Host Plants and Natural Enemies of Papaya Mealybug, *Paracoccus marginatus* (Hemiptera: Pseudococcidae) in Thailand

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Abstract

The papaya mealybug, *Paracoccus marginatus* Williams & Granara de Willink (Hemiptera: Pseudococcidae) is native to Mexico and Central America. Between 2008 and 2009 it was detected variously in south India, Indonesia, Malaysia, Sri Lanka and Thailand. Field surveys of host plants of *P. marginatus* in Thailand between 2008 and 2010 revealed 10 species of host plants in 6 families: papaya, *Carica papaya* L. (Caricaceae): Lan Thom or plumerias, *Plumeria acuminata* Aiton and *Plumeria rubra* L. (Apocynacea); Ya Khon Cham Dok Khao or Spanish needles, *Bidens pilosa* L. and *Bidens pilosa* L. var. *radiata* Scherff (Compositae); Pattawia, *Jatropha integerrima* Jacq.: cassava, *Manihot esculenta* Crantz (Euphorbiaceae); Cha Ba or hibiscus, *Hibiscus rosa-sinensis* L. (Malvaceae); and Phut Sam Si or yesterday, today and tomorrow, *Brunfelsia uniflora* (Pohl) D. Don and Makhuea Phuang or Turkey berry or prickly solanum or devil's fig, (*Solanum torvum* Swartz) (Solanaceae). Eleven species of natural enemies were found: two parasitic insects, *Anagyrus* sp. and *Anasius* sp. (Hymenoptera: Encyrtidae); and ten predaceous insects, including five coccinellids, *Cryptogonus orbiculus* (Gyllenhal), *Sasajiscymnus quinquepunctatus* (Weise), *Scymnus quadrillum* Motschulsky, *Scymnus* sp., and *Stethorus* sp. (Coleoptera: Coccinellidae); a carnivorous apefly, *Spalgis epius* (Westwood) (Lepidoptera: Lycaenidae, Miletinae); two species of green lacewings, (*Chrysoperla* sp. (*carnea* group) and *Mallada basalis* (Walker) (Neuroptera: Chrysopidae); and an unidentified syrphid fly (Diptera: Syrphidae). Preliminary field observation indicated that the encyrtid, *Anagyrus* sp., the coccinellid, *S. quinquepunctatus*, and the apefly, *S. epius*, were dominant species in the natural enemy guild. These species should be investigated further as they may be useful in the augmentative biological control of *P. marginatus* in Thailand.

Keywords: papaya mealybug, host plants, natural enemies, biological control, invasive alien species

Introduction

Since the beginning of the 2000s, a number of invasive alien species (IAS) have been discovered in Thailand. The most recent detection was that of the papaya mealybug, *Paracoccus marginatus* Williams & Granara de Willink (Hemiptera: Pseudococcidae), on papaya in 2008 (Anon, 2008a, 2008b). This mealybug is native to Mexico and Central America and spread to the Caribbean in 1994 and to Florida, USA in 1998 (Walker et al., 2006). Papaya mealybug was subsequently reported in the Pacific region: from Guam in April 2002 (Meyerdirk et al., 2004; Plant Protection Service, 2003) from the Republic of Palau in March 2003 (Muniappan et al., 2006; Plant Protection Service, 2003), and Hawaii in the Island of Maui in May 2004 (Heu et al., 2007). In Asia, it was

reported from Bogor, Indonesia in 2008, in southern India in 2008 (Muniappan et al., 2008); from Sri Lanka in 2008 (Hettiarachchi, 2009; Hettiarachchi and Silva, 2009); from Malaysia in 2009 (Anon., 2009).

P. marginatus is highly polyphagous. Ben-Dov (1994) listed *Carica papaya* (Caricaceae); *Ambrosia cumanensis* and *Parthenium hysterophorus* (Compositae); *Acalypha* sp., *Manihot chloristica* and *Manihot esculenta* (Euphorbiaceae); *Mimosa pigra* (Mimosaceae); and *Hibiscus* sp. and *Sida* sp. (Malvaceae) as host plants. Miller et al. (1999) collected specimens of papaya mealybug from a wide variety of host plants in Central America, the Caribbean and the U.S. Miller and Miller (2002) listed 35 plant species as host plants for *P. marginatus*. The host plants are either annual or perennial field crops plants, plantation crops, shrubs or trees, fruit trees, ornamental plants, or weeds. Many hosts are of economic importance. In Cuba, de los Angeles et al. (2000) reported that *P. marginatus* caused significant damage to cassava and papaya when it was found for the first time in 1999. It was also found on a wide variety of other plants but no economic damage has been observed on major economic crops so far. Meyerdirk et al. (2004) reported that papaya mealybug has a wide host range of over 60 species of plants including economically important plants and heavy infestations on papaya in Guam in 2002. Similar infestations were also reported on Palau in 2003 (Muniappan et al., 2006). Heu et al. (2007) reported that in Hawaii, heavy infestations of papaya mealybug have been observed on papaya, plumeria, hibiscus and jatropha. Currently, in Thailand the papaya mealybug attacks and causes significant damage to papaya and ornamental plants such as plumeria and hibiscus. It damages a few other plants and weeds to a lesser extent.

Among the natural enemies of the papaya mealybug worldwide, five species of parasitoids specific to mealybugs were collected in Mexico by USDA, ARS researchers and Mexican cooperators as potential biological control agents for papaya mealybugs. In addition to the parasitoids, a number of predaceous insects were reported. Heu et al. (2007) reported that in Hawaii a number of coccinellids prey on papaya mealybug and contributed significantly to the augmentative biological control of this pest.

With relatively heavy infestation of *P. marginatus* detected on papaya and plumeria in 2008 in Thailand and earlier reports of its polyphagous habit, it is justifiable to explore its host plants which may be cultivated plants of economic importance or other wild and uncultivated plant species. It is also desirable to undertake a preliminary evaluation of the natural enemies associated with *P. marginatus* on those host plants to evaluate their potential as biological control agents.

The objective of the present investigation was to conduct a survey on the host plants of *P. marginatus* and simultaneously the natural enemies guild associated with them in some provinces in the northern, northeastern, central, and eastern regions of the country. These would provide a basis for further assessment of the potential of the natural enemies for augmentative biological control of the papaya mealybug in Thailand.

Materials and Methods

Field Survey of Host Plant of *P. marginatus*

A field survey of the papaya mealybug and its host plants was carried out from late 2008 until mid 2011 at different locations between latitude 12.00°N to 20.00° N and 99.00°E to 102.00° E, covering Chiang Rai, Phayao, Chiang Mai, Lamphun, Lampang, Sukhothai and Phitsanulok in the northern region; Khon Kaen, Chaiyaphum and Nakhon Ratchasima in the northeastern region; Nakhon Sawan, Sing Buri, Lop Buri, Ang Thong, Suphan Buri, Phra Nakhon Si Ayutthaya, Pathum Thani, Nakhon Nayok, Kanchanaburi, Phetchaburi, Ratchaburi, Nakhon Pathom, Samut Songkhram, Samut Sakhon, Bangkok, Prachin Buri and Chachoengsao in the central region; and Chon Buri, Rayong and Chanthaburi in the eastern region.

Preliminary identification of specimens of papaya mealybug was made in the laboratory according the descriptions given by Ben-Dov (1994), Miller and Miller (2002), Walker et al. (2006) and Williams and Granara de Willink (1992). Since the surveyed plants could be infested by other species of mealybugs, questionable

specimens were provisionally identified using the technique given by G.W. Watson (personal communication). In this technique live mealybug specimens are placed in 70% ethyl alcohol; rapid identification of papaya mealybug is confirmed if the body contents turn from yellow to black in 24 hours or less. The latitudes and longitudes of the study sites were recorded using built-in GPS Meter Smart Mobile Phone Model Nokia E72.

Field Survey of Natural Enemies of *P. marginatus*

The field survey of the insect natural enemies of *P. marginatus* was carried out simultaneously with the survey of its host plants in all locations. The survey was carried out in accordance with methods given in Van Driesche and Bellows (1996). The natural enemies were collected by examining the colonies of *P. marginatus* on the host plants for any parasitoids and predators found feeding *in situ* on the mealybug colonies. For the parasitoids, adult specimens were collected by aspirator and preserved in 70% ethyl alcohol in vials. Live mealybug colonies were also collected together with host substrate, brought back to the laboratory and held for the emergence of any adult parasitoids. For the predators, the larvae and adults of coccinellids and other predatory insects were collected live and kept in plastic containers, brought back to the laboratory for identification and further study. Rough observations were also made on the distribution, density and extent of parasitism and predation by each species of natural enemy. Voucher specimens of all natural enemies were deposited in the National Biological Control Research Center (NBCRC) Natural Enemies Reference Depositary (NERD), NBCRC Upper Northern Regional Center at Mae Jo University, Chiang Mai.

Results and Discussion

Host Plants of *P. marginatus*

In this study, a total of ten species of plants in six families was found to serve as host plants of *P. marginatus* (Table 1). Apart from the economically important papaya, plumeria and cassava attention was also given to the long list of host plants previously reported in other countries in Central America, the Caribbean, the Pacific region and Asia. The survey revealed that in Thailand *P. marginatus* does not have such a wide range of host plants. Heavy infestation on papaya was found at all the study sites. Partial infestation on cassava was found at Nakhon Ratchasima and Chiang Mai and substantial infestation on Lan Thom or plumeria was found at almost all survey sites, especially in the central provinces such as Bangkok, Suphan Buri, Nakhon Pathom, Samut Sakhon and Chachoengsao.

In Thailand *P. marginatus* was first found in 2008 with relatively severe damage on papaya, *Carica papaya* L. (Caricaceae), cassava, *Manihot esculenta* Crantz (Euphorbiaceae), and plumeria, *Plumeria acuminata* Aiton and *Plumeria rubra* L. (Apocynaceae) only. Cha Ba, *Hibiscus rosa-sinensis* L. (Malvaceae) was infested to some extent. The following was infested to a negligible extent: Pattawia, *Jatropha integerrima* Jacq. (Euphorbiaceae); Phut Sam Si or yesterday, today and tomorrow, *Brunfelsia uniflora* (Pohl) D. Don (Solanaceae); Makhuea Phuang, *Solanum torvum* Swartz. (Solanaceae); and the invasive weeds Ya Kon Cham Khao or Spanish needle, *Bidens pilosa* L. and *Bidens pilosa* L. var. *radiata* Scherff (Compositae). From late 2009 through 2010 to mid-2011, *P. marginatus* was found mainly on papaya and to some extent on cassava, but rarely on plumeria, and almost not at all other host plants found earlier. It was also possible that other mealybug species, such as the pink hibiscus mealybug, *Maconellicoccus hirsutus* (Green), striped mealybug, *Ferrisia virgata* (Cockerell), citrus mealybug, *Phenacoccus citri* (Risso) and solanum mealybug, *Phenacoccus solani* Ferris, were misidentified as *P. marginatus* on those host plants during earlier surveys and that this has given rise to such a long list hosts.

The reported host plants of *P. marginatus* were very diverse. The ranged from annuals to perennials from shrubs to trees and from species of high economic value to weeds. According to Ben-Dov (1994), the holotype female of *P. marginatus* deposited at the British Museum, Natural History (BMNH) was collected from cassava in Tabasco, Mexico. In Cuba, de los Angeles et al. (2000) reported over 30 species of host plants consisting of mango, pomegranate, cherry (*Eugenia uniflora*),

Table 1 Host plants of papaya mealybug, Paracoccus marginatus, found in Thailand.

Plant species	Common name	Location	GPS data	
			Latitude	Longitude
APOCYNACEAE:	Lan Thom Daeng	Nakhon Pathom	13.55°11.40′N	100.34°55.24′E
Plumeria acuminata Aiton	Plumeria	Bangkok		
	Frangipani		13.91°36.11′N	100.58°97.22′E
Plumeria rubra L.	Lan Thom Khao	Almost all	12.00-20.00°N	90.00-102.00°E
	Plumeria Frangipani	locations		
		surveyed		
	Papaya			
CARICACEAE:			12.00-20.00°N	90.00-102.00°E
Carica papaya L.		Almost all		
		locations		
COMPOSITAE		surveyed		
Biden pilosa L.	Ya Khon Cham Dok	Chiang Mai	18.52°48.92′N	98.58°49.07′E
	Khao	Chiang Rai	20.02°18.75′N	100.00°51.39′E
	Spanish needle			
Biden pilosa L.var radiata	Ya Khon Cham	Chiang Mai	18.52°48.92′N	98.58°49.07′E
Scherff	Khao Dok Yai	Chiang Rai	20.02°18.75′N	100.00°51.39′E
	Chiang Rai daisy			
EUPHORBIACEAE	Pattawia			
Jatropha integerrima Jacq	Peregrina			
	Cotton-leaved	Bangkok	13.75°69.46′N	100.75°38.77′E
	jatropha			
	Cassava			
	Manioc			
Manihot esculenta				
Crantz	Cha Ba	Nakhon	15.20°97.22′N	101.76°58.33′ E
	Hibiscus	Ratchasima	18.52°48.92′N	98.58°49.07′E
MALVACEAE		Chiang Mai		
Hibiscus rosa-sinensis L.			13.81°65.61′N	100.05°07.98′E
		Bangkok		
SOLANACEAE				
Brunfelsia	Phut Sam Si	Chiang Mai	18.91°59.21′N	99.01°32.57′E
uniflora (Pohl) D.Don	Yesterday, today &			
	tomorrow			
	Makhuea Phuang			
Solanum torvum Swartz	Turkey berry			
	Prickly solanum	Lamphun	18.42°44.51′N	99.01°32.57′E
	Devil's fig			

Global Positioning System (GPS) were recorded at every study site using built-in GPS Meter Smart Mobile Phone Model Nokia E72.

orange, pineapple, tomato, aubergine or eggplant, sweet pepper (*Capsicum annuum*), beans (*Vigna* sp., *Dolichos lablab*, *Hebestigma cubense*, *Cajanus cajan* and *Phaseolus* sp.); cotton, *Acalypha* sp., *Annona muricata*, *Manilkara zapotilla*, *Solanum torvum*, *Solanum nigrum*, *Erythrina* sp., *Bidens* sp., *Ligustrum* sp., *Pluchea odorata*, *Hibiscus* spp., *Cordia alba*, *Cordia* sp., *Jatropha* spp., *Guasima tomentosa*, *Dahlia pinnata* and cacao (*Theobroma cacao*). Miller and Miller (2002), in the redescription of *P. marginatus* including descriptions of the immature stages and adult male, stated that since its introduction into Florida in 1998 it had been collected on 18 species of host plants and reported from more than 25 genera of host plants including economically important crops such as papaya, citrus, yams, cassava and hibiscus. They also provided a list of 35 species of confirmed host plants and references. Meyerdirk et al. (2004) reported that the papaya mealybug has a wide host range of over 60 species of plants including economically important plants such as custard apple, cassava, sweet potato and eggplant. Anon. (2004) listed 34 species in 20 families as host plants of *P. marginatus*. Other than some plants and crops of agricultural importance including papaya, they are as diversified as castor, *Ricinus communis* L. (Euphorbiaceae), coral tree or Thong Lang, *Erythrina abyssinica* (Leguminosae), giant sensitive plant or Maiyarap Yak, *Mimosa pigra* L., (Mimosaceae), Khae Farang, *Gliricidia sepium* (Jacq.) Walp. (Leguminosae), night jasmine or Ra Tri, *Cestrum nocturnum* L. (Solanaceae), pagoda flower or Nom Sawan, *Clerodendrum paniculatum* L. (Labiatae), teak, *Tectona grandis* L. (Labiatae) and corn, *Zea mays* L. (Poaceae). Walker *et al.* (2006) reported that there were over 55 species in more than 25 genera of host plants recorded in Central America, the Caribbean and Florida, USA. The economically important host plants included papaya, hibiscus, avocado, citrus, cotton, tomato, eggplants, peppers, beans and peas, sweet potato, mango, cherry, and pomegranate. In Florida, Amarasekare et al. (2008) investigated the life history of *P. marginatus* on four host plants consisting of papaya, hibiscus, plumeria, and parthenium weed, *Parthenium hysterophorus*, (Compositae).

In Asia, Muniappan et al. (2008) in the first report of *P. marginatus* causing severe damage to papaya in Bogor, in Indonesia and Coimbatore, Tamil Nadu in India, speculated that it could cause losses in crops such as papaya, cassava, sour sop, sweetsop, mango, avocado, and ornamental plants such as hibiscus and plumeria. In Sri Lanka, *P. marginatus* was reported from breadfruit, mango, guava, rambutan, citrus, okra, tomato, chili, melon, and cassava (Hettiarachchi, 2009; Hettiarachchi and Silva, 2009). *P. marginatus* was also reported by Mahalingam et al. (2010) to spread to Kerala, Karnataka, Maharashtra and Tripura in India and found attacking agricultural crops such as cotton, okra, tomato, egg plant, cassava; horticultural crops such as mango, guava, mulberry and weeds such as *Eupatorium* and *Parthenium*. It was also found to attack the tree crops such as Mayom Pa, *Ailanthus excels* Roxb. (Simaroubaceae), mulberry, *Morus alba* L. (Moraceae), Ngio, *Bombax ceipa* L. (Bombaceae) and Ngao, *Ceiba pentandra* (L.) Gaertn. (Bombaceae), and Pho Thale, *Thespesia populnea* (L.) (Malvaceae).

The results of the host plant study indicated that in Thailand *P. marginatus* did not have such a wide host range as reported from other countries. Some of the host plants reported in Thailand, such as the giant sensitive plant, corn and several other plants were questionable as the true hosts of *P. marginatus* and they need to be further authenticated. It has been cautioned that information on *P. marginatus* itself and its host plants record may not be entirely accurate (G.W. Watson, personal communication). At the same time, it was also known that *P. marginatus* favors many plants with heavy latex, e.g. papaya plumeria or frangipani, cassava, *Euphorbia* spp., sweet potato and attacks such plants at all stages of the plant life. The validity of previously recorded host plants for *P. marginatus* in Thailand needed to be confirmed.

Natural Enemies of *P. marginatus*

The survey of the natural enemies of *P. marginatus* revealed a total of 11 species of insect natural enemies, comprising two parasitic insects and nine predaceous insects (Table 2).

In Thailand two encyrtid parasitoids, *Anagyrus loecki* and *Anasius* sp. were found and their identity

Table 2 Natural enemies of papaya mealybug, *Paracoccus marginatus*, found on different host plants in Thailand.

Natural enemy	Host plant	Location	GPS data	
			Latitude	Longitude
Parasitic insects				
Hymenoptera				
Encyrtidae:				
Anagyrus sp.	Papaya	Almost all locations	12.00-20.00°N	90.00-102.00°E
	Plumeria	surveyed		
	Cassava			
Anasius sp.	Papaya	Chiang Mai	18.52°48.92′N	98.58°49.07′E
Unidentified encyrtid	Papaya	Chiang Mai	18.52°48.92′N	98.58°49.07′E
Predaceous insects				
Coleoptera				
Coccinellidae,				
Scymninae:	Papaya	Lamphun	18.27°38.74′N	98.54°57.33′E
Cryptogonus orbiculus	Plumeria	Bangkok	13.91°36.11′N	100.58°97.22′E
(Gyllenhal)		Suphan Buri	14.45°20.36′N	14.45°20.36′N
		Phra Nakhon Si Ayutthaya	13.51°05.63′N	13.51°05.63′N
		Chachoengsao		
		Bangkok	13.21°43.69′N	100.01°20.71′E
	Papaya		13.81°65.61′N	100.05°07.98′E
Scymnus quadrillum		Almost all locations		
Motschulsky	Papaya	surveyed	12.00-20.00°N	90.00-102.00°E
Scymnus spp.	Plumeria			
Sasajiscymnus	Papaya	Almost all locations	12.00-20.00°N	′90.00-102.00°E
quinquepunctatus (Weise)	Plumeria	surveyed		
Stethorus sp.	Plumeria	Chachoengsao	13.21°43.69′N	100.01°20.71′E
Lepidoptera				
Lycaenidae,				
Miletinae:				
Spalgis epius	Papaya	Chiang Mai	18.52°48.92′N	98.58°49.07′E
(Westwood)		Chiang Rai	20.40°44.57′N	100.00°94.61′E
Neuroptera				
Chrysopidae:				
Chrysoperla sp. (*carnea*-	Papaya	Almost all locations	12.00-20.00°N	90.00-102.00°E
group)	Plumeria	surveyed		
Mallada basalis	Papaya	Almost all locations	12.00-20.00°N	90.00-102.00°E
(Walker)	Plumeria	surveyed		
Diptera				
Syrphidae:				
Unidentified	Papaya	Chiang Mai	18.52°48.92′N	98.58°49.07′E
syrphid fly		Chiang Rai	20.40°44.57′N	100.00°94.61′E
		Phayao	19.06°50.00′N	100.00°37.14′E

Global Positioning System (GPS) were recorded at every study site using built-in GPS Meter Smart Mobile Phone Model Nokia E72.

remains to be established. Five species of parasitoids have been associated with *P. marginatus* in its native range in Mexico (Noyes and Schauff, 2003); *Acerophagus papayae* Noyes and Schauff, *Anagyrus californicus* Compere, *Anagyrus loecki* Noyes and Menezes, *Pseudaphycus* sp., and *Pseudleptomastix mexicana* Noyes and Schauff (Hymenoptera: Encyrtidae). Of these five encyrtids, *A. loecki*, *A. papayae* and *P. mexicana* were introduced and used for classical biological control of the papaya mealybug in Florida in 2000 (Walker et al., 2006), in Guam in 2002 (Meyerdirk et al., 2004), in Palau in 2003 (Muniappan et al., 2006), in Hawaii in 2005 (Heu et al., 2007) and in Sri Lanka in 2009 (Hettiarachchi, 2009).

The nine predaceous insects found in Thailand comprised; five lady beetles *Cryptogonus orbiculus* (Gyllenhal), *Sasajiscymnus quinquepunctatus* (Weise), *Scymnus quadrillum* Motschulsky, *Scymnus* sp. and *Stethorus* sp. (Coleoptera: Coccinellidae); the carnivorous apefly, *Spalgis epius* (Westwood) (Lepidoptera: Lycaenidae); two lacewings *Chrysoperla* sp. (*carnea*-group) and *Mallada basalis* (Walker) (Neuroptera: Chrysopidae); and an unidentified syrphid fly (Diptera: Syrphidae). All of these natural enemies are endemic to Thailand.

Walker et al. (2006) reported that in Florida, the natural enemies of the papaya mealybug included the commercially available mealybug destroyer, *Cryptolaemus montrouzier*i Mulsant (Coleoptera: Coccinellidae), lady beetles, lacewings, and hover or syrphid flies, all of which were generalist predators that have a potential impact on mealybug populations. In Hawaii, Heu et al. (2007) reported that a number of coccinellids such as *Nephus bilucernarius* (Mulsant), *Scymnus taiwanus* (Ohta), *Hyperaspis silvestrii* Weise, *C. montrouzieri* and *Curinus coeruleus* Mulsant were found to pray on papaya mealybug and contributed significantly to the regulation of mealybug populations. Surprisingly, *C. montrouzieri* and *C. coeruleus* which were introduced into Thailand from Hawaii in the 1970s and 1980s, respectively and became feral species in the country, were not encountered at all during the course of this investigation.

In Thailand, Chunram and Sasaji (1980) and Chunram (2002) identified 133 species of predaceous and phytophagous coccinellids in 49 genera, 15 tribes and 6 subfamilies. Although considered generalist predators, many of the coccinellids were also found feeding preferentially on mealybugs. In this investigation the coccinellids found associated with and preying on *P. marginatus* were *C. orbiculus*, *S. quinquepunctatus*, *S. quadrillum*, *Scymnus* sp. and *Stethorus* sp. Chunram (2002) reported that *Pseudoscymnus (= Sasajiscymnus) quinquepunctatus* (Weise) was a predator of mealybugs on mango and citrus.

S. epius is a less known predator of mealybugs. Along with other miletinids under family Lycaenidae it has been referred to as homopterophagous butterfly (Venkatesha, 2005). Its common name, apefly, was derived from the appearance of the dorsal view of its pupa which resembles the face of a monkey, and thus its Thai common name was *"Phi Suea Dak Dae Hua Ling"* (Lekagul et al., 1977) which is literally "a butterfly whose pupa resembles a monkey head." Although recorded only from Chiang Mai and Chiang Rai in present study, *S. epius* is found widely distributed in all geographical regions of the country. It was collected and recorded as *Spalgis epeus epeus* (Westwood) by Godfrey (1930, 1932), as *Spalgis epeus* by Lekagul *et al.* (1977) and as *Spalgis epius epius* by Corbet and Pendlebury (1978) and Pinratana (1981).

Among all parasitic and predaceous insects associated with *P. marginatus* in this study, the encyrtid parasitoid, *Anagyrus* sp., the predaceous coccinellid, *S. quinquepunctatus* and the carnivorous apefly, *S. epius* were found with the papaya mealybug year round. They also exhibited promising potential as biological control agents for *P. marginatus* and deserved further investigation, especially to determine their amenability to laboratory mass rearing for field releases.

Conclusions

P. marginatus is an invasive alien species (IAS) that has only recently (2008) been detected in Thailand. In this country, papaya is the main host of *P. marginatus*. The severe infestations reported elsewhere on other host plants of economic importance have not been seen in Thailand. The validity of many of these records should be confirmed. Experience in other countries indicates that both classical biological control (i.e. the introduction of natural enemies from their native

range) and augmentative biological control (i.e. control by utilizing endemic natural enemies). The natural enemy guild found in Thailand in this investigation included two encyrtid parasitoids, five predaceous coccinellids, a carnivorous apefly, two lacewings and a syrphid. Among these, the encyrtid, *Anagyrus* sp., the coccinellid, *S. quinquepunctatus* and the carnivorous apefly, *S. epius*, were associated with on *P. marginatus* year round and at almost in all locations. Further investigation on their life history, biological attributes and their potential as biological control agents for *P. marginatus* are recommended to determine their suitability for augmentative biological control of the papaya mealybug in Thailand.

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