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Biology and morphometry of *Paracoccus marginatus* Williams and Granara de Willink (Hemiptera: Pseudococcidae)

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ABSTRACT: Biology and morphometry studies of *Paracoccus marginatus* Williams and Granara de Willink (Hemiptera: Pseudococcidae) on papaya (*Carica papaya* L), jatropha (*Jatropha curcus* L.), mulberry (*Morus alba* L.), and potato (*Solanum tuberosum* L.) were carried out in AINPAO laboratory, College of Horticulture, Kerala Agricultural University, Vellanikkara. Among the four host plants, *P. marginatus* on papaya recorded the highest pre-imaginal periods (egg to third instar nymphs in females and egg to pupa in males) for both females and males, whereas the lowest pre-imaginal period was observed on potato. Female *P. marginatus* recorded the highest and lowest adult longevity on papaya and jatropha respectively. The fecundity of *P. marginatus* on the four host plants varied in the order, papaya > potato > jatropha > mulberry. On papaya, mulberry and jatropha, the sex ratio of *P. marginatus* was more male-biased whereas on potato it was slightly female-biased. A non significant variation was observed on morphometrics (length and width) of all stages of male and female *P. marginatus* on four different host plants.

KEYWORDS: Papaya mealy bug, *Paracoccus marginatus*, biology, morphometry

INTRODUCTION

Paracoccus marginatus Williams and Granara de Willink (Hemiptera: Pseudococcidae), native to Mexico and Central America (Miller *et al*., 1999), is an insect pest that attacks several genera of cultivated and non cultivated plants (Miller and Miller, 2002; Mani and Shivaraju, 2012). Muniappan *et al*., (2008) have for the first time reported the incidence of *P. marginatus* on papaya in Tamil Nadu and later in Kerala (Krishnakumar and Rajan, 2009; Lyla and Philip, 2010; ManiChellappan *et al.,* 2013), Karnataka, Andhra Pradesh, Maharashtra, Tripura and

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Odisha., life history understanding of an insect pest is important in predicting its development, emergence, distribution, abundance (Amarasekare *et al*., 2008) and for the better methods of management of *P. marginatus*. Not much detailed information was available on biology and morphometry of *P. marginatus* except the studies of Amarasekare *et al*. (2008) and Thangamalar *et al*. (2010). In the present study detailed biology with morphmetrics (length and width) of all stages of male and female *P. marginatus* were carried out on four different host plants and compared.

MATERIALS AND METHOD

Biology and morphometric studies of *P. marginatus* were carried out in All India Network Project on Agricultural Ornithology laboratory, College of Horticulture, Kerala Agricultural University, Vellanikkara, Kerala. Specimens of papaya mealybug used in this study were confirmed to be *P. marginatus* by the insect identification keys provided by Miller and Miller (2002). The host plants used in this study were papaya (*Carica papaya* L), jatropha (*Jatropha curcus* L.), mulberry (*Morus alba* L.), and potato (*Solanum tuberosum* L.) since they were known to be infested with *P. marginatus* (Mani and Shivaraju, 2012).

Laboratory culture of *P. marginatus* : The laboratory culture of *P. marginatus* was maintained on sprouted potatoes as per Gautam (2008). Cleaned potato sprouts were used as hosts for rearing *P. marginatus*. Potato tubers were thoroughly washed under tap water and air dried. A small incision (7mm depth and 2 cm length) was made on the tubers, opposite to eye sprouts using a sharp sterilized blade. The potatoes were then soaked in gibberellic acid (GA) solution (1 %) for 30 minutes to encourage sprouting and then air dried. After GA treatment, the potatoes were transferred to trays containing wet sterilized sand. The trays were covered with a black muslin cloth to promote rapid sprouting and kept in dark place. Every day the sand was sprinkled with water to maintain moisture. After six days or when the sprouts reached 2.5 – 3.0 cm in length, the potatoes were cleaned and transferred to trays lined with moist tissue paper. Depending on the size of the potato tubers, each sprouted potato was infested with four to five ovisacs of *P. marginatus*. To maintain the colony of *P. marginatus*, for each week, twenty newly sprouted potatoes were infested with ovisacs of PMB.

Life cycle of *P. marginatus* on four different host plants

a. Selection of host plants: The individual leaves of all four host plants with petioles were removed and kept in petri plates lined with moist cotton cannot withstand for about one month even if the base of the petiole is covered with a water soaked cotton swab to prevent desiccation of leaf. Hence, in all the four cases either the whole plant or a plant stump with intact root system was used in the study.

For papaya, three months old seedlings (20 cm height and 4 – 5 leaves) and for mulberry and jatropha, three months old plant stump with intact root system (17.5 cm height and 3 – 5 leaves) were used. In all plants a fully expanded young leaf preferably at the top most position

was selected and all the remaining leaves were removed (Amarasekare *et al*., 2008). Medium sized potato tubers (100g) with sprouts (3 cm height) were also selected for studying biology of *P. marginatus*. All host plants were maintained inside Mylar cages to prevent any kind of extraneous infestation. Ten replications were made for each host plant to get an unbiased data.

b. Duration of pre-imaginal time of male and female *P. marginatus*: Each host plant was inoculated with eggs of *P. marginatus* (10 eggs per leaf) using a camel hair brush. The eggs used in all replications of a single host plant were collected from a single female within 24 h of oviposition. All plants were observed daily for egg hatch. The interval between each moulting was checked by examining exuvia on the leaves using a hand lens (10 X magnification) and the exuviae were removed after each moult. Morphological determination of all the instars was done under a stereo zoom microscope (Leica®) in the laboratory. The number of days to egg hatch, emergence of first instars, duration of second instar males and females, duration of third instar males (pre-pupa) and females and duration of fourth instar males (pupa) were recorded. From this data, the pre-imaginal time of male and female mealybugs (egg to pupa in males and egg to third instars in females) (Zaviezo *et al*., 2010) were calculated.

c. Generation time and reproductive period: The adult female mealybugs were individually transferred to new petri plates (containing leaves of each host plant lined with moistened cotton) for monitoring the reproductive period (pre oviposition, oviposition and post oviposition periods). From this data the generational time of female mealybugs (egg to oviposition) (Zaviezo *et al*., 2010) was worked out.

d. Adult longevity, fecundity and sex ratio: To study adult longevity the male and female mealybugs were observed daily until they died. In case, when the host plants have missing number of mealybugs, they were discarded from the experiment. For determining fecundity, number of eggs in ovisacs was counted in five ovisacs taken from each host plant. Sex ratio was calculated by counting the total number of adult males and females in each Petri plates and expressed as 'male: female'.

Morphometry of *P. marginatus* on four different host plants: All stages of live *P. marginatus* (eggs, first instars, second and third instars of males and females, fourth instar males and adult males and females) (Fig.1) were separated from the rearing colonies on four different host plants and morphometric characters (length and width) were measured using stereo zoom microscope (Leica®) with image analyzer facility. Five specimens of each of all stages of male and female *P. marginatus* from four different host plants were taken and a total of 180 specimens were sampled. All measured specimens were then preserved in ethyl alcohol (70 %) for further reference.

RESULTS AND DISCUSSION

Biology of *P. marginatus* on four different hosts: The life cycle study of *P. marginatus* on four different host plants revealed that there were differences in the developmental time of different stages of *P. marginatus* on these plants.

Duration of pre-imaginal time of male and female *Paracoccus marginatus*: Eggs of *P. marginatus* had maximum incubation period on papaya [8.2±0.63 days (d)] and on potato had the minimum (5.11±0.78 d). The hatching period of eggs of papaya mealybug on jatropha and mulberry was 7.3±0.82 and 5.8±0.79 d respectively. The difference in the hatching period of eggs is in accordance with the results obtained by, Amarasekare *et al*., (2008), Thangamalar *et al*., (2010), Tanwar *et al*., (2010), Mishra (2011), Kalaniyangoda *et al*., (2011) and Suganthy *et al*., (2012) on different host plants. Studies made by Amarasekare *et al*., (2008) showed the incubation period was 8.6±0.1 d on acalypha, 8.4±0.1 d on hibiscus, 8.8±0.1 d on parthenium and 8.5±0.1 d on plumeria. Thangamalar *et al.,* (2010) observed at 20 and 25^{0}C temperature gradients eggs hatched in 3 – 4 days and 10 days respectively. Alison *et al*., (2003) and Tanwar *et al*., (2010) reported ten days of hatching period for *P. marginatus*. According to Suganthy *et al*., (2012) the incubation period of papaya mealybug on sunflower under greenhouse and laboratory conditions were 6.3±0.58 and 7.20±1.30 d respectively. The results of Mishra, (2011) (4.8±0.9 d on potato) and Kalaniyangoda *et al*., (2011) (4 – 7 d on potato) also confirmed the present study result of incubation period of *P. marginatus* on potato.

For the first instar nymphs the shortest duration was seen on potato (3.56±0.53 d) and that on mulberry it was the highest (5.9±0.74 d). First instars on papaya and jatropha almost had same duration (4.6±0.52 and 4.2±0.57 d respectively). According to Amarasekare *et al*., (2008), among the four host plants (acalypha, hibiscus, parthenium and plumeria) studied by them, first instars on plumeria showed the highest duration (6.6±0.1 d) and parthenium showed lowest duration (5.8±0.1 d). Suganthy *et al*., (2012) reported first instar larvae of papaya mealybug on sunflower took four days under both greenhouse and laboratory conditions and this is in conformity with the present result of first instars on jatropha and papaya. But, Mishra (2011) reported only 2.6±0.5 days on potato, somewhat a different result.

The duration of second instar male and female nymphs were almost equal on papaya (4.2±0.63 d for females and 4.3±0.67 d for males) and jatropha (3.8±0.42 d for females and 3.6±0.52 d for males). However, on mulberry and potato, there was a difference of approximately one day. On mulberry, females had longer developmental period (5.4±0.52 d) than males (4.7±0.48 d) while on potato males had longer duration (5.22±0.67 d) than females (4.22±0.44 d). But, Amarasekare *et al*., (2008) reported second instar males had longer developmental period than second instar females. The difference may be due to different host plants.

Third instar females of *P. marginatus* had maximum duration on potato (6.11±0.60 d) and minimum on jatropha (4.7±0.67 d). However, on both papaya (5.1±0.32) and mulberry (5.1±0.88 d), third instar females had almost same duration and in accordance with the result obtained by Suganthy *et al*., (2012) on sunflower under greenhouse and laboratory conditions (5.00±1.00 and 4.80±0.45 d respectively). The results of Amarasekare *et al.,* (2008) on plumeria (5.1±0.1 d) also support the above result. Amarasekare *et al.,* (2008) also reported duration of third instar females on parthenium was 4.7±0.1 d which again confirmed present result on jatropha. Studies made by Mishra (2011) on potato showed third instar females took 6.30±0.9 d which were in accordance with the present result on potato.

Table 1. Duration of pre-imaginal stage of male and female *P. marginatus*

Life stages of *P. marginatus*	Host plant species (duration in days)			
	Papaya*	**Mulberry***	**Jatropha***	**Potato****
Egg	8.5 ± 0.85	5.8 ± 0.79	7.3 ± 0.82	5.11 ± 0.78
I instar nymph nymph	4.6 ± 0.52	5.9 ± 0.74	4.2 ± 0.57	3.56 ± 0.53
II instar female nymph	4.2 ± 0.63	5.4 ± 0.52	3.8 ± 0.42	4.22 ± 0.44
III instar female nymph	5.1 ± 0.32	5.1 ± 0.88	4.7 ± 0.67	6.11 ± 0.60
II instar male nymph	4.3 ± 0.67	4.7 ± 0.48	3.6 ± 0.52	5.22 ± 0.67
III instar male (pre-pupa) nymph	2.6 ± 0.52	2.3 ± 0.67	2.3 ± 0.48	2.56 ± 0.53
IV instar male (pupa)	4.2 ± 0.63	4.6 ± 0.52	4.2 ± 0.63	4.78 ± 0.44
Preimaginal phase (duration in days)				
Adult female	22.4 ± 1.35	22.2 ± 1.69	19.9 ± 1.45	19.00 ± 0.86
Adult male	23.9 ± 1.20	23.3 ± 0.82	21.5 ± 1.65	20.67 ± 1.22

*–mean of ten observations, **–mean of nine observations

The developmental time of pre-pupal males on the four host plants were almost identical (2.6±0.52 d on papaya, 2.3±0.67 d on mulberry, 2.3±0.48 d on jatropha and 2.56±0.53 d on potato). Similar trend was seen in duration of pupal males also (4.2±0.63 d on both papaya and jatropha, 4.6±0.52 d on mulberry and 4.78±0.44 d on potato). However, studies of Amarasekare *et al*., (2008) on different plants (acalypha, hibiscus, parthenium and plumeria) showed that the duration of pupal males on each host plant varied significantly and ranged between 2.6±0.1 and 4.5±0.1 d. Studies made by Suganthy *et al.,* (2012) also showed a varying result of 3.33±0.55 d on sunflower.

On all four host plants studied pre imaginal time period (egg to third instar nymphs in females and egg to pupa in males) was different for both females and males. In all host plants males had longer preimaginal developmental time than females. The longer total preimaginal time for males can be explained mainly by the presence of an additional pupal stage whereas this stage was absent in females. Among the four host plants, *P. marginatus* on papaya had the highest preimaginal time period for both females (22.4±1.35 d) and males (23.9±1.20 d) and that on

potato (19.0±0.86 for females and 20.67±1.22 d for males) had the shortest. On papaya, the longer pre imaginal time of females might be due to longer incubation period and in males it was due to longer egg period and pupal duration. On potato, egg period and first instar stage were shorter as compared to the same stages of *P. marginatus* on other host plants and this account for the shorter pre imaginal period on potato.

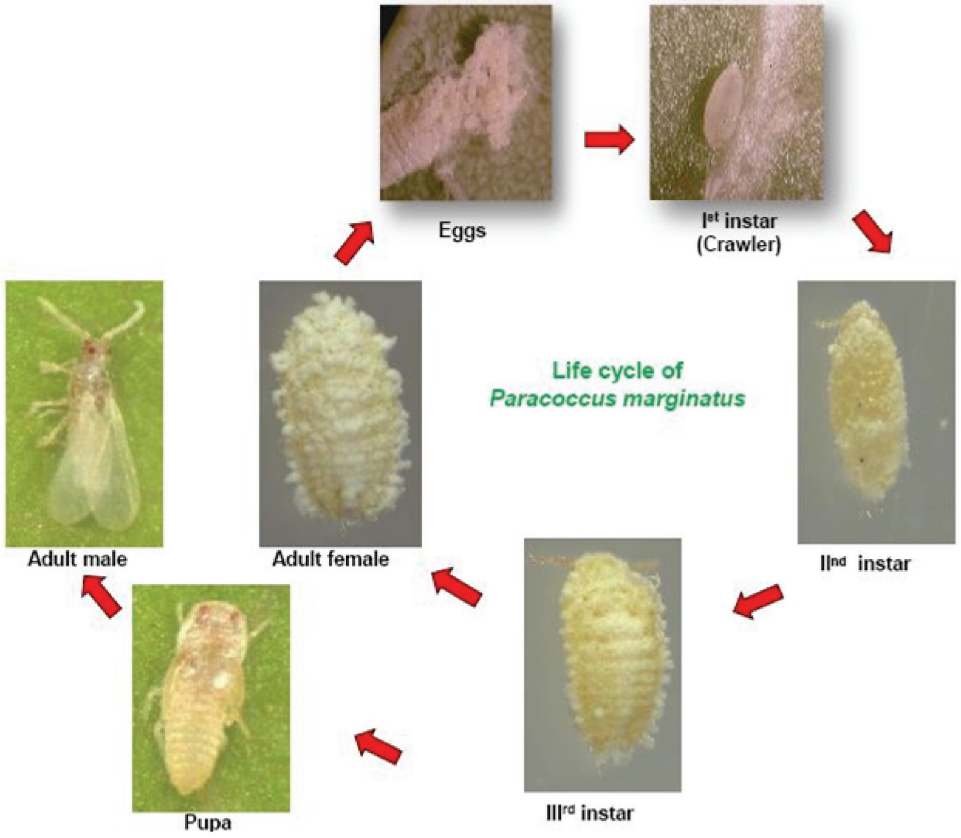

Fig. 1 Life stages of *Paracoccus marginatus*

Generation time and reproductive period: Pre oviposition period of female *P. marginatus* was maximum on potato (5.67±0.71 d) and minimum on jatropha (3.3±0.48 d). On both papaya (4.1±0.57 d) and mulberry (4.0±0.82 d), the period was almost equal. The present study result on potato was supported by the findings of Mishra (2011), who reported 6.4±1.7 d of pre oviposition period for *P. marginatus* on potato. However, according to Amarasekare *et al*., (2008) *P. marginatus* had 6.8±0.4 and 7.6±0.7 d of pre oviposition period at 25 and 30 ^{0}C respectively.

The oviposition period varied between six and eight days depending on the host plant. *P. marginatus* on papaya (7.8±0.63 d) and mulberry (6.4±0.84 d) had maximum and minimum oviposition periods respectively. The oviposition period on jatropha (7.0±0.47 d) and potato (7.12±0.60 d) had almost same duration. Studies made by Suganthy *et al*., (2012) confirmed the present result. According to them the oviposition period was 7.33±0.58 d on sunflower under greenhouse and 8.20±0.84 d under laboratory conditions. However, the present study results only partially agree with those obtained by Amarasekare *et al*., (2008), who reported *P. marginatus* had a oviposition time of 11.4 ± 0.8 d at 25 ^{0}C and 11.6 ± 1.4 d at 30 ^{0}C.

Table 2. Generation time, adult longevity and total life cycle of *Paracoccus marginatus*

Reproductive periods of *P. marginatus*	**Duration (in days)**			
	Papaya*	**Mulberry***	**Jatropha***	**Potato****
Pre oviposition	4.1 ± 0.57	4.0 ± 0.82	3.3 ± 0.48	5.67 ± 0.71
Oviposition	7.8 ± 0.63	6.4 ± 0.84	7.0 ± 0.47	7.12 ± 0.60
Generational phase	34.0 ± 1.15	32.6 ± 2.17	30.3 ± 1.16	31.78 ± 1.64
Adult longevity (duration in days)				
Female	17.6 ± 0.84	13.4 ± 0.84	11.2 ± 0.63	14.22 ± 0.83
Male	2.7 ± 0.48	2.1 ± 0.74	2.0 ± 0.67	2.22 ± 0.44
Total life cycle (duration in days)				
Female	39.7 ± 1.70	35.6 ± 1.78	31.2 ± 1.23	33.22 ± 1.30
Male	26.6 ± 1.07	25.4 ± 0.84	23.6 ± 1.78	23.44 ± 1.23

*–mean of ten observations, **–mean of nine observations

Generation time (pre imaginal developmental period and oviposition period) was four days shorter on jatropha (30.3±1.16 d) than on papaya (34.0±1.15 d). The generational time of mulberry and potato were 32.6±2.17 and 31.78±1.64 d respectively. According to Amarasekare *et al*., (2008) *P. marginatus* had 24.4 – 25.5 d of generational time at 25 ^{0}C depending on the plant. Studies on different species of mealybugs reared on different host plants at 25 ^{0}C had a longer generational time than *P. marginatus viz., Planococcus ficus*(Signoret) (28.1 d on grapevine; Walton and Pringle, 2010), *Maconellicoccus hirsutus* (Green) (32.4 d on hibiscus; Chong *et al*., 2008), *Planococcus kraunhiae* (Khuwana) (37.8 d on broad bean seeds; Narai

and Murai, 2002) and *Pseudococcus calceolariae* (Maskell) (48.6 d on potato, 56.6 d on lemon and 71.1 d on squash; Zaviezo *et al*., 2010).

Adult longevity, fecundity and sex ratio: Adult longevity of female *P. marginatus* was significantly higher than males in all host plants. Female adult longevity varied between eleven and eighteen days and host plant dependent whereas in males it was around two or three days and host plant independent. Female *P. marginatus* on papaya had the highest adult longevity (17.6±0.84 d) and that on jatropha it was the lowest (11.2±0.63 d). Adult longevity of female *P. marginatus* on mulberry and potato were 13.4±0.84 and 14.22±0.83 d respectively. The results were supported by the findings of Suganthy *et al*., (2012) on sunflower. According to them adult longevity of female *P. marginatus* on sunflower was 20.33 ± 1.53 d under greenhouse and 21.20 ± 2.77 d under laboratory conditions. Adult longevity of *P. marginatus* was almost similar to that determined by Chong *et al*., (2008) on *Maconellicoccus hirsutus*, where in *M. hirsutus* female lived for 21 days and males merely 2.5 days at a temperature between 25 and 30^{0}C. However other species had a greater longevity than *P. marginatus*. In *Pseudococcus calceolariae* female adult longevity was 31.3 ± 1.2 d and in males, it was 5.6 ± 0.4 d (Zaviezo *et al.*, 2010) whereas in *Planococcus kraunhiae* adult females had 25 days of longevity (Narai and Murai, 2002).

Table 3. Fecundity and sex ratio of *P. marginatus*

Host plant	Fecundity* (no.of eggs)	Sex Ratio (♂ : ♀)**
Papaya	442.6 ± 28.98	1.04:1
Mulberry	318.8 ± 16.36	2.03:1
Jatropha	350.6 ± 23.04	1.63:1
Potato	375.4 ± 13.01	0.89:1

*–mean of five observations, **–mean of ten observations

The total life cycle of *P. marginatus* varied greatly depending on the host plant and females had longer total developmental time than males. Females showed maximum life cycle duration on papaya (39.7±1.70 d) mainly due to longer adult longevity whereas those on jatropha it was the shortest (31.2±1.23 d). The total life cycle on mulberry and potato were 35.6±1.78 and 33.22±1.30 d respectively. In all host plants, total developmental time for males varied only slightly *i.*e., between 23.44±1.23 and 26.6±1.07 days. These are in agreement with the results of Suganthy *et al*., (2012) on sunflower, who reported a total life cycle of 39.33±2.53 d for females and 24.00±1.73 d for males under green house conditions. Substantial works has been

conducted and reported by various authors on the total life cycle of males which further confirmed our result (acalypha: 28.4±0.1d, hibiscus: 27.6±0.1d, parthenium: 27.7±0.1d and plumeria: 30.0±0.1d, Amarasekare *et al*., 2008; males took 27-30 days Tanwar *et al*., 2010).

The fecundity of *P. marginatus* on the four host plants varied in the following order: papaya (442.6±28.98) > potato (375.4±13.01) > jatropha (350.6±23.04) > mulberry (318.8±16.36). Several workers opined that *P. marginatus* usually lay 100 to 600 eggs in an ovisac (Miller and Miller, 2002; Walker et al, 2006; Tanwar *et al*., 2010; Kalaniyangoda *et al.,* 2011). Sharma *et al*., (2013) reported a female papaya mealybug laid 200-500 eggs in an ovisac. The result was also supported by the findings of Suganthy *et al*., (2012), who reported the fecundity was 329.33±20.03 and 380.0±28.66 on sunflower under greenhouse and laboratory conditions respectively. According to Amarasekare *et al.,* (2008) the fecundity ranged between 82.0±11.7 (30 ^{0}C) and 300.2±40.4 (25 ^{0}C) depending upon the temperature gradient.

In three host plants [papaya (1.04♂:1♀), mulberry (2.03♂:1♀) and jatropha (1.63♂:1♀)] the sex ratio of *P. marginatus* was more male-biased while on potato (0.89♂:1♀) the sex ratio was slightly female-biased. According to Amarasekare *et al.* (2008) among the four host plants (acalypha, hibiscus, parthenium and plumeria) studied by them, the sex ratio of adults emerging on plumeria was more female-biased than on the other three hosts. The mean proportion of adult females ranged from 53 to 59 per cent.

The differences observed in the life history parameters of *P. marginatus* might be due to different host plant varieties. According to Amarasekare *et al*., (2008) nutritive factors, allelochemical compounds, physical differences in leaf structures, etc. affected the life cycle of *P. marginatus*, although none of these factors were studied in depth. The life history parameters of other mealybug species were also found to be affected by different host plant species. Mortality of *Planococcus citri* (Risso) was higher on green than on red or yellow variegated *Coleus blumei* 'Bellevue' (Bentham) plants whereas faster development and higher fecundity was shown by red variegated plants (Yang and Sadof, 1995). Similarly, the developmental time of female *Planococcus kraunhiae* (Kuwana) was shorter when reared on germinated *Vicia faba* L. seeds than on leaves of *Citrus* sp. L. and on *Cucurbita maxima* Duchesne (Narai and Murai, 2002).

Morphometry of *Paracoccus marginatus* on four different host plants

Variations existed with regard to morphometry (length and width) of all stages of male and female *P. marginatus* on four different host plants (Table 4), however, the variations were not significantly different.

Egg : The eggs were translucent, oblong in shape and greenish yellow in colour. The eggs were laid in an ovisac, developed on the ventral side of the adult female mealybug. The eggs on papaya and potato showed same length (0.34±0.01 mm) but different width (0.15±0.01 on papaya and 0.13±0.01 mm on potato). However, the length and width of eggs on jatropha and

mulberry were almost identical (0.31±0.04 and 0.13±0.01 mm on jatropha and 0.31±0.02 and 0.12±0.01 mm on mulberry respectively). Similar results were obtained by Kalaniyangoda *et al*., (2011) on potato.

First instar nymph: Freshly emerged first instar nymphs were oblong in shape and light yellow in colour with three pairs of legs and a pair of six segmented antennae. Similar to eggs of *P. marginatus*, the length and width of first instar nymphs were also same on papaya (0.42±0.08 and 0.21±0.02 mm respectively) and potato (0.42±0.02 and 0.21±0.01 mm respectively). However, length and width of first instars on jatropha (0.39±0.04 and 0.17±0.02 mm respectively) and mulberry (0.36±0.06 and 0.18±0.01 mm respectively) were less than that on papaya and potato. These results were in accordance with the results of Miller and Miller (2002), Kalaniyangoda *et al.,* (2011) and Al Hilal *et al.,* (2012) on different hosts. According to Miller and Miller (2002), the slide mounted length and width of first instar nymphs of *P. marginatus* were 0.4 mm (0.3 – 0.6) and 0.2 mm (0.2 – 0.3) respectively. Al Hilal *et al.,* (2012) also reported first instar nymphs were 0.42±0.074 mm long and 0.27±0.024 mm wide on papaya.

Second instar: In general appearance and morphological features the second instar nymphs were similar to first instars except in size. They secreted white waxy powder on the dorsal side of the body after about 24 hours of first moult. The sexes of individual mealybugs could be determined during the later part of the second instars as males changed their colour from yellow to pink (Amarasekare *et al.*, 2008). As a result, from this stage onwards the morphometrics of male and female *P. marginatus* were taken separately.

Second instar female nymph: Second instar nymphs intended to become females were oblong shaped and yellow coloured. They had six segmented antennae. The morphometrics of second instar females on four host plants showed variation ie., second instar female nymphs on jatropha had maximum length (0.75±0.15 mm) and minimum (0.69±0.01 mm) on potato whereas those on papaya had the maximum width (0.46±0.05 mm) and minimum width on potato (0.34±0.04 mm). The length and width of second instar nymphs on mulberry were 0.74±0.05 and 0.36±0.01 mm respectively. Our observations in confirmation with the views of Miller and Miller (2002) and Al Hilal *et al*., (2012). Studies made by Kalaniyangoda *et al*., (2011) also showed similar results on potato (0.6±0.05 and 0.4±0.08 mm length and width respectively).

Third instar female nymph: Third instar nymphs of females were also oblong in shape with yellow in colour having six or seven segmented antennae. Third instar females on four host plants showed significant variation in their length and width compared to all other stages. The length and width of third instar females varied in the following order: papaya (1.23±0.18 and 0.64±0.05 mm) > jatropha (1.19±0.19 and 0.63±0.04 mm) > mulberry (1.04±0.19 and 0.54±0.03 mm) > potato (0.90±0.02 and 0.45±0.03 mm). According to Miller and Miller (2002) the length of third instar females ranged between 0.7 and 1.8 mm and width between 0.3 and 1.1 mm. Al Hilal *et al.*, (2012) observed a length of 0.89±0.11 mm and width of 0.51±0.02 mm for third instar females of *P. marginatus* on papaya.

Adult female : Adult females of *P. marginatus* had yellow coloured body, dusted with white mealy wax and eight segmented antenna. Adult females also showed noticeable variation among different host plants. Adult females on papaya had maximum body size (2.47±0.17 long and 1.55±0.13 mm wide) and that on mulberry it was the minimum (2.03±0.07 long and 1.01±0.07 mm wide). The length and width of third instar females on jatropha were 2.12±0.11 and 1.26±0.06 mm respectively and that on potato were 2.38±0.05 and 1.32±0.08 mm respectively. Studies made by Miller and Miller (2002) showed the length of adult females ranged between 1.5 and 2.7 mm and width between 0.9 and 1.7 mm. Similar results were obtained by Kalaniyangoda *et al.,* (2011) on potato and Al Hilal *et al.,* (2012) on papaya. Walker *et al*., (2006), Tanwar *et al*., (2010) and Sharma *et al*., (2013) also reported that the adult female of *P. marginatus* body was about 2-3 mm long and 1.4 mm wide.

Table 4. Morphometrics of life stages of *P. marginatus* on four different host plants

Life stages of *P. marginatus*	Morphometrics of life stages of *P. marginatus* *							
	Papaya		Mulberry		Jatropha		Potato	
	Length (mm)	Width (mm)	Length (mm)	Width (mm)	Length (mm)	Width (mm)	Length (mm)	Width (mm)
Egg	0.34±0.01	0.15±0.01	0.31±0.02	0.12±0.01	0.31±0.04	0.13±0.01	0.34±0.01	0.13±0.01
I instar nymph	0.42±0.08	0.21±0.02	0.36±0.06	0.18±0.01	0.39±0.04	0.17±0.02	0.42±0.02	0.21±0.01
II instar female nymph	0.72±0.02	0.46±0.05	0.74±0.05	0.36±0.01	0.75±0.15	0.35±0.02	0.69±0.01	0.34±0.04
III instar female nymph	1.23±0.18	0.64±0.05	1.04±0.19	0.54±0.03	1.19±0.19	0.63±0.04	0.90±0.02	0.45±0.03
Adult female	2.47±0.17	1.55±0.13	2.03±0.07	1.01±0.07	2.12±0.11	1.26±0.06	2.38±0.05	1.32±0.08
II instar male nymph	0.75±0.02	0.44±0.02	0.72±0.04	0.35±0.03	0.73±0.14	0.37±0.02	0.65±0.07	0.36±0.04
III instar male nymph (pre-pupa)	0.97±0.12	0.44±0.06	0.90±0.03	0.40±0.01	0.93±0.05	0.42±0.02	0.86±0.04	0.36±0.02
IV instar male nymph (pupa)	0.95±0.04	0.42±0.02	0.94±0.05	0.38±0.01	0.91±0.07	0.39±0.04	0.91±0.06	0.36±0.04
Adult male	0.96±0.03	0.25±0.04	0.97±0.01	0.23±0.01	0.96±0.05	0.24±0.01	0.93±0.01	0.22±0.01

* — mean of five observations

Second instar male nymph: The nymphs were usually pink in colour but occasionally yellow coloured with six segmented antenna. Among the four host plants, the length of second instar males were almost the same on three hosts (0.75±0.02 on papaya, 0.73±0.14 on jatropha and

0.72±0.04 mm on mulberry) with the exception on potato (0.65±0.07 mm). Likewise the width of second instar males also showed similarity on jatropha (0.37±0.02 mm), potato (0.36±0.04 mm) and mulberry (0.35±0.03 mm). However, second instar males on papaya was wider (0.44±0.02 mm) than all other host plants. The morphometric characters of second instar males of papaya mealybug studied by Miller and Miller (2002), who reported the length of second instar male nymphs ranged between 0.5 and 1 mm and width between 0.2 and 0.6 mm. Al Hilal *et al.,* (2012) also reported a length of 0.6±0.05 mm and width of 0.4±0.09 mm for second instar male nymphs.

Third instar male nymph (pre-pupa): Third instar males were also pink coloured and oblong shaped. Antennae were present without definite segmentation (Miller and Miller, 2002). The length and width of third instar males varied in the following order: papaya (0.97±0.12 and 0.44±0.06 mm) > jatropha (0.93±0.05 and 0.42±0.02 mm) > mulberry (0.90±0.03 and 0.40±0.01 mm) > potato (0.86±0.04 and 0.36±0.02 mm). These results were in conformity with the results of Miller and Miller (2002) on papaya (0.9 mm long and 0.4 mm wide) and Al Hilal *et al.,* (2012) on potato (1.05±0.23 mm long and 0.59± 0.16 mm wide).

Fourth instar male (pupa): Male cocoons were cylindrical in shape and white in colour. Pupae had ten segmented antennae. Fourth instar males or pupal males on jatropha (0.91±0.07 mm) and potato (0.91±0.06 mm) had the same length and that on papaya (0.95±0.04 mm) and mulberry (0.94±0.05 mm) also showed almost same length. Similarly, on jatropha (0.39±0.04 mm), mulberry (0.38±0.01 mm) and potato (0.36±0.04 mm) almost had same width. Similar morphometric characters were explained by Miller and Miller (2002) and Al-Hilal *et al.,* (2012).

Adult male: Adult males of *P. marginatus* were elongate and oval in shape, having greatest width at the thorax. They had ten segmented, bristle shaped antennae and appeared to be much longer than that of female antennae. Adult males on mulberry showed maximum length (0.97±0.01) and that on potato it was minimum (0.93±0.01 mm) while adult males on both of these plants almost had same width (0.23±0.01 and 0.22±0.01 mm respectively). However, adult males on papaya and jatropha showed similar length (0.96±0.03 on papaya and 0.96±0.05 mm on jatropha) and width (0.25±0.04 on papaya and 0.24±0.01 mm on jatropha). The results were in conformity with the results of Miller and Miller (2002) on papaya (1 mm length and 0.3 mm width), Kalaniyangoda *et al*., (2011) on potato (0.9 mm long and 0.20 mm wide) and Al Hilal *et al.,* (2012). Walker *et al.,* (2006), Galaniche *et al.,* (2010), Tanwar *et al*., (2010) and Sharma *et al.,* (2013) also reported adult males of *P. marginatus* were 1 mm long and 0.3 mm wide.

It was found that there exists variations in the body size of male and female *P. marginatus* in all the four host plants. According to Umbarihowar and Hastings (2002) host plants played an important role in regulating insect population. Yang and Sadof (1995) reported that variegation in *Coleus blumei* (Benth.) could increase the abundance of citrus mealybug, *Planococcus citri*. Hence, we could concluded that the difference observed in the morphometry of different stages of male and female *P. marginatus* might be due to the nutritive factors, allelochemical compounds present in the host plants, nutritional quality of food, and leaf nitrogen concentration (Hogendorp *et al.,* 2006), rearing conditions, etc.

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