D, Etienne J, Tiego G. 2000. Introduction of two important pests to French Guiana: *Maconellicoccus hirsutus* and *Paracoccus marginatus* (Hem., Coccoidea, Pseudococcidae). [French] Introduction de deux ravageurs d'importance pour la Guyane française: *Maconellicoccus hirsutus* et *Paracoccus marginatus* (Hem., Coccoidea, Pseudococcidae). *Bulletin de la Societe Entomologique de France.* **105**(5): 485–486.
- Matile Ferrero D, Etienne J. 1998. *Paracoccus marginatus* Williams & Granara de Willink, nouvelle introduction en Guadeloupe et a Saint-Barthelemy (Hemiptera, Pseudococcidae). *Revue Francaise d'Entomologie.* **20**: 142.
- McComie LD. 2000a. Known host plants of *Paracoccus marginatus*. In : *Proceedings of A Technical Meeting and Workshop on Biological Control of Papaya Mealybug, Paracoccus marginatus*, Basseterre, St. Kitts, 25–26 July, 2000.
- McComie LD. 2000b. Progress Report on the Papaya Mealybug (*Paracoccus marginatus*) project in St. Kitts and Nevis. Presented at *Procicaribe Cimpnet Meeting* 2000, Kingston, St Vincent 17–18 August, 2000.
- Meyerdirk D, Stibick J, Ambrose E. 2000. Guidelines for a papaya mealybug survey in the Caribbean islands. Presented at a *A Technical Meeting and Workshop on Biological Control of Papaya Mealybug, Paracoccus marginatus*, Basseterre, St Kitts, 25–26 July, 2000.
- Meyerdirk D. 2000. Review of mealybug biological control successes. In: *Proceedings of A Technical Meeting and Workshop on Biological Control of Papaya Mealybug, Paracoccus marginatus*, Basseterre, St Kitts, 25–26 July 2000.
- Meyerdirk DE, Muniappan R, Warkentin R, Bamba J, Reddy GVP. 2004. Biological control of the papaya mealybug, *Paracoccus marginatus* (Hemiptera: Pseudococcidae) in Guam. *Pl Prot Qtly* **19**(30): 110–114.
- Meyerdirk D 2003. Control of papaya mealybug, *Paracoccus marginatus* (Hemiptera: Pseudococcidae): Environmental assessment (Supplement). Center for

Plant Health Science and Technology, National Biological Control Institute, Plant Protection and Quarantine, Animal and Plant Health Inspection Service, United States Department of Agriculture, Riverdale, MD.

- Meyerdirk DE, Kauffman WC. 2001. Status on the development of a biological control program for *Paracoccus marginatus* Williams, papaya mealybug, in the Caribbean. Paper presented at IV International Scientific Seminar of Plant Health. Veradero, Cuba. June 10–15, 2001 (abstract).
- Miller DR, Williams DJ, Hamon AB. 1999. Notes on a new mealybug (Hemiptera:Coccoidea: Pseudococcidae) pest in Florida and the Caribbean: The papaya mealybug, *Paracoccus marginatus* Williams and Granada de Willink. *Insecta Mundi* **13**: 179–181.
- Miller DR, Miller GL. 2002. Redescription of *Paracoccus marginatus* Williams, D. J. and Granara de Willink, (Homoptera:Coccoidea: Pseudococcidae), including descriptions of the immature stages and adult male. *Proc Ent Soc Washington* **104** (1): 1–23.
- Mundale M, Nakat R. 2011. Successful control of papaya mealybug using *Acerophagus papayae* in farmer's field. National symposium on harnessing Biodiversity for biological control of crop pests- abstracts, NBAII, Bangalore, p. 27.
- Muniappan, R, Meyerdirk DE, Sengebau FM, Berringer DD, Reddy GVP. 2006. Classical biological control of the papaya mealybug, *Paracoccus marginatus* (Hemiptera: Pseudococcidae) in the Republic of Palau. *Florida Entomol.* **89**: 212–217.
- Muniappan R, Shepard BM, Watson GW, Carner GR, Rauf A, Sartiami D, Hidayat P, Afun JVK, Ziaur Rahman AKM. 2009. New records of invasive insects (Hemiptera: Sternorrhyncha) in Southeast Asia and West Africa. *J Agric Urban Ent.* **26**: 167–174.
- Muniappan R, Shepard BM, Watson GW, Carner GR, Sartiami D, Rauf A, Hammig MD. 2008. First report of the papaya mealybug, *Paracoccus marginatus* (Hemiptera: Pseudococcidae), in Indonesia and India. *J Agric Urban Ent.* **25** (1): 37–40.
- Nakat RV, Pokharkar DS, Dhane AS, Tamboli ND. 2011. Biological impact of *Acerophagus papayae* (N & S) on suppression of papaya mealybug, *Paracoccus marginatus* (W & G) in Pune region of Maharashtra. Proceedings of the National consultation meeting on strategies for deployment and impact of the imported parasitoids of papaya mealybug, Classical biological control of papaya mealybug (*Paracoccus marginatus*) in India, pp. 79–81.
- Ngyuen R. 2000. Crawford announces new biological control crop pest. Department Press Release 10.10.2000. Division of Plant industry Florida Department of Agriculture and Consumer services Gainesville, F. L.
- Noyes JS, Schauff ME. 2003. New *Encyrtidae* (Hymenoptera) from Papaya Mealybug (*Paracoccus marginatus* Williams and Granara de Willink) (Hemiptera: Sternorrhyncha: Pseudococcidae). *Proc Ent Soc Washington* **105**: 180–185.
- Pantoja A, Abreu E, Pena J, Robles W. 2007. *Paracoccus marginatus* Williams and Granara de Willink (Homoptera: Pseudococcidae) affecting papaya in Puerto Rico. *J Agric University of Puerto Rico.* **91** (3/4): 223–225.
- Pokharkar DS, Nakat RV, Tamboli ND, Dhane AS. 2011. Papaya mealybug, *Paracoccus marginatus* Williams and Granara de Willink (Hemiptera: Pseudococcidae) and its natural enemies in Maharashtra. National symposium on harnessing Biodiversity for biological control of crop pests- abstracts, NBAII, Bangalore, p. 29.
- Pollard GV. 1999. Update on new pest introductions. *Paracoccus marginatus*. CARAPHIN News 18: 7.
- Qadri, S. M. H. 2011. Central Silk Board initiatives in tackling the menace of papaya mealy bug (*Paracoccus marginatus*) in Mulberry. Proceedings of the National consultation meeting on strategies for deployment and impact of the imported parasitoids of papaya mealybug, Classical biological control of papaya mealybug (*Paracoccus marginatus*) in India, pp. 47–50.
- Qadri SMH, Shekhar MA, Vinod Kumar, Narendra Kumar JB. 2011. An impact and constraints on the establishment of *Acerophagus papayae* for the management of papaya mealybug in mulberry ecosystem. National symposium on harnessing Biodiversity for biological control of crop pests-abstracts, NBAII, Bangalore, p. 37.
- Rabindra RJ. 2010. NBAII Pioneers Successful classical biological control of papaya mealybug. *NBAII News letter* **11**(2): 1.
- Ramirez A, Sáez L. 2002. Papaya mealybug (*Paracoccus marginatus*) in Puerto Rico. Biological Control Laboratory, Department of Agriculture of Puerto Rico. Training Workshop Papaya Mealybug Biological Control Program. October 23–25, 2002, San Juan, Puerto Rico. 7 p.

- Regupathy A, Ayyasamy R. 2009. Need for generating baseline data for monitoring insecticide resistance in new invasive mealy bug *Paracoccus marginatus* Williams and Granara de Willink (Insecta: Hemiptera: Pseudococcidae), the key pest of papaya and biofuel crop, *Jatropha curcas*. *Res Pest Mgmt Newsletter* **19**: 37–40.
- Regupathy A, Ayyasamy R. 2011. Impact of papaya mealybug *paracoccus marginatus* on papain industry. Proceedings of the National consultation meeting on strategies for deployment and impact of the imported parasitoids of papaya mealybug, Classical biological control of papaya mealybug (*Paracoccus marginatus*) in India, pp. 57–59.
- Ronald A, Heu MT, Fukada, Patrick C. 2007, Papaya mealybug, *Paracoccus marginatus* Williams and Granara de Willink (Hemiptera: Pseudococcidae). New Pest Advisory. <http://www.hawaiiag.org/hdoa/npa/npa04-03-PMB.pdf>
- Sález L. 2000. Parasitoides naturales de la chinche harinosa de la papaya, *Paracoccus marginatus* (Williams y Granara de Willink) y parasitoides naturales e importados de la chinche harinosa rosada del hibisco (*Maconellicoccus hirsutus* (Green) en dos regiones en Puerto Rico. Master's Thesis, University of Puerto Rico, Mayaguez Campus. 80 p.
- Sajeev TV. 2011, Classical biocontrol of papaya mealy bug *Paracoccus marginatus* (Hemiptera: Pseudococcidae): the forestry perspective. Proceedings of the National consultation meeting on strategies for deployment and impact of the imported parasitoids of papaya mealybug, Classical biological control of papaya mealybug (*Paracoccus marginatus*) in India, pp. 61–62.
- Schauff ME. 2000. Parasitoids of the papaya mealybug (*Paracoccus marginatus*). Systematic Entomology Laboratory, USDA, ARS, National Museum of Natural History, Washington, D. C. 205560–111068.
- Shylesha AN, Joshi S, Rabindra RJ, Shekhar MA, Narendra Kumar, Dhanyavathi PN, Shivaraju C. 2011a. A successful case study of classical biological control of papaya mealybug, *Paracoccus marginatus*. National symposium on harnessing Biodiversity for biological control of crop pests – abstracts, NBAIL, Bangalore, p. 99.
- Shylesha AN, Dhanyavathi PN, Shivaraju C. 2011b. Mass production of parasitoids for the classical biological control of papaya mealybug, *Paracoccus marginatus*. Proceedings of the National consultation meeting on strategies for deployment and impact of the imported parasitoids of papaya mealybug, Classical biological control of papaya mealybug (*Paracoccus marginatus*) in India, pp.63-67.
- Shylesha AN, Rabindra RJ, Shekhar MA, Vinod Kumar, Narendra Kumar and. Krishnamurthy A. 2011c. Impact of classical biological control of the papaya mealybug, *Paracoccus marginatus* using *Acerophagus papayae* in Karnataka. Proceedings of the National consultation meeting on strategies for deployment and impact of the imported parasitoids of papaya mealybug, Classical biological control of papaya mealybug (*Paracoccus marginatus*) in India, pp. 73–78.
- Shylesha AN, Rabindra RJ, Bhumannavar BS. 2011d. The papaya mealybug, *Paracoccus marginatus* (Coccoidea:Pseudococcidae). Proceedings of the National consultation meeting on strategies for deployment and impact of the imported parasitoids of papaya mealybug classical biological control of papaya mealybug (*Paracoccus marginatus*) in India, pp. 1–8.
- Shylesha AN, Joshi S, Rabindra RJ, Bhumannavar BS. 2010. Classical biological control of the papaya mealybug. Extension Folder, National Bureau of Agriculturally Important Insects, Bangalore, 4 p.
- Suresh S, Jothimani R, Sivasubramanian P, Karuppuchamy P, Samiyappan R, Jonathan E I. 2010. Invasive mealybugs of Tamil Nadu and their management. *Karnataka J Agric Sci.* **23**: 6–9.
- Tanwar RK, Jeyakumar, Vennila S. 2010, Papaya mealybug and its management strategies. NCIPM Technical Bulletin, **22**: 26 p.
- Thangamalar A, Subramanian S, Mahalingam CA. 2010. Bionomics of papaya mealybug, *Paracoccus marginatus* and its predator *Spalgius epeius* in mulberry ecosystem. *Karnataka J Agric Sci.* **23**: 39–41.
- U.S. Department of Agriculture, Animal and Plant Health Inspection Service. 1999. Control of the papaya mealybug, *Paracoccus marginatus* (Homoptera: Pseudococcidae). Environmental Assessment, October 1999. Riverdale, MD.
- U.S. Department of Agriculture, Animal and Plant Health Inspection Service. 2000. Control of the papaya mealybug, *Paracoccus marginatus* (Homoptera:

- Pseudococcidae). Environmental Assessment (Supplement), June 2000. Riverdale, MD.
- Wahundenya I, Wijesekara A, Bhandara KANP, Galaniha LD 2009, Papaya mealybug control in Sri Lanka, Personal Communication.
- Walker A, Hoy M, Meyerdirk DE. 2003, Papaya Mealybug. Univ. Florida Featured Creatures. <http://creatures.ifas.ufl.edu/fruit/mealybugs/papa>.
- Walker A, Hoy M, Meyerdirk D. 2006. Papaya mealybug (*Paracoccus marginatus* Williams and Granara de Willink (Insecta: Hemiptera: Pseudococcidae). EENY- 302. Featured Creatures. Entomology and Nematology Department, Florida Cooperative Extension Service, Institute of Food and agricultural Sciences, University of Florida, Gainesville, FL.
- Watson GW, Chandler LR. 1999. Identification of mealybugs important in the Caribbean Region. 40 pp. Commonwealth Science Council and CAB International, CARINET.
- Williams DJ, Granara De Willink. MC. 1992. Mealybugs of Central and South America, CAB International, Wallingford, England, 635 p.