



SURVEY OF PAPAYA MEALYBUG, *PARACOCCLUS MARGINATUS* (HEMIPTERA: PSEUDOCOCCIDAE) AND ITS NATURAL ENEMIES IN PENINSULAR MALAYSIA

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ABSTRACT

Papaya mealybug (*Paracoccus marginatus*) is a highly invasive pest and is attaining the status of regular insect pest of papaya in South and South-East Asia. Keeping in view the importance of pest, a survey was conducted in three states of Peninsular Malaysia to observe pest infestation on papaya and other host plants and natural enemies. In Selangor state, the pest infestation was recorded only on farm managed papaya plants (30.33%), while on wild and home garden papaya plants the infestation was recorded in two states Negeri Sembilan (19.67%) and Selangor 31.64%). Besides papaya, *P. marginatus* infestation was recorded on seven other host plants i.e. hibiscus, roselle, cassava, jatropha, plumeria, eggplant and broad bean belonging to six plant families i.e. Apocynaceae, Caricaceae, Euphorbiaceae, Fabaceae, Malvaceae and Solanaceae. The two predators *C. montrouzieri* and *Apertochrysa* sp. were recorded feeding on *P. marginatus*. The results showed significantly higher population of *C. montrouzieri* (4.70 ± 0.50) as compared to *Apertochrysa* sp. (0.90 ± 0.20) at $P < 0.001$. Out of 7965 *P. marginatus* mummies collected, four species of parasitoids were emerged. The most dominant species found was *Acerophagus papayae* (Encyrtidae: Hymenoptera) the primary parasitoid and the remaining three parasitoids *Chartocerus* sp. (Signophoridae: Hymenoptera), *Marietta leopardina* (Aphelinidae: Hymenoptera) and *Cheiloneurus* sp. (Encyrtidae: Hymenoptera) were hyperparasitoids. Overall results of parasitoid investigation showed maximum frequency ($95.2 \pm 0.57\%$) of *A. papayae*. However, the frequencies among *Chartocerus* sp., *M. leopardina* and *Cheiloneurus* sp. were recorded at the rate of $3.50 \pm 0.50\%$, $1.00 \pm 0.30\%$ and $0.30 \pm 0.10\%$, respectively.

Keywords: Host plants, mealybug, natural enemies, papaya, tropical.

INTRODUCTION

Papaya, *Carica papaya* L. is native to tropical America but now it is considered as one of the most important fruits throughout the tropical and subtropical regions of

the world. It is rapidly becoming an important fruit internationally, as fresh and processed products (Da Silva *et al.*, 2007). Papaya, known as Buah Betik in Malaysia, is a small holder's crop being cultivated on an area of about 2681 hectares with total fruit production of 44,928 metric tons in 2011. Malaysia ranked as third major papaya fruit exporting country after Mexico and Belize in 2010. Large amount of Malaysian papaya (57.45%) is exported to international markets with total export value of 9.17 million US\$ (FAOSTAT, 2013). Papaya is attacked by a variety of organisms including insect pests, mites and pathogens (Ventura *et al.*, 2004; Pantoja and Peña, 2007). Total 122 insect species belonging to the families Coleoptera, Diptera, Hemiptera, Lepidoptera and Thysanoptera are infesting different parts of papaya plant. Among them, twenty six species are infesting fruit, eighty four species can potentially damage fruit but are mainly associated with foliage or trunk, five species to flower, six species to root and one species is reported as seed borer. The key pests of papaya are fruit flies, leafhoppers, aphids, mites, mealybugs and scales. The fruit flies, mealybugs and scales are most economically important pests with having additional quarantine concern (Pena *et al.*, 2005; Pantoja and Pena, 2007). The papaya mealybug is a notorious polyphagous pest recorded in five biogeographic regions of the world, i.e. Neotropic, Nearctic, Oceania/Australasia, Oriental/Indo-Malay and Afrotropical (Miller *et al.*, 1999; Meyerdirk *et al.*, 2004; Muniappan *et al.*, 2006; Heu *et al.*, 2007; Muniappan *et al.*, 2008; Ben-Dov, 2012). The most important hosts recorded are papaya hibiscus, mulberry, citrus, mango, avocado, tomato, eggplant, pepper, beans, peas, sweet potato, cotton, cherry, pomegranate and rubber, etc. (Miller and Miller, 2002; Heu *et al.*, 2007; Selvaraju and Sakthivel, 2011). In 1955, *P. marginatus* specimens were collected for the first time on cassava plant (*Manihot esculenta*) in Mexico. In Caribbean the pest was first recorded in St. Martin in 1995 and later accidentally spread to 14 countries in the Caribbean, United States and South America. In 2002, the pest was recorded from Guam infesting papaya plants severely and then in 2003 it was reported from Palau (Meyerdirk *et al.*, 2004).

The pest invaded Hawaiian islands in 2004 and caused serious losses to papaya plantation (Heu *et al.*, 2007). In 2008, a team of Integrated Pest Management Collaborative Research Support Program (IPM CRSP) researchers reported *P. marginatus* for the first time from Indonesia and India, causing serious damage to papaya and showed their concern about the presence and spreading of the pest in neighboring countries and alerted the South and South-East Asian scientists to be vigilant about spreading of the pest to other localities (Muniappan *et al.*, 2008). Within short period of time, the pest was reported in many Asian countries including Bangladesh, Cambodia, Malaysia, Maldives, Pakistan, Philippines, Sri Lanka, Taiwan and Thailand (Anonymous, 2010; Galanihe *et al.*, 2010; Mastoi *et al.*, 2011; Muniappan *et al.*, 2009). Because of alien mealybug species, it was managed successfully through introduction of three encyrtid parasitoids i.e. *Anagyrus loecki*, *Pseudleptomastix mexicana* and *Acerophagus papayae* in Guam, Palau, Florida, Hawaii, India and Sri Lanka. (Walker *et al.*, 2003; Meyerdirk *et al.*, 2004; Muniappan *et al.*, 2006; Muniappan *et al.*, 2009). Keeping in view the presence of pest in neighbouring Indonesia, an investigation was conducted in three states of Peninsular Malaysia for the establishment of the pest

and its infestation status on farm managed as well as wild and home garden papaya plants. The record of other host plants and the diversity of natural enemies which suppressing the *P. marginatus* population in natural environment was also included in the study.

MATERIALS AND METHODS

Sampling

A survey for *P. marginatus* infestation and its natural enemies was conducted in three states of Peninsular Malaysia (Plate 1) during 2009 to 2010. A total of 12 locations namely Bidor and Felda Sungai Behrang in Perak State, Lenggeng, Mahang, Mantin and Port Dickson in Negeri Sembilan State and UPM Campus, Sri Serdang, Bukit Serdang, Serdang Lama, Serdang Raya and Kuala Selangor in Selangor State were surveyed.

Infestation of *P. marginatus* on farm managed papaya plants

Total of seven papaya farms, one in Mantin (Negeri Sembilan State), three in Sri Serdang (Selangor State) and three in Bidor (Perak State) were visited to observe *P. marginatus* infestation. One hundred papaya plants were selected randomly from each farm for observation and recording of *P. marginatus* infestation. All aerial plant parts including leaves, fruits and stem were observed for *P. marginatus* infestation.

Infestation of *P. marginatus* on wild and home garden papaya plants

The survey for *Paracoccus marginatus* infestation in wild and home garden papaya plants was also conducted in three states of Peninsular Malaysia namely Perak having two locations (Bidor and Felda Sungai Behrang), Negeri Sembilan having four locations (Lenggeng, Mahang, Mantin and Port Dickson) and Selangor having six locations (UPM Campus, Sri Serdang, Bukit Serdang, Serdang Lama, Serdang Raya and Kuala Selangor).

Infestation of *P. marginatus* on other host plants

Paracoccus marginatus infestation was also surveyed on host plants around 10 meter diameter of papaya plants in all surveyed locations. All the aerial plant parts were carefully observed for infestation of *P. marginatus*. The host plants survey is shown in Table 1.

Natural enemies of *P. marginatus*

A total of 30 severely infested papaya leaves were collected from the locations where *P. marginatus* were surveyed and taken to laboratory to investigate natural enemies of the pest. The immature stages of predators collected were further reared on its actual host (*P. marginatus*) in the laboratory for emergence of adults. While mummies collected were separately placed in glass vials covered

with muslin cloth until the emergence of all parasitoids. A total of 7965 *P. marginatus* mummies were collected and observed for diversity of parasitoids. The specimens of natural enemies (predators and parasitoids) collected were identified with the help of available literature (Booth and Pope, 1986; Noyes and Schauff, 2003; Noyes, 2012). The specimens were also sent to Plant Pest Diagnostics Centre (PPDC) California Department of Food and Agriculture (CDFA), USA and Natural History Museum London, UK for confirmation.



Plate 1. Map of Peninsular Malaysia showing three states of study area.

Data analysis

The data were analyzed for the mean infestation percentage of *P. marginatus* in relation to host plants, farm managed, wild and home garden papaya plants. The percent infestation was calculated by following formula:

$$\text{The infestation (\%)} = \frac{\text{Number of infested plants}}{\text{Total number of observed plants}} \times 100$$

Analysis of variance (ANOVA) and Student t-tets were used to analyse the data for predators and parasitoids collected during the study whereas Least Significant Difference (LSD) was used for the mean comparisons at $P < 0.05$. All the analysis were done using SAS 6.2. The survey results showed no infestation in Perak; therefore, observed data only from Negeri Sembilan and Selangor states were analyzed.

RESULTS AND DISCUSSION

Infestation of *P. marginatus* on farm managed papaya plants

The results of survey for *P. marginatus* infestation conducted in Perak, Negeri Sembilan and Selangor states of Peninsular Malaysia, show that *P. marginatus* infestation was found only in Selangor state in Serdang (Department of Agriculture Farm) with 30.3% infestation on farm managed papaya plants, whereas, rest of states had no infestation (Table 2). Regupathy and Ayyasamy (2010) surveyed for infestation of papaya plantations with *P. marginatus* in Tamil Nadu, India and found 95% infestation.

Infestation of *P. marginatus* on wild and home garden papaya plants

Survey on wild and home garden papaya plants was also conducted in the same three states. The two states viz. Negeri Sembilan and Selangor showed *P. marginatus* infestation. However, Perak state had no *P. marginatus* infestation. *Paracoccus marginatus* infestation data showed greater infestation (72.1%) around UPM Campus at Selangor state, followed by 42.9% in Port Dickson at Negeri Sembilan state.

The overall *P. marginatus* infestation data showed 28.0% in Sri Serdang, 20.0% in Kuala Selangor, 16.7% in Serdang Raya and 13.3% in Bukit Serdang, all located in Selangor State. Whereas, Mantin, Mahang and Lengguing had 20.0%, 18.2% and 7.1% infestation, respectively at Negeri Sembilan state. As compared to Negeri Sembilan, the higher *P. marginatus* infestation was recorded in Selangor (Table 3).

Infestation of *P. marginatus* on other host plants

The results from same states viz. Negeri Sembilan and Selangor revealed that *P. marginatus* had specific host plants and the pest was observed on eight plant species (Plate 2) belonging to six families i.e Apocynaceae, Caricaceae, Euphorbiaceae, Fabaceae, Malvaceae and Solanaceae. Visual observations showed typical symptoms of *P. marginatus* infestation e.g. cotton like masses on different plant parts, yellowing of leaves, plant stunting, build-up of honey dew and development of sooty mold, early leaf and fruit drop and leaf deformation. In these host plants, *P. marginatus* affected leaves, tender shoots, stems, flowers and fruits.

The survey on host plants of *P. marginatus* showed highest infestation (100%) on roselle plants, whereas lowest (17.7%) infestation was observed in cassava plants. The overall survey results for *P. marginatus* infestation on host plants showed 57.1% infestation on eggplant, 36.0% on hibiscus, 35.3% on plumeria, 33.3% on broad bean and 25.0% on jatropha plants (Table 4).

Although, more than 200 plant species have been reported as host plants around the world (Miller *et al.*, 1999; Miller and Miller, 2002; Hodges *et al.*, 2005; Galanihe *et al.*, 2010; Cham *et al.*, 2011; Patil *et al.*, 2011; Selvaraju and Sakthivel, 2011; Sakthivel *et al.*, 2012), but from Malaysia *P. marginatus* was

reported on eight host plants only. Thailand being a neighbouring country of Malaysia recorded infestation of *P. marginatus* on ten host plants, i.e. *Carica papaya*, *Plumeria acuminata*, *Plumeria rubra*, *Bidens pilosa*, *Bidens pilosa*, *Jatropha integerrima*, *Manihot esculenta*, *Hibiscus rosasinensis*, *Brunfelsia uniflora* and *Solanum torvum* (Saengyot and Burikam, 2011) while in Taiwan Chen *et al.* (2011) recorded the pest on twelve host plants.

Natural enemies of *P. marginatus*

Two predator species, one primary parasitoid and three hyperparasitoids were found, and list is presented in Table 5.

Predators

Two insect predator species collected were *Apertochrysa* sp. and *Cryptolaemus montrouzieri* found feeding on *P. marginatus*.

***Apertochrysa* sp**

It is commonly known as green lacewing. The predator is frequently found in Selangor. Larvae are voracious feeder of *P. marginatus* eggs, nymphs and adults. Larvae with pincers like tiny tongues which vigorously attacks different stages of *P. marginatus*, sucking fluid contents of the host body (Plate 3).

Cryptolaemus montrouzieri

It is commonly known as Australian ladybird or mealybug destroyer. This predator was frequently found in all *P. marginatus* infested areas in Negeri Sembilan and Selangor States. The adult female lays eggs in ovisacs of *P. marginatus*. Eggs hatch inside the ovisacs and larvae starts feeding on *P. marginatus* eggs. Due to continuous feeding on waxy mealybugs, larvae secrete long tufts of white waxy filaments which make them difficult to differentiate from mealybugs. Adults are shiny black with head and pronotum orange in color. Both adults and larvae prefer to feed on eggs of *P. marginatus* (Plate 4).

Table 6 describes the comparative analysis of population of two predators recorded on *P. marginatus* that showed significantly higher population of *C. montrouzieri* as compared to *Apertochrysa* sp. ($P < 0.001$). Comparative mean population of *Apertochrysa* sp. and *C. montrouzieri* at different sampling locations is given in Table 7. The results indicated a significant difference in the population of two predators at various locations ($P < 0.05$). The highest population of *Apertochrysa* sp. was recorded at UPM Campus (2.30 ± 0.60) that was not significantly different from Sri Serdang (1.50 ± 0.30). No population of *Apertochrysa* was recorded at Kuala Selangor and Port Dickson. *Cryptolaemus montrouzieri* population was significantly higher at Port Dickson (6.50 ± 1.40), whereas the lowest population (2.70 ± 0.30) was recorded from Sri Serdang.

Cryptolaemus montrouzieri is a world known predator of mealybugs and comparative studies showed its preference towards papaya mealybugs (Mishra *et al.*, 2012). Walton and Pringle (2004) reported the presence of *Nephus*

predatory beetles and the parasitoids *Coccidoxenoides perminutus* Girault, *Anagyrus* sp. and *Leptomastix dactylopii* (Howard) on different species of mealybugs in South Africa. Studies by Saengyot and Burikam (2011) on natural enemies of *P. marginatus* in Thailand identified coccinellid *Sasajiscymnus quinquepunctatus* (Weise) and carnivorous apefly, *Spalgis epius* (Westwood) as dominant predator species along with two species of green lac wings. *C. montrouzieri* and *S. epius* were also recorded as dominant predators of *P. marginatus* in different parts of India, confirming their significant role in the population regulation of the bug (Pokharkar *et al.*, 2010; Regupathy and Ayyasamy, 2011). In the studies undertaken, significantly higher population of *C. montrouzieri* were recorded in accordance with the studies mentioned above in different regions of the world.



Plate 2. Host plants of *P. marginatus* (a) Papaya (b) Hibiscus (c) Roselle (d) Cassava (e) Jatropha (f) Eggplant (g) Plumeria (h) Broad bean.



Plate 3. *Apertochrysa* sp. (Larva) feeding on *P. marginatus*



Plate 4. *C. montrouzieri* (Adult) feeding on *P. marginatus*

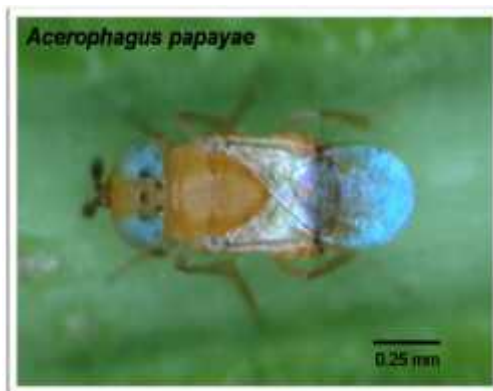


Plate 5, Primary parasitoid

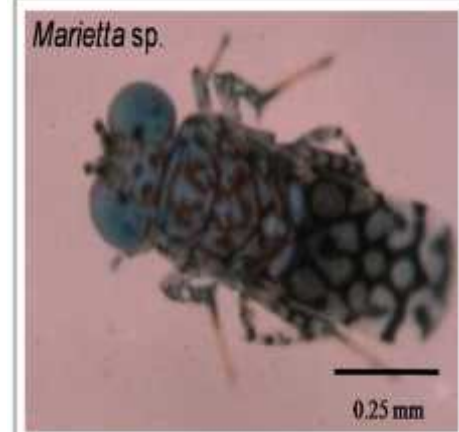
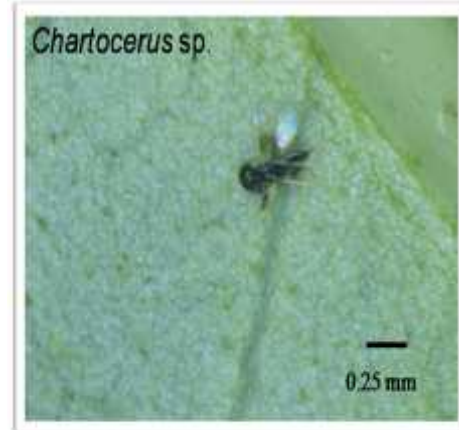


Plate 6. Hyperparasitoids

Table 1. Host plants surveyed for infestation of *P. marginatus*.

Common name	Botanical name	Family
Hibiscus	<i>Hibiscus rosa-sinensis</i>	Malvaceae
Roselle	<i>Hibiscus sabdariffa</i>	Malvaceae
Cassava	<i>Manihot esculenta</i>	Euphorbiaceae
Jatropha	<i>Jatropha curcus</i>	Euphorbiaceae
Eggplant	<i>Solanum melongena</i>	Solanaceae
Plumeria	<i>Plumeria rubra</i>	Apocynaceae
Broad bean	<i>Vicia faba</i>	Fabaceae
Papaya	<i>Carica papaya</i>	Caricaceae
Sugarcane	<i>Saccharum spp.</i>	Andropogoneae
Carambola (Starfruit)	<i>Averrhoa carambola</i>	Oxalidaceae
Rambutan	<i>Nephelium lappaceum</i>	Sapindaceae
Citrus	<i>Citrus spp.</i>	Rutaceae
Sapodilla (Ciku)	<i>Manilkara zapota</i>	Sapotaceae
Custard apple	<i>Annona reticulata</i>	Annonaceae
Jackfruit	<i>Artocarpus heterophyllus</i>	Moraceae
Durian	<i>Durio spp.</i>	Malvaceae
Guava	<i>Psidium guajava</i>	Myrtaceae
Pineapple	<i>Ananas comosus</i>	Bromeliaceae
Banana	<i>Musa spp.</i>	Musaceae

Table 2. Percent infestation of *P. marginatus* on farm managed papaya plants.

Name of State	No. of plants observed	No. of infested plants	Infestation (%)
Negeri Sembilan Mantin	100	0	0.00
Selangor Sri Serdang (Dept. of Agri. Farm)	300	91	30.33
Perak Bidor	300	0	0.00

Table 3. Percent infestation of *P. marginatus* on wild and home garden papaya plants.

Location	No. of plants observed	No. of infested plants	Infestation (%)
Negeri Sembilan			
Lenggeng	56	4	7.14
Mahang	44	8	18.18
Mantin	116	24	20.69
Port Dickson	28	12	42.86
Total Selangor	244	48	19.67
UPM Campus	104	75	72.11
Sri Serdang	100	28	28.00
Bukit Serdang	60	8	13.33
Serdang Lama	60	4	06.66
Serdang Raya	60	10	16.66
Kuala Selangor	30	6	20.00
Total	414	131	31.64

Table 4. Percent Infestation of *P. marginatus* on other host plants.

Host plants	Plant parts affected	Observed plants	Infested plants	Infestation (%)
Hibiscus	Tender shoots and leaves	100	36	36.00
Roselle	Flowers and shoots	8	8	100.00
Cassava	Leaves	300	53	17.66
Jatropha	Stem and leaves	36	9	25.00
Eggplant	Leaves	28	16	57.14
Plumeria	Leaves	34	12	35.29
Broad bean	Pods	12	4	33.33

Table 5. Natural enemies of *P. marginatus*.

Scientific name	Family	Order	Type
<i>Apertochrysa</i> sp. Tjeder, 1966	Chrysopidae	Neuroptera	Predator
<i>Cryptolaemus montrouzieri</i> Mulsant, 1853	Coccinellidae	Coleoptera	Predator
<i>Acerophagus papayae</i> Noyes and Schauff, 2003	Encyrtidae	Hymenoptera	Primary parasitoid
<i>Chartocerus</i> sp. <i>Marietta leopardina</i> Motschulsky, 1863	Signophoridae Aphelinidae	Hymenoptera Hymenoptera	Hyperparasitoid Hyperparasitoid
<i>Cheiloneurus</i> sp. Westwood, 1833	Encyrtidae	Hymenoptera	Hyperparasitoid

Table 6. Mean population of two predators recorded on *P. marginatus*.

Predator	Mean \pm SE	<i>t</i>	<i>P</i>
<i>Apertochrysa</i> sp.	0.90 \pm 0.2	6.89	< 0.001
<i>C. montrouzieri</i>	4.70 \pm 0.50		

Table 7. Mean population of two predators of *P. marginatus* at different locations.

Locations	Predators	
	<i>Apertochrysa</i> sp.	<i>C. montrouzieri</i>
Sri Serdang	1.50 \pm 0.30a	2.70 \pm 0.30c
UPM Campus	2.30 \pm 0.60a	3.20 \pm 0.40bc
Kuala Selangor	-	6.00 \pm 0.50ab
Port Dickson	-	6.50 \pm 1.40a
Mantin	0.70 \pm 0.30b	5.20 \pm 1.40abc

*Means followed by same letters in same column are not significantly different ($p < 0.05$).

Table 8. Percent population of different parasitoids on *P. marginatus*.

Parasitoid	Percent \pm SE
<i>A. papaya</i>	95.20 \pm 0.57a
<i>Chartocerus</i> sp.	3.50 \pm 0.50b
<i>M. leopardina</i>	1.00 \pm 0.30c
<i>Cheiloneurus</i> sp.	0.30 \pm 0.10c

*Means with same letters are not significantly different ($P < 0.005$).

Primary parasitoid

Acerophagus papayae (Hymenoptera: Encyrtidae) is primary parasitoid that spends a significant portion of its life cycle attached with a single host viz. *P. marginatus*. The body length of this parasitoid is 1.0 mm, color generally pale orange except brown marks on the neck of pronotum, cercal plates in abdomen and apical portion of ovipositor sheath. This parasitoid has compound eyes greenish and ocelli red. Antennal club three segmented with five funicles and 5th funicle segment is smaller and dusky in color. Forewings hyaline (transparent/glassy) with conspicuous sub-circular infuscate area from stigmal vein to posterior wing margin (Plate 5). Male is generally similar to female except in a smaller size (0.6-0.7 mm length), un-segmented antennal club, cercal plates in abdomen extensively darkened and forewings with an inconspicuous infuscate area close to stigma vein only. The parasitoid is a most efficient and host specific on *P. marginatus*. It is native to Mexico and can be cultured easily and used in a classical biological control program to manage *P. marginatus* in environmental friendly way. Out of 7965 mummies collected, *A. papayae* was emerged in 95.20 \pm 0.57% mummies (Table 8).

Hyperparasitoids

The hyperparasitoids parasitize primary parasitoid and so far no secondary parasitoids were reported on *Acerophagus papayae* in *P. marginatus* all over the world. Nevertheless in this study, three hyperparasitoids namely *Chartocerus* sp., *Marietta leopardina* and *Cheiloneurus* sp. were recorded (Plate 6). The results of hyperparasitoid showed that *Chartocerus* sp. had maximum population frequency (3.50 \pm 0.50%) while very low population frequencies (1.00 \pm 0.30% and 0.30 \pm 0.10%) were recorded in *Marietta leopardina* and *Cheiloneurus* sp., respectively (Table 8). The *Chartocerus* sp. had smooth body having length of 0.5 mm with glossy black color, gaster broadly sessile, antennal club un-segmented and larger than remaining antennal parts (Hayat, 2004). The body length of *Marietta leopardina* was 0.5 mm with striking patterns on head, thorax and abdomen including fore wings and legs (Noyes, 2012). However, *Cheiloneurus* sp. had 0.8 mm body length, tuft of setae on the scutellum apex, forewings infuscate, and gaster tapering (Noyes and Chua, 1977; Anis and Hayat, 2002). The lower population frequencies of secondary parasitoids might be due to the reasons of newly invasion of *P. marginatus* and *A. papayae* in Malaysia. The species of *Cheiloneurus* were commonly reported in Asia and are well known as secondary parasitoids. Nalini and Manickavasagam (2011) recorded two *Cheiloneurus* sp.

from Tamil Nadu, India acting as secondary parasitoids on different mealybug species. Noyes and Chua (1977) also collected and identified many *Cheiloneurus* species from tropical Malaysia.

CONCLUSION

Paracoccus marginatus is well established and frequently observed on papaya plants as well as seven other host plants namely: hibiscus, roselle, cassava, jatropha, plumeria, eggplant and broad bean in Peninsular Malaysia. Two predators i.e. the mealybug destroyer, *Cryptolaemus montrouzieri* and green lacewing, *Apertochrysa* sp. were found feeding on *P. marginatus* in its natural environment. One primary parasitoid, *Acerophagus papayae* with 95% population frequency and three hyperparasitoids namely *Chartocerus* sp., *Marietta leopardina* and *Cheiloneurus* sp. with less than 5% population frequencies were also recorded.

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