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A review on *Paracoccus marginatus* Williams, papaya mealy bug (Hemiptera: *Pseudococcidae*)

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Abstract
Paracoccus marginatus Williams-Papaya mealy bug (PMB) is one among the serious pests in horticultural crops and this causes a great economic drain to a nation depending on the sector of agriculture. These white silent army is becoming a cosmopolitan by it behaviour spreading its host range to more and more-wider ecological strata. From beneath the leaf to the root is a wide stage for this pest to destroy the crop with immature/low yield. PMB is one among the many types of mealybug species and is the toughest among the group by being sedentary and execute hyper activity according to favourability in environment. Management strategies are so limited over this pest because of the thick waxy coating they hold that keep away its delicate body from synthetic contact. Since it is a major pest, quarantine protocols are strictly needed for this pest not only for a national perspective but also from a farm hand seed material to another adjacent. Application of biopesticides with recommended dose of surfactant was the most recommended practice though it holds constrain in wide field applications. If proper natural multiplications are possible in the required time, introduction of parasitoids against PMB provides scope to manage the pest in large field of pest attack.

Keywords: *Paracoccus marginatus*, Papaya mealy bug, Horticulture pest.

Introduction
Paracoccus marginatus Williams and Granara de Willink, the Papaya mealy bug (PMB) is a small polyphagus hemipteran of the family *pseudococcidae*. Mealy bug are sucking insect pests of plants with a wide host range including tropical fruits, vegetables and ornamental plants thus are effective pest on a tropical nation's economy. Infestation of the mealy bug appears as a cluster of cotton like masses on the shoot of the plant. Effective stage of parasitic action of *P. marginatus* is the adulthood which sucks the sap of the plant and weakens it. White dusted yellow or necrotic leaves are the characteristic physical feature of an affected plant. The honey dew excreted by the bug attracts ants to form mutual associations. Spread of this honey over the leaves of the host plant becomes an abode for the black sooty mould formation which impairs photosynthetic efficiency of the affected plants (Schneider *et al*. 2010) [26]. PMB has caused havoc in agricultural and horticultural crops and imparts huge lose to farmers. The extreme infestation not only contaminates the yield but also it leads to the destruction of whole plant. Since the dispersal is mediated by the most cosmopolitan animal Ants, restriction measures on that way are generally a vain.
Achievement as a serious pest in tropics is mainly due to its fast growth and short life span in just 28 days within which sudden seasonal flex probabilities are less. The insect exhibit K selection as being a K strategist by laying 150-600 eggs by a potential female. At ambient environment egg exhibit about 80-90% chance of hatching followed by moulting into adult.

Origin and Distribution
The Papaya mealy bug is believed to be native to Mexico and Central America, where it never acquires the status of a serious pest, probably due to the presence of an endemic natural enemy complex (Tanwar *et al*. 2010) [29]. The specimens of the pest were collected first in 1992 from the Neotropical region in Beliz, Costa Rica, Guatemala, and Mexico. PMB became a pest when it invaded the Caribbean region. Since 1994 it has been recorded in 14 Caribbean countries. The pest was recorded in Bradenton, Florida in 1998 on *Hibiscus* and by 2002 it spread to 18 different plant species in 30 different cities. The establishment of this pest in Guam in 2002 and Palau in 2003 resulted in further spread to neighbouring Hawaiian Islands

in the Pacific. It was noticed in the South and Southeast Asia during 2008-2009. In India it was recorded in July 2007 at Tamil Nadu Agricultural University, Coimbatore and subsequently spread to neighbouring districts. The pest has been reported in Tripure, Erode, Salem, Namakkal and Karur districts of Tamil Nadu. The pest is now spreading to other districts too (Muniappan *et al*. 2009) [18]. The pest has been recently been noticed in the neighbouring states as Karnataka and Kerala. Thiruvananthapuram, Kollam, Pathanamthitta, Alappuzha, Kottayam, Ernakulum and Trissur districts in Kerala are seriously under silent attack of this pest from 2009 onwards. From the extreme southern tip of India the wave of attack is spreading towards the North and from the current trend preferably from East to West.

Fig 1: *Paracoccusmarginatus*- Papaya Mealy Bug (PMB)

Fig 2: PMB in papaya plant (Source: WWW.The hindu.com)

Biology

Mealy bugs are most active in warm, dry weather since rain hinders the spread of the mealybug. Its proliferation rate is also low in rainy seasons. Around ten to twenty species of mealy bugs are prominent as parasites and PMB was the most publicised villain. Females usually lay 150-600 eggs in an ovisac, although a report of giving birth to living young was there (*edis.ifas.ufl.edu* 2010) [8]. Egg laying usually occurs over the period of three to four days, egg hatch in about ten days and nymph or crawlers begin to search for feeding sites. Female crawlers have four instars, with a generation taking more than a week to complete, depending on the temperature. Males have five instars, the fourth of which is produced in a cocoon and referred to as the pupa. The fifth instar of the male is the only winged form of the species capable of flight. Adult females attract the males with the help of sex pheromones. Under greenhouse conditions, reproduction occurs throughout the year, and in certain species may occur without fertilization. In general, mealybugs having piercing-sucking mouthparts and feed by inserting their mouthparts into plant tissue and sucking out sap. Females have no wings, and move by crawling short distances or by being blown in air currents. The adult female is approximately 2.2 mm long and 1.4 mm wide. A series of short waxy caudal filaments, less than one fourth the length of the body exist around the margin. Body is yellow, covered with mealy wax, not thick enough to hide body colour, without discrete bare areas on dorsum, with many short waxy filaments around body margin (NBAII data 2008) [20]. Two characteristics those are important in distinguishing PMB adult female from all other species of *paracoccus* are; the presence of tubular dusts restricted to marginal areas of the body, and the presence of pores on the hind coxae. The female PMB can easily be identified by the presence of eight antennal segments, in contrast to nine in *Maconellicoccus mariginatus* (pink hibiscus-mealy bug). Ovisac is three to four times the body length and develops ventrally beneath the body of the female. Adult males are pink, especially during the pre-pupal and pupal stages, but appear yellow in the first and second instars (Ram Renjan, 2006) [25]. Adult males are approximately 1mm long, with an elongate oval body that is widest at the thorax (0.3mm). Adult males have ten segmented antennae, a distinct aedeagus, lateral pore clusters, a heavily sclerotized thorax and head. They are characteristically distinct and different from females with their well-developed wings and flight.

Diagnostic characteristics

Slide mounted specimens can be readily identified by the following combination of characters: Antennae eight segmented. Venter with multi-locular pores usually in posterior and anterior bands on segments 6^{th} to 8^{th} and restricted to posterior band on segments 4^{th} to 5^{th}. Trilocular pores concentrated around setal bases. Oral-collar tubular ducts of one size, in conspicuous clusters usually on marginal areas associated with cerarri, also present in medial and mediolateral areas of abdominal segments 3^{rd} to 7^{th}, often with two or three pores on 1^{st}segment, present on thorax in setae clusters near middle and hind pairs of legs, absent from head. Oral rim tubular ducts in mediolateral areas from prothorax to 1^{st}segment, with three to six ducts on each side of body; absent from dorsum of anal lobe. Hind coxae, characteristic with numerous translucent pores and hind tibiae lack these pores. In adult males, Body elongation, about 1 mm long, widest around thorax. Genitalia heavily sclerotized, aedeagus apparents, wings approximately as long as the body with small basal vein (NBAII data 2008) [20].

Thermal response

Effect of temperature on the life history of the mealybug was one of the physiological aspects well studied. PMB survives effectively in a temperature range of 25±5 ºC. Slight physiological adjustments are thought to be executed by the pest using water balance in its body. At temperature away from optimum egg may get hatch but the development from nymph to 1^{st} instar was arrested. No egg was found to be hatching beyond a temperature of 37 ºC The developmental time for egg to adult was the longest at 18 ºC for both males and females. Approximately 80-90% of the egg survived in temperature range of 20 ºC -30 ºC. The highest fecundity was at 25 ºC with each female producing an average of 300 eggs. Adult longevity, and preoviposition and oviposition periods increased with decreasing temperature up to 25 ºC. The proportion of females was 42% at 25 ºC. The estimated minimum temperature threshold for the adult males and females were 14.5 ºC and 13.9 ºC respectively. The ability of

PMB to develop, survive, and reproduce successfully between 18 and 30 ºC suggests it has the capability to develop and establish in areas within this temperature range (Amarasekare *et al*., 2008) [1].

Host range

Heavy attack of papaya mealy bug has been noticed on wider range of cultivated crops and weed hosts belonging to different families of plant kingdom. 158 species of mealybug are recognised as pest worldwide (Douglass Miller *et al.*, 1999) [7]. These species most frequently originate from the Palearctic region (29%), followed by Nearctic (17%), Neotropical (16%), Oriental (15%), Afrotropical (12%) and Australasian (11%) regions. Approximately 22% of the mealybug pests are polyphagous, 20% occur on grasses, 16% on citrus and tropical fruits, and 6% on coffee (Jose Carlos Franco *et al*., 2009) [10]. The host range is widening in a pretty alarming rate. A very few plants which are common in the tropics that are under the threat list of papaya mealy bug infection are listed in Table 1.

It was also noticed that during unfavourable condition the pest undergo a kind of complete 'population reverse metamorphosis' by spending whole energy the adult females lay maximum number of eggs i.e., the population for unfavourable season hold only preserved eggs in waxy coating. In this time female preferably chose non-living hiding substrates to preserve their egg mass as cotton fluffy caskets Figs. 3 and 4.

Fig 3: A terrace farmer showing PMB egg mass in a bio-fertilizer can

Fig 4: PMB egg mass in the can, more numbers on the cleft

Table 1: Tropical host-plants of PMB

Type	Scientific name	Common name	Family
Cultivated Horticultural crops	*Cajanus cajan*	Red gram	Leguminosae
	Carica papaya	Papaya	Caricaceae
	Ceiba pentandra	Silk cotton	Malvaceae
	Capsicum sp.	Chilli plant	Solanaceae
	Gossypium hirsutum	Cotton plant	Malvaceae
	Hibiscus rosa sinensis	Shoe flower	Malvaceae
	Hibiscus exculenta	Ladies finger	Malvaceae
	Jatropha curcus	Jatropha	Euphorbiaceae
	Manihot esculenta	Cassava	Euphorbiaceae
	Morus alba	Mulberry	Moraceae
	Psidium guajava	Guava	Myrtaceae
	Lycopersicon esculentum	Tomato	Solanaceae
	Solanaum torvum	Turkey berry	Solanaceae
	Solanum melongena	Brinjal	Solanaceae
	Tectona grandis	Teak	Verbanaceae
	Ananas comosus	Pineapple	Bromeliaceae
	Vitis vinifera	Common Grape vine	Vitaceae
	Pisum sativum	Pea plant	Leguminosae
	Musa sp.	Banana	Musaceae
	Mangifera Indica	Mango	Anacardiaceae
	Cocous nucifera	Coconut	Palmaceae
	Solanum sp.	Potato	Solanaceae
Other weed and Medicinal plants	*Abutilon indicum*	Country mallow	Malvaceae
	Achyranthus aspera	Latjira	Amaranthaceae
	Cleome viscosa	Wild mustard	Capridaceae
	Commelina benghalensis	Spider wort	Commelinaceae
	Convolvulus arvensis	Chandvel	Convolvulaceae
	Euphorbia hirta	Garden sprug	Euphorbiaceae
	Phyllanthus niruri	Hazardani	Euphorbiaceae
	Leucas aspera	Dronapushpi	Lamiaceae
	Ocimum sanctum	Tulsi	Lamiaceae
	Parthenium hysterophorus	Congress grass	Asteraceae
	Tridax procumbens	Ghamra	Compositae
	Trianthema portulacastrum	Pig weed	Aizoaceae
	Canthium inerme	Turkey berry	Rubiaceae
	Phyllanthus niruri	Keezhar nelli	Phyllanthaeceae
	Nerium oleander	Arali	Apocynaceae

Mutualism

Some species of ant 'farm' mealybug, protecting them on the plants they eat, eating the honeydew that the mealybug release from the terminations of their alimentary canals. This unusual relationship as mutualism also exhibit 'Trophophoresy', where the queen ant takes a mealybug from her birth nest during her mating flight (LaPolla, Dlussky 2010) [13]. This mealy bug will serve as a 'seed' individual through which a new colony of mealybugs will be created. One of the ant groups exhibit this trophophoresy called *Acropyga* ants. These 'dairying ants' milk the mealybug by stroking them with their antennae (Gaelen Burke *et al*. 2009) [9].

Bacterial endosymbionts

Endosymbionts with micro-organism is common in insects, with more than 10% of insect species relying upon intracellular bacteria for their development and survival (Muniappan *et al*. 2006) [19]. Aphids and mealybugs harbour a vertically transmitted (from parent to its offspring) obligate symbiosis with *Buchnera aphidicola* (Proteobacteria: Enterobacteriaceae), referred to as the primary symbiont, which is located inside specialised cells, the bacteriocytes

(Paul Baumann *et al*. 2006) [24]. The original contamination occurred in a common ancestor 280 to 160 million years ago and has enabled the members of the family *pseudococcidae* to exploit a new ecological niche, phloem sap feeding on vascular plants. *Buchnera aphidicola* provides its host with essential amino acids, which are present in low concentrations in plant sap. The stable intra-cellular conditions as well as the bottleneck effect experienced during the transmission of a few bacteria from the mother to each nymph increase the probability of transmission of mutations and gene deletions (Douglas 1998, Vicente Perz-Broca *et al*. 2006) [6, 32]. As a result the size of the *B. aphidicola* genome is greatly reduced, compared to its putative ancestor (Linda M. Hooper-Bui 2008) [14]. Despite the apparent loss of transcription factors in the reduced genome, gene expression is highly regulated, as shown by the tenfold variation in expression levels between different genes under normal conditions (Mira and Moran 2002) [17]. There are some endosymbionts reported in PMB that are horizontally transmitted i.e., from one lineage to another and possibly from one species to another (Jose Vinuelase *et al*. 2007 and Tsuchida *et al*. 2005) [11, 31]. So far, the role of only some of the secondary symbionts has been reported from PMB such as, *Regiella insecticola*, which plays a role in defining the host-plant range, *Hamiltonella defensa*, which provides resistance to parasitoids, and *Serratia symbiotica* that prevents the deleterious effect of heat (Makiko Sakurai *et al*. 2005, Julia Ferrari *et al*. 2007, Simon *et al*. 2003 and Oliver *et al*. 2006) [15, 12, 27, 22].

Management strategies

Mealybug-control often involves the control of attendant ants that are important for the proper development of mealybugs. Without the ants, mealybug populations are small and slow to invade new areas and the field would be free of a serious infestation. Therefore, management of mealybug often includes the control of ant species. It is also important to know the species present as management programs for various mealybugs may differ. Plant protection products have limited effectiveness against mealybugs because of the presence of waxy covering of its body (Tanwar *et al*. 2010) [29]. Management of mealybug involves the following tactics.

Chemical control prescribed generally includes indirect or initial chemical control and direct and crucial chemical control. Indirect chemical control include the following basic steps. Locate ant colonies and destroy them with drenching of chlorpyriphos 20 EC @ 2.0 ml/litre of water (Tanwar *et al*. 2010) [29]. Regular monitoring of the crop for mealybug infestation and its natural enemies, stop application of insecticide immediately after noticing mealybug on some plants in the crop field (Tanwar *et al*. 2010) [29]. If the activities of natural enemies are not observed, use of other recommended chemicals can be employed at their respective concentrations. In direct or crucial chemical control application of recommended concentration of Profenophos, chlorpyriphos, Buprofezin, Dimethoate, Imidaclopride, Thiametoxam, Acetampride are the most commonly employed against the PMB.

In biological control use of natural enemies are the one among many which has wide publicity. Natural enemies of the papaya mealybug include the commercially available mealybug destroyer *Cryptolaemus montrouzieri*, ladybird beetles, lacewings, hover flies, *Scymnus* sp. and certain hymenopteran and dipteran parasitoids. Conservation of these natural enemies in nature plays important role in reducing the mealybug population. Use of the parasitoids *Anagyrus loecki*, *Pseudleptomastix mexicana* and *Acerophagous papayae* to a total of 46200 individuals were introduced from Puerto Rico and field released in Guam from June to October, 2002. A reduction of over 99% of papaya mealybug was observed about a year after the introduction of these parasitoids (Meyerdirk *et al*. 2004) [16]. This has reduced risk of introduction of this mealybug to neighbouring islands in the Pacific region. In the nature, *lepidopteran* predator, *Spalgis epius* (*Lycaenidae*) is a well-known representative of carnivorous butterfly feeding on various species of pseudococcidae and coccids. *Spalgis epius*, being the dominant predator, feeds effectively on the ovisacs, nymphs and adult of papaya mealybug. Newly hatched larvae of *Spalgis epiusare* are pale pink in colour and remain inside the mealybug ovisac devouring the eggs of the mealybug. The creamy white second instar larvae comes out of the ovisac with a white waxy coating camouflaged with mealybug population, making it very difficult to distinguish the predator from its prey. Australian ladybird beetle (*C. montrouzieri*) predates on mealybugs, eating 3000-5000 mealybugs in various life stages and is released at 10 beetles per tree or at 5000 beetles/ha. It was also reported that Exotic parasitoids/ predators such as *Anagyrus loecki* Noyes and Menazes, *Acerophagous papaya* Noyes and Schauff and *Pseudleptomastrix Mexicana* Noyes and Schauff (Hymenoptera: Encyrtidae) were released in Sri Lanka in 2009 (imported from Puerto Rico) and resulted in 95 to 100% control of the PMB in some part of that country.

Selection of pesticides with little ecological footprints is a key factor in developing sustainable agriculture systems. Policy guiding the selection of pesticides often emphasizes natural products and organic certified pesticides to increase sustainability, because of the prevailing public opinion that natural products are uniformly safer, and thus more environment friendly, than synthetic insecticides (Bahlai *et al*. 2010) [2]. Still now there is very limited biopesticides for the management of this pest as solely contributed for or either as in general. Public are generally applying various synthetics that are recommended to aphids over PMB since both are polyphagous hemipterans of the same family pseudococcidae. A variety of biopesticide based management strategies are been assigned to check the growth of them in field either with or without scientific support. Mealybugs are more resistant than aphids because of the presence of white powdery wax covering and with a thicker chitinous cuticle. Various literatures recommend the application of surfactant for the removal of waxy covering to expose them. The insecticidal formulations based on *Datura stramonium*, *Azadiracta indica* and *Nicotiana tabacum* are in common practice along with suitable surfactants (Pascual Villalobos and Robledo 1998, Tierto Niber *et al*. 2009, Soo Hoo and Fraenkel 1966, de Araujo *et al*. 2009, Delobel and Malonga 1987 and Neal *et al*. 2009) [23, 30, 28, 3, 4, 21].

Phytosanitary measures

Detection of mealybug is relatively easy by inspection, so the basic requirement that imported consignment of plants for planting should be free from the pest can be fulfilled by inspection. The plant quarantine act of 1912 in US reduces the expected boom in the mealy bug spread out in the 1910 and 1990 (Douglars et al. 2002) [5]. Monitoring the movement of fresh farm products, including flowers between countries as well as between states of another is the first step in controlling any spread within the region. This applies to both the import/export trade to passenger traffic and by implementing strict quarantine measures in 2003 by the European and Mediterranean Plant Protection Organization (EPPO)-A1 action list. EPPO member countries have recommended

regulating some pests as quarantine pests. Similar case of caution should be monitored in a national level for PMB.

Conclusion

Success in agriculture was a gamble between man and factors such as weather, disease, pest, etc. Through predictability in weather and disease a major share of issues relating to these can be avoided with precautions and preventions but pests are a major issue in the middle of unacceptability of synthetic pesticides among public. Emergence of new pests as a havoc is an often event to cause a mass lose in the sector of agriculture. Papaya mealybug is such an issue that generate a huge loss to nations in the tropical belt for almost a decade from 2005 to now. PMB is delicate but being tough by its adaptations as a pest, it scores the status as a major pest around the tropical globe. Implementation of strong quarantine measures and strict use of management measures in every field where the infestation is there are demanded for the control.

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