BIOLOGY AND DAMAGE ASSESSMENT OF PAPAYA MEALYBUG, *PARACOCCUS MARGINATUS*

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BIOLOGY AND DAMAGE ASSESSMENT OF PAPAYA MEALYBUG, *PARACOCCUS MARGINATUS*

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CERTIFICATE

This is to certify that the thesis entitled **"BIOLOGY AND DAMAGE ASSESSMENT OF PAPAYA MEALYBUG, *PARACOCCUS MARGINATUS*"** submitted to the Department of Entomology, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE** in **ENTOMOLOGY**, embodies the result of a piece of *bona fide* research work carried out by **Marina Afroze**, Registration No. **12-04963** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

I further certify that any help or source of information, received during the course of this investigation has been duly acknowledged.

Dated: June, 2018
Dhaka, Bangladesh

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Dedicated To
My Beloved Parents

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The Author

BIOLOGY AND DAMAGE ASSESSMENT OF PAPAYA MEALYBUG, *PARACOCCUS MARGINATUS*

ABSTRACT

Two experiments were conducted to study the biology and damage assessment of papaya mealybug. Biology of papaya mealybug studied in the laboratory of the department of Entomology and damage assessment was conducted in the farm, Sher-e- Bangla Agricultural University, Dhaka-1207 during June, 2017 to August, 2018. In damage assessment study, T_1 is covered with fine net and sprayed with imidacloprid, at 15 days interval to avoid mealybug infestation and T_2 was infested by mealybug. The adult female laid 97-150 eggs with an average 122.8. The ovipositional period and incubation period was 6.0 ± 1.22 days and 5.8 ±1.09 days respectively. The female has three instars and male has four instars nymphs. At 1st instar male and female could not be distinguished. The average duration, length and breadth of 1st instar nymph were 4.8± 0.83 days, 0.41± 0.08 mm, and 0.25 ± 0.03 mm. The average duration of 2nd, 3rd instar female nymph and adult female was 4.2±0.83 mm, 3.4±0.54 mm and 10± 2 days respectively. The average length of 2nd, 3rd female nymph and adult female was 0.69± 0.03 mm, 1±0.14 mm and 1.94±0.27 mm respectively. The average breadth of 2nd, 3rd female nymph and adult female was 0.44±0.02 mm, 0.72±0.05 mm and 1.38 ±0.05 mm respectively. The average duration of 2nd, 3rd instar, pupa and adult male was 3.6± 0.54 days, 2.8 ± 0.83 days, 3.6 ±0.54 days and 2.4 ±.54 days respectively. The average length of 2nd, 3rd instar, pupa and adult male was 0.70±0.06 mm, 0.85±0.02 mm, 0.94±0.04 mm and 0.98 ±0.03 mm respectively. The average breadth of 2nd, 3rd instar, 4th instar and adult male was 0.38 ±0.04 mm, 0.41 ±.02 mm, 0.26 ±0.03 mm, and 0.26±0.01 mm respectively. Mealybug infestation reduced plant height (34.35%), number of leaves per plant (86.08%), petiole length (53.31%), number of flowers per plant (86.23%), number of fruits per plant (89.43%), individual fruit weight (88.01%) as well as total fruit yield per plant (98%).

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LIST OF ACRONYMS

ABBREVIATIONS	ELABORATIONS
@	at the rate of
AEZ	Agro-Ecological Zone
Agric.	Agriculture Agricultural
Ann.	Annual
Anon.	Anonymous
ANOVA	Analysis of Variance
BARI	Bangladesh Agricultural Research Institute
BBS	Bangladesh Bureau of Statistics
Biotech.	Biotechnology
Biotic.	Biotica
Bot.	Botany
C	Celsius
CABI	Centre for Agriculture and Bioscience International
CRSP	Center for Research in Security
Curr.	Current
d	day
Econ.	Economic
Entomol.	Entomology
Envior.	Environment
EPPO	The European and Mediterranean Plant Protection Organization

ABBREVIATIONS	ELABORATIONS
IAPSS	International Association of Public School Superintendents
IITA	International Institute of Tropical Agriculture
Int.	International
IPM	Integrated Pest Management
J.	Journal
mm	Millimeter
NBAII	National Bureau of Agriculturally Important Insects
p.	Page no
Pp.	Page no
Protect.	Protection
Res.	Research
Sci.	Science
Seric.	Sericulture
Soc.	Society
SRDI	Soil Resource Development Institute
Stud.	Studies
Symp.	Symposium
Univ.	University
Wash.	Washington
Zool.	Zoology

CHAPTER I

INTRODUCTION

Papaya is an important crop in our country. It is cultivated all over the country. Now-a- days papaya is severely damaged by a pest known as papaya mealybug *(Paracoccus marginatus)* Williams and Granara de Willink (Hemiptera: Pseudococcidae). The papaya mealybug, *P. marginatus* Williams and Granara de Willink (Hemiptera: Pseudococcidae) is native to Mexico and/or Central America (Miller *et al*., 1999). It was first described in 1992 (Williams and Willink, 1992) and re-described by Miller & Miller (2002).

Papaya mealybug is a polyphagous insect. The adult female is yellowish color, and is covered with a white waxy coating. Adult male have well-developed wings (Miller and Miller, 2002). The Papaya mealybug has been recorded on over 55 species from 25 families, including a variety of economically important crops (Walker *et al*., 2003). Economically important crop hosts and weed hosts include papaya, hibiscus, avocado, citrus, cotton, tomato, eggplant, peppers, beans, peas, sweet potato, mango, cherry and pomegranate. The specimens of the pest were collected first in 1992 from the Neotropical region in Beliz, Costa Rica, Guatemala, and Mexico. Papaya mealybug became a pest when it invaded the Caribbean region. Since 1994 it has been recorded in 14 Caribbean countries. Both Nymph and adult damage the plant. Papaya mealybug infestation appears on above ground parts on leaves, stem and fruits as clusters of cotton-like masses. The insect sucks the sap by inserting its stylets into the epidermis of the leaf, fruit and stem. While feeding, it injects a toxic substance into the leaves, resulting in chlorosis, plant stunting, leaf deformation or crinkling, early leaf and fruit drop, and death

of plants. The honeydew excreted by the bug results in the formation of black sooty mould which interferes in the photosynthesis process and causes further damage to the crops. Heavy infestations are capable of rendering fruit inedible due to the buildup of thick white waxy coating. Honeydew attracted the ant which helps in transfer the mealybug one plant to another (Tanwar *et al*., 2010).

The papaya mealybug has been identified firstly in Bangladesh in the year 2009 (Muniappan *et al*., 2011). Within the last few years this insect pest spreads many parts of the country very rapidly and has become major concern to papaya growers in Bangladesh (Karim *et al*., 2012). A drop in papaya production in Bangladesh is recorded in the recent years, and among other factors, it is assumed that mainly infestation of this non-indigenous pest is responsible and causing huge economic losses to farmers (Helemul, 2013). The infestation also depends on the atmospheric condition like temperature, rainfall, humidity. Heavy rainfall reduces the population and damage severity (Galanihe *et al*., 2010).

Sometimes it occurs to assume the status of a major pest and it causes severe damage to economically important crops and huge losses to farmers. Here, biology of papaya mealybug is studied.

Knowledge of the life history of an insect is very helpful in predicting its development, emergence, distribution and abundance. This information can further assist to device appropriate management tactics. It is important to study its life history of this mealybug.

Management of mealybugs is often difficult because plant protection products are of limited effectiveness against mealybugs because of the presence of waxy covering of its body. Therefore, it is needed to determine the damage severity of this pest in Bangladesh and to develop

sustainable management practices for this pest. At present papaya is cultivated about 3126 acre of land in Bangladesh and total production is about 133370 M Tons (BBS: 2018-2019). But now-a-days papaya production is greatly reduced by the attack of papaya mealybug. Papaya growers also reported that they destroy infested fruit in the field instead of bringing them in the market because the transportation cost did not meet from the sale price, where the retailers also faced difficulty to sell the infested papaya as the consumers are not willing to buy the infested papaya from the market. Some farmers stopped cultivating papaya after suffering losses from attacks by the nonnative pest *P. marginatus.* If the experiment can be conducted successfully it will help to develop a management practice for papaya mealybug.

OBJECTIVES

a. To study the biology of papaya mealybug, (*P. marginatus)* in the laboratory.

b. To assess the damage caused by papaya mealybug in the field.

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CHAPTER II

REVIEW OF LITERATURE

2.1 Taxonomy

Domain: Eukaryota

Kingdom: Metazoa

Phylum: Arthropoda

Subphylum: Uniramia

Class: Insecta

Order: Hemiptera

Suborder: Sternorrhyncha

Family: Pseudococcidae

Genus: *Paracoccus*

Species: *Paracoccus marginatus*

2.2 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). The first specimens were collected in Mexico in 1955. The papaya mealybug was described in 1992 from the Neotropical Region in Belize, Costa Rica, Guatemala, and Mexico (Williams and Granara de Willink 1992. It was not recorded from the Caribbean islands before 1994, since 1994 it has been recorded in 14 Caribbean countries. After invading the Caribbean Islands in 1995, it spread to 24 countries within a period of 14 years (Walker *et al.*, 2003; Meyerdirk *et al.*, 2004; Hue *et al.*, 2007; Rich, 2008). 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. It

was first recorded from USA (Florida) in 1998 (Miller *et al*., 2002).In India it was recorded in July 2007 at Tamil Nadu Agricultural University, Coimbatore and subsequently spread to neighboring districts. The papaya mealybug has been identified firstly in Bangladesh in the year 2009 (Muniappan *et al*., 2011). It was noticed in South and Southeast Asia during 2008–09. *P. marginatus* was first reported in India in 2008, and in subsequent years it has invaded 9 additional Asian countries (Muniappan, 2009, 2011; Chen *et al*., 2011; Myrick *et al*., 2014). The pest has been reported in Coimbatore, Tirupur, Erode, Salem, Namakkal and Karur districts of Tamil Nadu. The pest is now spreading to other districts too. The pest has been recently noticed in other states such as Karnataka, certain parts of Andhra Pradesh and Malappuram and Thrissur districts of Kerala. Thiruvananthapuram, Kollam, Pathanamthitta, Alappuzha, Kottayam, Ernakulum and Trissur districts in Kerala are seriously under silent attack of this pest from 2009 onwards. The pest has now spread to Pune area of Maharashtra also and is likely to be reported from other parts of the country as well. The pest has been recently been noticed in the neighboring states as Karnataka and Kerala. The pest is now spreading to other districts too (Muniappan *et al*., 2009). This pest also present inIndonesia (Muniappan, 2009a; CABI/EPPO, 2012), Philippines, (Muniappan *et al*., 2009b; CABI/EPPO, 2012) Cambodia (Muniappan*etal*.,2009b; CABI/EPPO, 2012),Thailand (Muniappan *et al*., 2009b; CABI/EPPO, 2012), Benin (Muniappan *et al*., 2009b; CABI/EPPO, 2012), Ghana (Muniappan *et al*., 2009b; CABI/EPPO, 2012), Sri Lanka (Galanihe *et al*., 2010; CABI/EPPO, 2012), Malaysia (Mastoi *et al*., 2011; CABI/EPPO, 2012), Taiwan (Shupei *et al*., 2011; CABI/EPPO, 2012), Maldives (CABI/EPPO, 2012), Cuba (CABI/EPPO, 2012) , Tanzania (IITA, 2015), Kenya (Macharia *et al*., 2017).

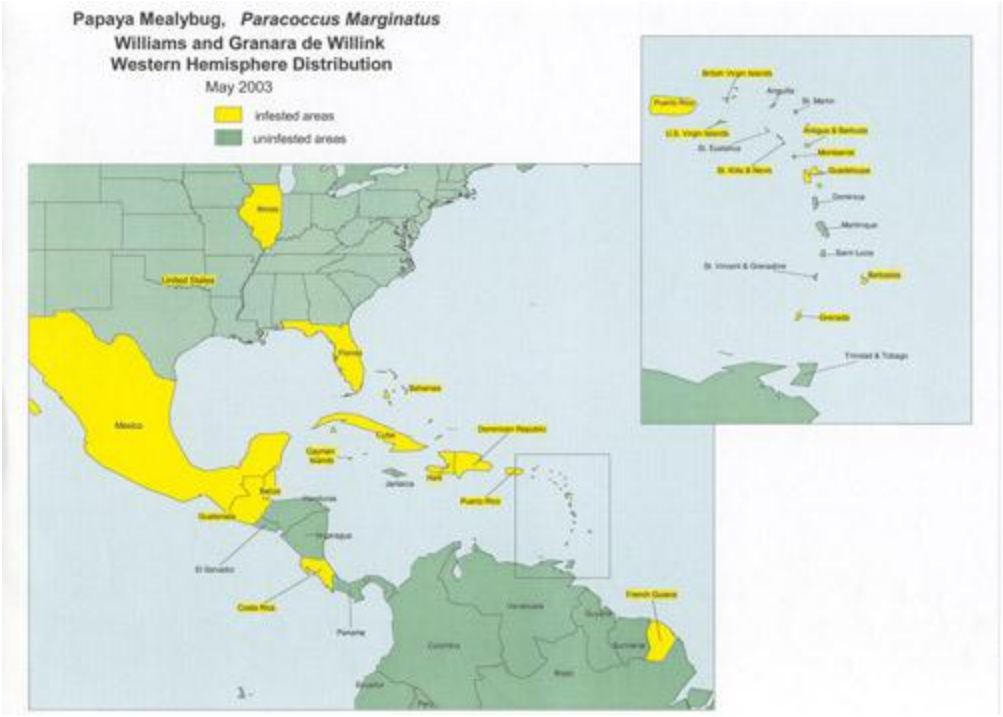

Figure 2.1 Distribution of the papaya mealybug, *Paracoccus marginatus* Williams and Granara de Willink, as of May 2003. Drawing by Dale Meyerdirk, National Biological Control Institute.

2.3 Host Range

The main host of *P. marginatus* is papaya (Williams and Willink, 1992). The papaya mealybug is a polyphagous pest. Miller and Miller (2002), worked on the incidence and developmental stage of *P. marginatus* in different host plants in USA. Weed species such as *Parthenium hysterophorus* L. are also recorded as host plants of papaya mealybug (Miller and Miller, 2002). It has been recorded on 55 host plants in more than 25 genera (Walker *et al*., 2003). In our country it is the major pest of papaya but also attack the other economically important crops like eggplant, ber, guava, custard apple, okra with varying level of

infestation. Papaya mealybug infested more than 40 host-plant species in Sri Lanka (Galanihe *et al*., 2010). In India it infested more than 80 plant species including number of agricultural and horticultural crops, ornamental plants,trees and weed species (Selvaraju and Sakthivel, 2011). *P. marginatus* has a wide host range including tropical fruits, vegetables and ornamental plants. It is a severe pest of papaya (Tanwar *et al*., 2010, Bhawane *et al*., 2011, Chellapan *et al*., 2013a) and mulberry (Tanwar *et al*., 2010, Lalitha *et al*., 2015) in India. Mealybug, *P. marginatus*, is reported to attack *Plumeria* spp. in various countries (Cham *et al*., 2011, Chen *et al*., 2011) and from India (Muniappan *et al*., 2008, Chellapan *et al*., 2013b, Gowda *et al*., 2014). Tanwar *et al*. (2010), Chellapan, (2011) and Sakthivel *et al*. (2012) have also reported guava as a host of papaya mealybug, *P. marginatus* in India. The pest feeds on phloem sap of mulberry plants both from stem and leaf resulting in loss of moisture and decline in nutritional values. Growth of dense black sooty mould on leaves over the honeydew excreted by the pest makes them unfit to feed silkworm. Feeding papaya mealybug affected mulberry leaves adversely affects the economic traits of silkworm and silk yield (Sakthivel, 2011). Number of weed species in mulberry garden serves as alternate host to the papaya mealybug. From these weeds, the pest easily migrates to the new sprouts after each pruning and build up its population heavily on plant maturity (Sakthivel *et al*., 2012). Mulberry (*Morus alba L*.), the food plant of silkworm (*Bombyx mori L*.) is highly susceptible to this pest and its continued menace in Tamil Nadu after outbreak in 2009, poses threat to sericulture throughout the year (Sakthivel, 2013). A total of 29 plant species in 12 plant families were re-corded to be host of *P. marginatus* in the Akraman and Nsawam areas of Ghana. Of the recorded plant species, 16 (55%) were vegetable, food and fruit crops, belonging to 9 plant families, while 8 (28%) were weeds

or wild plants and the rest 5 (17%) were ornamental plants. In CABI they reported the host of papaya mealybugar *Acacia* (wattles), *Acalypha* (Copper leaf), *Adenium, Aglaonema*, *Ananas comosus* (pineapple), *Annona squamosa* (sugar apple), *Bidens* (Burmarigold), *Cajanus cajan* (pigeon pea), *Capsicum annuum* (bell pepper), *Cestrum nocturnum* (night jessamine), *Citrus sinensis* (navel orange), Coffea (coffee), *Dahlia pinnata* (garden dahlia), *Erythrina spp.*, *Eugenia uniflora* (Surinam cherry), Gardenia, *Gossypium hirsutum* (Bourbon cotton), *Guazu maulmifolia* (bastard cedar), *Hibiscus* (rosemallows), *Hibiscus rosa-sinensis* (China-rose), *Hibiscus sabdariffa* (Roselle), *Ipomoea* (morning glory), *Jatropha curcas* (jatropha), *Jatropha integerrima*, *Lablab purpureus* (hyacinth bean), *Ligustrum* (privet), *Malpighia glabra* (acerola), *Malvaviscus arboreus* (wax mallow), *Mangifera indica* (mango), *Manihot esculenta* (cassava), *Mimosa pigra* (catclaw mimosa), *Morus* (mulberry tree), *Morus alba* (mora), Mussaenda, *Pachysta chyslutea* (lollypops), *Parthenium hysterophorus* (parthenium weed), *Persea americana* (avocado), *Phaseolus* (beans), Plumeria (frangipani), Psidium guajava (guava), *Puni cagranatum* (pomegranate), *Rosa sinensis* (roses), Sida, *Solanumly copersicum* (tomato), *Solanum melongena* (aubergine), *Solanum nigrum* (black nightshade), *Solanum torvum* (turkey berry), *Theobroma cacao* (cocoa), *Vigna radiata* (cowpea). Selvaraju and Sakthivel (2011), reported heavy population built up of papaya mealybug on two weeds, *A. indica* L. and *P. hysterophorus* L. in agro ecosystem. In India, the pest was first reported from Coimbatore, Tamil Nadu infesting papaya and since then a list of agricultural and horticultural crops damaged by this noxious exotic pest is growing at an alarming rate. Within a span of few months after the first record, it caused an extensive damage to the sericulture industry by spreading over 3000 acres of mulberry plantation in Tamil Nadu. Many

mulberry gardens have dried up due to severe infestation and some farmers gave up sericulture due to severe infestation and uprooted mulberry (Shekhar and Qadri, 2009, Mahalingam *et. al*., 2010). It was observed in Coimbatore during 2006 and it became a serious pest on papaya, bhindi, cotton, teak and sunflower (Anon, 2008). Chellappan *et al*. (2013); reported that in kerala 95 host plant belonging to 39 families are recorded. Highest number of host plant of *P. marginatus* was recorded under the family Euphorbiaceae.

Cham *et al*. (2011) observed the host range of papaya mealybug (*P. marginatus*) in two ecological zones of Ghana. They identified 50 plant species in 20 families as host of *P. marginatus,* including economically important hosts such as *Carica papaya*, *Manihot esculenta*, *Mangifera indica*, *Solanum melongenaCitrus* sp. and *Theobroma cacao*. Favourite hosts included *Carica papaya*, *Manihot esculenta*, *Solanum melongena*, *hibiscus* sp., *Jathropha* sp., *Plumeria* sp., *Abutilon indicum* and *Adansonia digitata*. Three new families, Plumbaginaceae, Bombaceae, and Lythraceae and eight new plant species; *Launaea taraxacifolia*, *Euphorbia heterophylla*, *Codiacum variegatum*, *Codiacum aucubaefolium*, *Securinega virosa*, *Adansonia digitata*, *Lagerstroemia indica*, and *Plumbago auriculata* were identified as hosts of *P. marginatus*. *P. marginatus* was also found to co-exist with other mealybug species in some economically important host plants.

Saengyot and Burikam, (2011), reported that in Thailand 10 species of in 6 families as host of *P. Marginatus* such as papaya, *Carica papaya* L. (Caricaceae, *Plumeria acuminate*, *Plumeria rubra L.*, *Bidens pilosa L.*, *Bidens pilosa L. var. Radiate*, *Jatropha integerrima*, cassava, *Maniho tesculenta*; hibiscus, *Hibiscus rosa sinensis* L. devil's fig, *Solanum torvum Swartz* etc were found.

2.4 Nature of damage

Papaya mealybug is a sucking pest that injects a toxic substance into the leaves, fruits, stems, flowers while feeding. Mealybugs are generally observed as clusters of white cotton-like masses on leaves, stems, flowers or fruit (Walker *et al*., 2003). It feeds on the sap of plants by inserting its stylets into the epidermis of the leaf and into the fruit and stem. The leaves become crinkled, yellowish, and withered (Tanwar *et al*., 2010; Suganthy *et al*., 2012; Kirsur *et al*., 2014). In doing so, it injects a toxic substance into the leaves. The result is chlorosis, plant stunting, leaf deformation, early leaf and fruit drop, a heavy buildup of honeydew, and death. Heavy infestations are capable of rendering fruit inedible due to the buildup of thick white wax. Fruit may become completely covered by a layer of mealybugs and wax secretions (Miller *et al*., 2001). Papaya mealybug has only been recorded feeding on areas of the host plant that are above ground, namely the leaves and fruit (Galanihe *et al*., 2010).The honeydew excreted by the bug results in the formation of black sooty mould which interferes in the photosynthesis process and causes further damage to the crops. Heavy infestations are capable of rendering fruit inedible due to the buildup of thick white waxy coating. Mealybugs are known to offer ants with their sugary excretion (honeydew) and in return ants help in spreading the mealybugs and provide protection from predator ladybird beetles, parasites and other natural enemies. This ant also causes nuisance. There was 80-90 per cent reduction in mealybug population by *A. papayae* in various regions of India (Shylesha *et al*., 2010, Shylesha *et al*., 2011, Krishnamurthy *et al*., 2011 and Qadri *et al*., 2011).

2.5 Damage assessment

Galanihe *et al.* (2010) reported the damage assessment in 12 farmer fields in Gampaha district revealed that by mid-September 2008, an average of 85.9% (range 60- 100%) of the papaya plants in the area were infested with papaya mealybug. Of the infested plants that were left untreated with the recommended insecticides, 94.8% were died, Of the infested plants that were treated, 27.0% died while the survivors showed varying degrees of control and by March 2009, 90% of the papaya plants in Gampaha district were damaged.

Sandeep and Gurlaz (2011), studied the papaya mealybug, *P. marginatus* on four host papays, guava, grapes and plumeria. Maximum infestation of this mealybug was observed on plumeria, followed by papaya, guava and grapes. As per the grading of the plants for mealybug infestation, plumeria and papaya were observed to be highly infested with all the stages of mealybug present in high numbers. All the plant parts such as leaves, twigs, stem and fruits were covered by the different stages of mealybug. Higher infestation in case of papaya was observed under protected cultivation as compared to the open field cultivation. Guava had a medium range of infestation with all the mealybug stages available in large numbers. Whereas, grapes had a low infestation with low number of mealybug population observed on different plant parts. The results of percent infestation demonstrated that highest per cent infestation was present in plumeria (85 %) followed by papaya (70%), guava (45%) and grapes (20%).

2.6 Biology

Seni and Sahoo (2014), studied the biology of *P. marginatus* on sprouted potato throughout the year revealed that the duration of first instar nymphs, the sexes of which could not be distinguished, ranged from 3-17 days. The duration was higher during the winter months 7-17 (11.64±3.32) days at 10-26°C and 40-88% R.H., whereas summer months were very congenial for their growth and took 4-9 (6.36±1.87) days for their development at 23-35°C and 54-92% R. H. and they completed 11 generation per year. The second instar female nymphs completed development at the age ranging from 7 to 23 days. They took 16-23 (19.58±2.4) days at 12-23°C and 60-84% R. H. during winter month which was the longest developmental period. They took few days to complete this stage during May month only 9-13 (11.14±1.58) days. In case of third instar female nymphs; they completed development at the age ranging from 11 to 29 days. The duration was maximum during the winter month 21-29 (24.44±2.74) days at 12-23°C and 60-84% R. H. whereas they completed this stage very shortly during May month took only 12-16 (13.98±1.58) days at 26-35°C and 50 to 90% R. H. The moulting of second, third and fourth instar male nymphs occurred within the cocoon at the age 7 to 21, 10 to 26 and 14 to 34 days respectively. The female took longer time to complete oviposition during winter months (9 to 18 days) at 8 to 23°C and 40 to 84% R. H. when its fecundity rate was 140 to 189. During other season the fecundity increased and it laid maximum during October month when a female laid 298 to 324 eggs in 4 to 9 days to at 20°-33°C and 60-87% R.H. Adult male longevity was 2-3 days.

Jithu *et al*. (2016) reported that females usually lay 150-600 eggs in an ovisac. 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.

Chellappan *et al.* (2013) observed the biology and morphometry 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.). Eggs of *P. marginatus* had incubation period 8.5±0.85, 5.8±0.79, 7.3±0.82, and 5.11±0.78 days on papaya, jatropha, mulberry and potato respectively. For the first instar nymphs had 4.6±0.52, 5.9±0.74, and 4.2±0.57 and 3.56±0.53 days on papaya, jatropha, mulberry and potato respectively. The duration of second instar female nymphs were 4.2±0.63, 5.4±0.52, 3.8±0.42 and 4.22±0.44 days on papaya, jatropha, mulberry and potato respectively. Third instar females of *P. marginatus* duration were 5.1±0.32, 5.1±0.88, 4.7±0.67 and 6.11±0.60 days on papaya, jatropha, mulberry and potato respectively. The duration of second instar male nymphs were 4.3 ± 0.67, 4.7 ± 0.48, 3.6 ± 0.52, 5.22 ± 0.67 days on papaya, jatropha, mulberry and potato respectively. Third instar males of *P. marginatus* duration were 0.6±0.52, 2.3 ±0.67, 2.3 ± 0.48, and 2.56±0.53 days on papaya, jatropha, mulberry and potato respectively. Fourth instar male (pupa) duration were 4.2 ± 0.63, 4.6 ± 0.52, 4.2 ± 0.63, 4.78 ± 0.44 days on papaya, jatropha, mulberry and potato respectively. Adult female duration was 22.4 ± 1.35, 22.2 ± 1.69, 19.9 ± 1.45, 19.00 ± 0.86 days and adult male 23.9 ± 1.20, 23.3 ± 0.82, 21.5±1.65 days and 20.67±1.22 days on papaya, jatropha, mulberry and potato respectively.

Al-Hilal *et al.* (2012) observed the papaya mealybug. They reported that *P. marginatus* is a small polyphagous sucking insect. This noxious insect pest passes through egg and three nymphal stages to become adult female. Its embryonic development is termed as pauro-metabolic metamorphosis or simple metamorphosis. In case of *P. marginatus,* generally four and three nymphal instars took place in case of male and female mealybug, respectively. The adult female of *P. marginatus* laid about 150 to 200 eggs inside the ovisacs. Eggs are pink colored, grain like measuring 0.12 cm in diameter. Length of first instar nymph was 0.42±0.074 mm and 0.024±0.27 mm in width. This instar appears yellowish in color. Length of second instar nymph was 0.6±0.054 mm and 0.089±0.4 mm in width. Body color appeared yellow in field conditions. Length of third instar nymph was 0.89±0.11 mm and it was 0.02±0.51 mm in width. Body appears yellow in color during field observation. The length of adult female was 2.08±0.354 mm and it was 1±0.063 mm in width. Body is yellow in color during field observation. Length of second instar nymph was 0.6±0.054 mm and 0.089±0.4 mm in width. Body looks like yellow in color during field observation. Length of third instar nymph was 1.05±0.23 mm and 0.156±0.59 mm in width. Body looks like yellow in color during field observation. Length of fourth instar nymph was 0.98 ±0.075 mm and 0.02±0.49 mm in width. Body color appeared pink but occasionally yellowish. Length of adult male was 1.5 mm and 0.5 mm in width. Body color appeared pink, but occasionally yellowish.

Amarasekare *et al*. (2008a) was studied Life history of the mealybug, *Paracoccus marginatus* Williams and Granara de Willink, on three ornamental plants *Hibiscus rosa-sinensis* L., *Acalypha wilkesiana* (Muell.-Arg.), and *Plumeria rubra* L. and one weed species (*Parthenium*

hysterophorus L.) under laboratory conditions. Mealybugs were able to develop, survive, and reproduce on all four hosts; however, there were differences in the life history parameters. Adult females that developed on Acalypha and Parthenium emerged approximately 1day earlier than those that developed on Hibiscus and Plumeria. Adult males had a longer developmental time on Plumeria than on the other hosts. Survival of first- and second-instar nymphs and cumulative adult survival were lowest on Plumeria. Longevity was not affected by hosts for males and females and averaged 2.3 ±0.1 and 21.2 ± 0.1 d, respectively. On Plumeria, 58.9 ± 1.7% of the adults were females, which was a higher female percentage than on the other hosts. No egg production occurred in virgin females. Pre reproductive and reproductive periods of the females were not affected by hosts and averaged 6.3 ± 0.1 and 11.2 ± 0.1 d, respectively. Mean fecundity of 186.3 ±1.8 eggs on Plumeria was lower than on the other three plant species. Life history parameters of *P. marginatus* on Hibiscus, Acalypha, Plumeria, and Parthenium show its ability to develop, survive, and reproduce on a wide variety of plant species.

Amarasekare *et al*. (2008b) reported that the temperature effect on the life history of the mealybug *P. marginatus* Williams & Granara de Willink (Hemiptera: Pseudococcidae). *P. marginatus* was able to develop and complete its life cycle at 18, 20, 25, and 30 $\pm 1^0$C. At 15, 34, and 35^0C, the eggs hatched after 27.5, 5.9, and 5.5 d of incubation, respectively, but further development of the first-instar nymphs was arrested. No eggs hatched at 37^0C. The developmental time for egg to adult was the longest at 18^0C for both males and females. Approximately 80 to 90% of the eggs survived between 20 and 30^0C. The highest fecundity was at 25^0C with each female producing an average of 300 eggs. Adult longevity, preoviposition and oviposition periods increased with decreasing

temperature up to 25^0C. The proportion of females was 42% at 25^0C and between 70% to 80%is 18, 20, and 30^0C. The ability of *P. marginatus* to develop, survives, and reproduces successfully between 18 and 30^0C suggests that it has the capability to develop and establish in areas within this temperature range.

Suganthy *et al.* (2011) studied the biology of mealybugs *viz.*, *Paracoccus marginatus* infesting sunflower. The egg, first, second and third instar nymphal periods of *P. marginatus* were 6.33±0.58, 4.00±1.00, 3.67±0.58 and 5.00±1.00 days, respectively. Adult longevity of females and males were 20.33±1.53 and 1.67±1.15 days, respectively. Total life cycle of *P. marginatus* was 39.33±2.53 days for females and 24.0±1.73 days for males. The oviposition period was 7.33±0.58 days and fecundity was 329.33±20.03 eggs on sunflower seedlings.

Tanwar *et al.* (2010) reported that papaya mealybugs are most active in warm, dry weather. Females have no wings, and move by crawling short distances or by being blown in air currents. Females usually lay 100 to 600 eggs. Eggs are greenish yellow and are laid in an ovisac sac that is three to four times the body length and entirely covered with white wax. Egg laying usually continues over a period of one to two weeks. Eggs hatch in about 10 days, and nymphs or crawlers begin to actively search for feeding sites. Females have three instars whereas males have four instars. Males have longer development time (27-30 days) than females (24-26 days) at 25± 1^0C, 65±2 %RH.

2.7 Morphology

Miller and Miller (2002), give a complete description of all instars of both sexes of the papaya mealybug, as well as a complete description of characters used to distinguish the papaya mealybug from other closely related species.

2.7.1 First instar gender not determined

Body is 0.4mm long and 0.2 mm wide. Dorsum contains 9 pairs of cerarii; cerarii is indfinite, when present, with 2 conical setae and 1 trilocular pore between conical setae. Cerarius 12 is absent. Anal-lobe cerrius without auxillary setae, 2 conical setae, 1 trilocular pores, without discoidal pores. Dorsal body setae are more slender than cerarian setae. Multilocular are pores absent; trilocular pores are scattered over surface, forming 2 longitudinal lines on each side of abdomen, excluding cerarrian setae. Discoidal pores are absent. Oral-rim tubular ducts are absent. Oral-collar tubular ducts are absent. Longest sub medial seta on segment VII 5 (4-8) µ long; without sub medial setae on segment VIII. Anal ring seta is 37 (30-42) µ long; 1.4 (1.2-1.6) times as long as width of anal ring. Venter has no multilocular pores. Trilocularpores are restricted to 10 positions on each side of body head, thorax, and anterior abdomen. Discoidal pores in sub marginal line on each side of abdomen, usually with 1 pore posterior of each spiracle. Oral-rim tubular duct and Oral-collar tubular ducts are absent. Setae as follows: 4- cisanal, longest 17 µ long; longest anal lobe seta 58 µ long; longest seta on trochanter 38 µ long. Anal lobe bar is slightly narrower than on adult female. Circulus is 37 µ long divided by inter segmental line. Labium is 48 µ long. Antennae 6 segmented, segment 3 contain 4 setae. Legs do not have any translucent pores. Hind femur is 59 µ long; hind tibia is 50 µ long; hind

tarsus is 57µ long. Hind tibia has 9 setae. Claw and tarsal digitules are same as on adult female except sometimes 1 claw dgitule slightly smaller on all legs (Miller and Miller, 2002).

2.7.2 Second instar female

The body color of this nymph is yellow. Body is 0.7mm long and 0.4mm wide. Dorsum with 6(4-11) pairs of cerarii. Cerarii indefinite, when present, with 2 conical setae and 1 trilocular pore between conical setae.Cerarius 12 is absent. Anal lobe cerarius with 1 auxiliary setae, 2 conical setae, 2trilocular pores, sometimes 1 discoidal pore. Dorsal body setae was more slender than cerarian setae. Multilocular pores are absent; trilocular pores are scattered over the surface, most abundant near setae; discoidal pores rare,about 0.5 diameter of trilocular pore. Oral-collar tubular ducts are absent. Longest sub medial seta on segment VII 6 µ long; without submedial setae on segment VIII. Anal ring seta is 60 µ long.Venter with multilocular pores are absent. Trilocular pores concentrated near setal bases. Absent in medial area of abdomen. Discoidal pores rare. Oral-rim tubular ducts a absent. Setae as follows: 4 cisanal, longest 20 µlong; longest anal lobe seta 95 µ long. Anal lobe bar is narrower than adult female. Circulus is 40 µ wide, generally divided by intersegmental line. Labium is 69 µ long. Antenna 6 segmented and 173 µ long. Antennal segment 3 contains 5 setae. Legs with translucent pores. Hind femur 78 µ long; hind tibia 66 µ long; hind tarsus 69 µ long. Hind tibia with 9 setae. Claw and tarsal digitules same as on adult female except sometimes 1 claw dgitule conspicuously smaller on all legs (Miller and Miller, 2002).

2.7.3 Second instar male

Body color is usually pink occasionally yellow. Body is 0.4mm long, 0.2 mm wide. Dorsum contain 4 pairs of cerarii; cerarii indfinite, when present, with 2 conical setae and 1 trilocular pore between conical setae. Cerarius 12 absent. Anal-lobe cerrius with 1(1-2) auxiliary setae, 2 conical setae, 2 (2-3) trilocular pores, without discoidal pores. Dorsal body setae are more slender than cerarian setae. Multilocular pores 1(0-2) present in medial areas of thorax and/ or head; trilocular pores scattered over surface, most abundant near setae. Discoidal pores, about 0.5 diameter of trilocular pore. Oral-rim tubular ducts are absent. Oral-collar tubular ducts are abundant over the surface. Longest sub medial seta on segment VII 6 (5-8) µ long; without sub medial setae on segment VIII. Anal ring seta is 54 (48-58) µ long; 1.3 (1.2-1.5) times as long as width of anal ring. Venter with multilocular pores mesad of each pair of legs, for hind pair of legs located on segment III. Trilocular pores are concentrated near setal bases. Discoidal pores are rare. Oral-rim tubular ducts are absent. Oral-collar tubular ducts of 2sizes: larger size same as dorsum, located marginally; smaller size present in longitudinally line along submargin of abdomen. Setae as follows: 4- cisanal, longest 21 µ long; longest anal lobe seta 91(83-108) µ long; longest seta on trochanter 47 µ long. Anal lobe bar is narrower than on adult female. Circulus is 50(40-75) µ long divided by inter segmental line. Labium is 67(62-42) µ long. Antennae is 6 segmented; 171(160-188) µ long and segment 3 contain 5 setae. Legs do not have translucent pores. Hind femur is 82 µ long; hind tibia is 68 µ long, hind tarsi are 62 µ long. Claw and tarsal digitules are same as adult female except 1 claw dgitule conspicuously smaller than on all legs (Miller and Miller, 2002).

2.7.4 Third instar female

Body is 1.1 (0.7-1.8) mm long, 0.7(0.3-1.1) mm wide. Dorsum with 6(1-10) pairs of cerarii: cerarii indefinite, when present, with 2 conical setae and trilocular pore between conical setae. Cerarius 12 absent. Anal-lobe cerrius contain 1(1-2) auxillary setae, 2 cnical setae, 5 (4-7) trilocular pores, 0 (0-1) discoidalpores. Dorsal body setae are more slender than cerariansetae. Multilocular pores absent; trilocular pores scattered over surface, most abundant near setae; discoidal pores rare, about 0.5 diameter of trilocular pore. Oral-rim tubular duct rarely present near position of cerarius 8 (of 10 specimens examined. 4 had 1 oral rim or large oral collar on at least one side of body). Oral-collar tubular ducts are absent. Longest sub medial seta on segment VI 7 (5-10) µ long; 1(0-2) sub medial setae on segment VIII, when present 7 (5-10) µ long. Anal ring seta is 87 (78-92) µ long.

Venter with multilocular pores is absent. Trilocular pores concentrated near setal bases, discoidal pores uncommon, of same size as on as dorsum. Oral-rim tubular duct sometimes present near body margin on abdominal segment II-III, or metathorax. Oral-collar tubular ducts are absent. Setae as follows: 4- cisanal, longest 33µ long; longest anal lobe 132 µ long; longest seta on trochanter 63µ long. Anal lobe bar is slightly narrower than on adult female. Circulus 87 µ long divided by inter segmental line. Labium is 85 µ long. Antennae is 6-7 segmented when 6 segmented, 3 segments contain 9 setae, 233 µ long. Legs do not contain translucent pores. Hind femur is 114 µ long; tibia 108 µ long. Claw and tarsal digitules is same as on adult female except sometimes 1 claw digitule slightly smaller than others (Miller and Miller, 2002).

2.7.5 Third instar male

Body is 0.9 mm long and 0.4 mm wide. Dorsum without cerarii; poster lateral margins of segments V, VI, VII and VIII each with 2 setae conspicuously longer than remaining setae on abdominal segments. Multilocular pores in medial areas of head, forming row on prothorax and metathorax. Trilocular pores are absent. Discoidal pores rare. Oral-rim tubular ducts are absent. Oral-collar tubular ducts are present around the margin, medial and sub medial ducts sometimes present on prothorax, metathorax and 1 or 2 abdominal segments. Longest sub medial seta on segment VII 18 (15-20) µ long; without sub medial setae on segment VIII. Anal ring seta is 25 (20-28) µ wide. Venter contains multilocular pores near anterior margin on head, near spiracles, near legs and in medial areas of prothorax and mesothorax on thorax, in rows on abdominal segments. Trilocularpores is absent. Discoidal pores are located near each pair of legs. Oral-rim tubular ducts are absent. Oral-collar tubular ducts are restricted in margin. Longest anal lobe seta is 67(50-78) µ long. Circulus appearing collapsed 62(45-98) µ long. Labium is absent. Antennal segment is indistinct. Hind femur is 90 µ long; division between hind tibia and tarsus is indistinct, hind tibia + tarsus is 134 µ long. Wings buds of mesothorax protruding from lateral margin, is 67(50 78) µ long. Hamulohalterae represented by small swelling on lateral margin of metathorax (Miller and Miller, 2002).

2.7.6 Fourth instar male (pupa)

Body color is usually pink. Body is 1.0(0.9-1.0) mm long, 0.3(0.3—0.4) mm wide. Dorsum without cerarii; postero lateral margins of segments III, IV, or V, to segment VIII each has 2 setae conspicuously longer than remaining setae on abdominal segments. Multilocular pores absent from head, forming conspicuous row on prothorax, mediolateral cluster on metathorax, without pores on mesothorax, in mcdiolateral clusters on each side of abdominal segments I—VI or VII; trilocular pores are absent; discoidal pores associated with multiloculars and oral collars. Oral-rim tubular ducts are absent. Oral-collar tubular ducts are present near body margin of prothorax and abdominal segments I or II to VII or VII, forming clusters of 2(1—5) ducts. Longest submedial seta present on segment VII and 20(16—28) µ long; segment VIII have no submedial setae. Anal-ring setae absent; anal ring is 27(25-30) µ wide. Venter with multilocular pores absent from head, row of pores between front coxae, present on remainder of thorax near spiracles and legs, in mediolateral clusters of 2(1—4) pores on each side of segments 11VI, VII, or VIII. Trilocular pores are absent. Discoidal pores are associated with oral-collars and multiloculars. Oral-rim tubular ducts are absent. Oral-collar tubular ducts present near body margin of prothorax usually forming cluster of several ducts, sometimes absent from abdomen or with 1 duct near body margin on each of abdominal segments II—VII or VIII. Longest anal-lobe seta is 60(48—72) µ long. Circulus is ill-defined. Labium is absent. Antenna is 10-segmented, 357(345—375) µ long. Hind femur is 109(105—115) µ long; hind tibia is 111(105—112) µ long; hind tarsus is 80(75-88) µ long. Wing buds of mesothorax protruding from lateral margin, is 336(250—385) µ long. Hamulohalterae is 36(22—42) µ long (Miller and Miller, 2002).

2.7.7 Adult Female

Body is yellowis color, dusted with mealy wax not thick enough to hide body color, without discrete bare areas on dorsum, with many short waxy filaments around body margin. Ovisac developed beneath and behind adult female. Body is 2.2 (1.5- 2.7) mm long, 1.4 (0.9-1.7) mm wide. Dorsum contain 16 (14-17) pairs of cerarii; cerarii 1, 2, 4, 5, 7, and 9 with 2 conical setae; ccerarii 3, 6 and 16 with 3(2-3) conical setae; cerarii 12, 13 and 15 with 2 (0-3) conical setae. Auxiliary setae is absent in Cerarius 12, 2 (0-3) conical setae, 5 (0-8) trilocular pores, 1(0-3) discoidal pores are present. Anal lobe cerarius contain 1(1-3) auxiliary setae, 2 conical setae, 13 (10-18) trilocular pores, 2 (0-3) discoidal pores. Dorsal body setae are more slender than cerariansetae. Multilocular pores are absent; trilocular pores scattered over surface, most abundant near setae; discoidal pores rare, about 0.5 diameter of trilocular pore. Oralrim tubular ducts usually restricted to marginal areas associated with cerarii, 1 specimen examined with 1 mediolateral duct on segment I and 1 in medial area of mesothorax; of 21 specimens examined cerarius 1 without associated oral rim, cerarius 2 with associated oral rim in 20 of 21 specimens, cerarius 4 with 12 on 21, cerarius 5 with 11 on 21, cerarius 6 with 17 on 21, cerarius 7 with 18 on 21, cerarius 8 with 20 on 21, cerarii 9 and 10 without associated oral rims, cerarius 11 with 15 on 21, cerarius 12 with 4 on 21, cerarii 13,15 and 16 without associated oral rim, cerarius 14 with 2 on 21 specimens. Oral-collar tubular ducts are absent. Longest submedial seta on segment VIIis 10(8-18) µ long. Anal-ring seta is 136(120-150) µ long; 1.4 (1.2-1.7) times as long as width of anal ring. Venter contain multilocular pores usually in posterior and anterior bands on segments VI-VII and restricted to posterior band on segment IV and V, 1or 2 specimens with 1 or 2 pores on segment III or with a few pores

on anterior margins of segments IVand V; 3 of 10 specimens with 1 multilocular pores near base of front or hind leg. Trilocular pores concentrated near setal bases. Discoidal pores uncommon of same size as on dorsum. Oral-rim tubular ducts in medio lateral areas from prothorax to segment I, contain 4 (3-6) ducts on each side of body. Oral-collar tubular ducts of 1 size, in conspicuous marginal clusters along body margin from segment II-VII, often with 2 or 3 pores on segment I, also present in medial and mediolateral areas of abdominal segments III-VIII, present on thorax in seta clusters near hind 2 pairs of legs, occasionally with 1 or 2 along body margin of thorax especially in area laterad of anterior spiracle and front legs, absent from head, setae as follows: 4 cisanal longest 52 (45-68) µ long; longest anal-lobe seta 170(155-200) µ long; longest seta on trochanter 104 (95-110) µ long. Anal-lobe bar is conspicuously wider than base of anal bar seta. Circulus is 65(49-80) µ wide generally divided by intersegmental line. Labium 137 (125-162) µ long. Antenna 8 segmented 372(335-400) µ long. Legs with transluscent pores restricted to hind coxa, ventral surface (when leg is lying flat as shown in illustration) with 40(14-62) pores, dorsal surface with 79(54-108) pores. Hind femur is 209 (95-225) µ long; hind tibia is 211 (185-228) µ long; hind tarsus is 94 (91-100) µ long. Hind tibia/ tarsus is 2.2 (2.0-2.3); hind femur/tarsus is 2.2 (2.0-2.3) µ long. Length of femur hind femur is 3.7 (3.0- 4.2). Hind tibia contains 15 (14-19) setae. Claw digtilues on all legs clubbed, approximately same size. Tarsal digitules on hind 2 pairs of legs clubbed each tarsus with 1 digitules on front pair of legs of 2 different sizes and shapes, 1 digitule on each tarsus clubbed and robust, other digitule without club and slender (Miller and Miller, 2002).

2.7.8 Adult male

Body elongate oval, 1.0(0.9.1.1)mm longest width at thorax 0.3(0.20.3) mm. Dorsum with 1 pair of tail forming pore clusters; each cluster with 2 elongate setae approximately 250 µ long, 1 sometimes 2 additional shorter setae, multilocular pore is 38(4—42) and 1 or 2 discoidal pores. Multilocular pore in marginal areas of prothorax and each abdominal segment, contains 5(3—7) on each side of segment 1, 2(1-3) on each side of segment II. Multilocular pores with 4 or 5 loculiquinoque loculars predominate, normally without pores on head. Discoidal pores associated with lateral abdominal multilocular pores. Body setae bristle shaped. Small abdominal tergites present on mid-dorsum of segments I—II and dorsum of segment VIII. Dorsal abdominal tergites usually not have associated setae. Meta postnotal ridge is conspicuous. Scutellum is rectangular shape, with several medial setae. Scuturm is sclerotized throughout except for a median longitudinal clear area which bears several setae. Prescutum is rectangular with well-defined prescutal ridge, weakly defined prescutal suture and several setae. Pronotal ridge heavily sclerotized. Harnulohalterae 75(67—82) µ long, with 1 apical hooked seta. Mesothoracic wings is 932(889—988) µ long, each with 2—3 basal setae. Head width is l80 (l48-l93) µ; dorsal eye is 34(30—40) µ in diameter, lateral ocellus is 17(12—20) µ in diameter and located at junction of preocular and post ocularridges. Dorsal arm of midcranial ridge is extending beyond posterior margin of dorsal eye. Median crest is weakly sclerotized with several setae. Ocular sclerite is weakly sclerotized. Penial sheath is 95 µ long, 70 µ wide with distinct ventral lobes; length/width ratio 1.4. Aedeagus is apically truncate. Venter contains hair-like setae only, present medially, submedially and laterally of most abdominal segments as well as few scattered prosternal and basisternalsetae. Abdominal sclcrotization confined to segment VIII.

Prosternal ridge is well developed sternite weakly sclerotized. Preoral ridge is weakly developed. Ocular sclerite is weakly sclerotized near ventral eye. Ventral mid cranialridge well developed, with lateral arms .Ventral eye is 39 µ in diameter. Antenna 10-segmented with bristle-shaped and fleshy setae, capitate setae present on apical segment; segments I 37µ long II 55µ long (Miller and Miller, 2002).

2.8 Management of papaya mealybug:

2.8.1 Physical control

During the rainy season (May to August), papaya mealybug populations decreased drastically because heavy rain washed the insects off the plants. However, mealybugs sheltered within unopened leaves and other hiding places survived and built up their numbers again during the warm, dry weather. This observation suggested that, by directing a powerful jet of water at infested plant parts, the pest could be controlled to some extent. The mealybugs spread by being carried by the wind, on birds and animals, and by infested plant parts/ planting material being trans-ported by man. Therefore, good crop sanitation could stop the insects spreading. Mealybug colonies were attended by many ant species, which visited infested plants to feed on the honeydew excreted by the mealybugs. Ants were seen carrying mealybugs also, thus helping the mealybugs to disperse. Burn-ing heavily infested plant parts helped to reduce the mealybug population.

These observations led to formulate the following Integrated Pest Management practices, which were recommended to the general public for control of papaya mealybug:

1. Destruction of all heavily infested plant parts on the spot
2. Avoiding transportation of infested plant material
3. Avoiding pruned, infested plant parts being left unattended or being placed in garbage bins or vehicles
4. Washing the insects off the plants with a powerful water jet
5. Spraying plants near houses and in home gardens with a soap + kerosene oil + water mixture
6. Use of recommended insecticides to treat commercially important crops
7. Use of botanical pesticides to treat agricultural crops in home gardens
8. Wrapping polythene/spongy tapes impregnated with insecticides around tree trunks to exclude (Galanihe *et al*., 2010).

2.8.2 Biological control

Mani *et al*. (2012) reported that *Acerophagus papayae* is very useful in biological control of papaya mealybug in India.

A study by Mastoi *et al*. (2015) reported two predators (*C. montrouzieri* and *Apertochrysa sp*.), one primary parasitoid (*A. papayae*) and three hyperparasitoids (*Chartocerus sp*., *M. leopardina* and *Cheiloneurus sp.)* in Malaysia with *C. montrouzieri* and *A. papaya* being the most abundant

Generalist predators such as larvae of ladybird beetles (Coleoptera: Coccinellidae) and green lace-wings (Neuroptera: Chloropidae) were found to have a low impact on papaya mealybug populations. The same predator groups including the commercially available mealybug destroyer, *Cryptolae musmontrouzieri* Mulsant (Coleoptera: Coccinellidae) have been reported from USA (Walker *et al*., 2003). In addition to

predators, five efficient parasitoids (Hymenoptera: Encyrtidae) specific to papaya mealybug were identified by the United States Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS) and USDA Ag-ricultural Research Service (ARS) in 1999: *Acerophagus papaya ,Anagyrusloecki*, *Anagyru scalifornicus* (Compere), *Pseudaphycus* sp. and *Pseudleptomastix Mexicana* (Walker *et al*., 2003; Meyerdirk*et al*., 2004).The five parasitoid species have been efficient at controlling papaya mealybug in all the countries where they have been released. USDA-APHIS found that the five parasitoid species brought about a 99.7% reduction in papaya mealybug populations in the Dominican Republic, and a 97% reduction in Puerto Rico, with parasitism levels of 35.5-58.3% (Meyerdirk and Kauffman, 2001). All five parasitoids have been observed at-tacking second- and third-instar *P. marginatus*. However, *Acerophagus* sp. emerged as the dominant parasitoid species in both Puerto Rico and the Dominican Republic (Meyerdirk and Kauffman, 2001).

Sandeep and Gurlaz (2011), also observed that generalist predators such as larvae and adults of ladybird beetles, especially *Scymnus* sp. (Coleoptera: Coccinellidae), green lacewings (Neuroptera: Chloropidae) and syrphid flies were found feeding on papaya mealybug individuals but they were observed to have a low impact on mealybug populations.

United States Department of Agriculture and Agricultural Research Service and co-operators in Mexico collected five parasitoids of *P. marginatus* namely *Apoanagyrusnr californicus* Compere, *A. loecki,A.papayae*, *Pseudaphycus* sp. and *P. Mexicana* (Hymenoptera: Encyrtidae) (Meyerdirk and Kauffman, 2001; Noyes and Schauff, 2003).

Patil *et al*. (2011) reported that several natural enemies viz., predators Spalgius epius (Westwood), *Scymnus* sp. and one parasitoid, A. papaya and *A. loecki* were recorded on papaya mealybug. Among the three natural enemies observed, *S. epius* were in good numbers and found predating upon all the stages of papaya mealybug.

Saengyot and Burikam (2011), reported 10 species of host plants and 11 species of natural enemies for *P. marginatus* from Thailand. These natural enemies included parasitoids, *Anagyrus* sp. and *Anasius* sp., predators, *Cryptogonus orbiculus* (Gyllenhal), *Sasajiscymnus quinquepunctatus* (Weise), *Scymnus quadrillum Motschulsky*, *Scymnus* sp., and *Stethorus* sp., *S. epius*, *Chrysoperla* sp., *Mallada basalis* (Walker) and an unidentified syrphid fly. Also, it was reported that *Anagyrus* sp., *S. quinquepunctatus*, and *S. epius* were the dominant species of natural enemies.

2.8.3 Chemical control

The three most effective insecticides identified in the experiments were recommended for use as foliar sprays against the papaya mealybugs on cultivated crops: thiamethoxam 25%WG at the rate of 1 g per liter; imidacloprid 200 g/l SL at the rate of 1 ml per liter; and Mineral oil (Sparrow oil) at the rate of 5 ml per liter (Galanihe, 2010).

CHAPTER III

MATERIALS AND METHODS

The experiment was conducted during the period from June, 2017 to August, 2018 to study the biology and damage assessment of papaya mealybug. This chapter includes materials and methods that were used in conducting the experiment and presented below under the following headings:

3.1. Identification of mealybug for Biology Studies

Biology studies of *P. marginatus* were carried out in Entomology laboratory, Sher-e-Bangla Agricultural University. Adult 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 was papaya (*Carica papaya* L).

3.1.1 Life cycle of *P. marginatus* on papaya plants

The individual leaves of host plants with petioles were removed and kept in Petri dish 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, the whole plant with intact root system was used in the study.

3.1.2 Transplanting of papaya seedlings

Three months old seedlings (20 cm height and 4–5 leaves) were planted in the earthen pot (Plate 3.1) and fully an expanded young leaf were preferably at the top most position selected for this experiment (Plate 3.2). From each plant five replications were made for each plant to get an unbiased data.

Plate 3.1 Papaya plant in earthen pot.

Plate 3.2 Adult female mealybug on leaves of plant lined with moistened cotton.

3.1.3 Duration of instars of male and female *P. marginatus*

Each plant was inoculated with eggs of *P. marginatus* (1 egg sack per leaf) using a camel hair brush. All plants were observed daily for egg hatching. The interval between each moulting was checked by examining exuviae on the leaves using a hand lens (10 X magnification) and the exuviae were removed after each moulting. Morphological determination of all the instars was done under a stereo microscope 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 and females and duration of fourth instar males (pupa) were recorded.

3.1.4 Reproductive period

The adult female mealybugs were individually transferred to new leaf (leaves of plant lined with moistened cotton) for monitoring the reproductive period (oviposition and incubation).

3.1.5 Adult longevity

Adult longevity of five male and female mealybugs was observed daily in three month old seedlings until they died.

3.1.6 Number of eggs

Five egg sacs were taken and eggs were counted under stereo microscope.

3.2 Damage Assessment

3.2.1 Location of the experimental field

The experiment was conducted at Farm of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka, during the period from June, 2017 to August, 2018. The location of the experimental site was at $23^0 46^{'}$ N latitude and $90^0 22^{'}$ E longitudes with an elevation of 8.24 meter from sea level.

3.2.2 Climate of the experimental area

The experimental area is characterized by subtropical rainfall during the month of June, 2017 to August, 2018 and scattered rainfall during the rest of the year.

3.2.3 Soil of the experimental field

Soil of the study site was silty clay loam in texture belonging to series. The area represents the Agro-Ecological Zone of Madhupur tract (AEZ No. 28) with pH 5.8-6.5, ECE-25.28 (Haider, 1991). The analytical data of the soil sample collected from the experimental area were determined in the Soil Resources Development Institute (SRDI), Soil Testing Laboratory, Khamarbari, Dhaka and have been presented in Appendix II.

3.2.4 Plant materials collection

The papaya variety used in the experiment was "Red lady". This is a high yielding variety. The seeds were collected from krishibid nursery.

3.2.5. Raising of seedlings

Papaya seedlings were raised in polybag of 15 cm ×10 cm size and the soil of the bag was mixture of sand, soil and cowdung (1:1:1). Two seeds were sown in every polybag. After sowing, seeds were covered with light soil. The emergence of the seedlings took place within 6 to 7 days after sowing.

3.2.6 Treatments of the experiment

The experiment contains two treatments and 10 replications.

T_1= Papaya plant covered with fine net and imidacloprid (Admire) 200 SL @ 1 ml/L of water sprayed at 15 days interval.

T_2 =Artificially infestion by papaya mealybug (100 nymph of papaya mealybug were released per plant).

Plate 3.3 Seed sowing in the earthen pot.

Plate 3.4. Artificial infestation of papaya mealybug on papaya plant.

3.2.7 Design and layout of the experiment

The experiment was laid out in Randomized Complete Block Design (RCBD) having two treatments with ten replications. An area of 25 m x 15 m was divided into two equal blocks. Each block was consists of 10 plots where two treatments were allotted randomly. There were 20 unit plots in the experiment. The size of each plot was 1.8 m x 2 m. The distance between two blocks and two plots were kept 1 m and 0.5 m respectively.

3.2.8 Cultivation procedure

3.2.8.1 Land preparation

The soil was well prepared and good tilth was ensured for commercial crop production. The land of the experimental field was ploughed with a power tiller on July, 2017. Later on the land was ploughed three times followed by laddering to obtain desirable tilth. The corners of the land were spaded and larger clods were broken into smaller pieces. After ploughing and laddering, all the stubbles and uprooted weeds were removed and then the land was made ready. The field layout and design was followed after land preparation.

3.2.8.2 Pit preparation

Size of the pit was 60 × 60 × 45 cm. 15 kg cow dung, 500 g TSP, 250 g gypsum, 20 g boric acid and 20 g zinc sulphate was given in every pit.

3.2.8.3 Manures and fertilizers and its methods of application

During land preparation, cow dung was incorporated into the soil at the rate of 10 t/ha. Recommended doses of fertilizer such as urea, TSP and MP at the rate of 150, 125 and 100 kg/ha respectively were applied**.** One month after transplanting 50 g urea and 50 g MP applied on each plant in every month.

3.2.8.4 Transplanting of seedlings

Healthy and uniform 30 days old seedlings were transplanted in the pit in July, 2018 seedlings are sown in per pit. At the time of seedlings polybag was remove carefully. The seedlings were watered after transplanting.

3.2.8.5 Intercultural operations

After transplanting the seedlings, various kinds of intercultural operations were accomplished for better growth and development of the plants, which were as follows:

3.2.8.5.1 Gap filling

When the seedlings were well established, the soil around the base of each seedling was pulverized. A few gaps filling was done by healthy seedlings of the same stock where initial planted seedling failed to survive.

3.2.8.5.2 Weeding

Weeding was accomplished whenever necessary by hand weeding method.

3.2.8.5.3 Staking

When the plants were well established, staking was given to each plant by rope and plastic wire to keep them erect. Within a few days of staking, as the plants grew up, other cultural operations were carried out.

3.2.8.5.4 Irrigation

Number of irrigation was given throughout the growing period by garden pipe and watering cane. The first irrigation was given immediate after the transplantation where as other were applied when and when required depending upon the condition of soil.

3.2.8.6 Harvesting

Fruits were harvested at ripening stage when they become mature. Harvesting was started from July, 2018 and was continued up to August 2018.

3.2.9 Data collection

Data on the following parameters were recorded from the sample plants during the course of experiment.

3.2.9.1 Plant height

The plant height was measured in centimeters from the base of plant to the terminal growth point of main stem on tagged plants was recorded at 10 days interval starting from reproductive stage. The average height was computed and expressed in centimeter.

3.2.9.2 Number of leaves per plant

The number of leaves per plant was manually counted at three stage early mid and reproductive stage.

3.2.9.3 Petiole length of the plant

The petiole length of the plant was manually measured by slide calipers at at three stage early mid and reproductive stage.

3.2.9.4 Number of flowers per plant

The number of flowers counted at the reproductive stage.

3.2.9.5 Number of fruits per plant

The number of fruits per cluster was counted at harvesting time.

3.2.9.6 Weight of individual fruit

An electric balance was used to measure the weight of fruit and was expressed in gram (g).

3.2.9.7 Total fruit yield per plant

Total fruit yield per plant was expressed in Kilogram (Kg).

3.3 Data Analysis

Percent damage due to infestation of mealybug calculated by following formula:

$$\text{Percent damage} = \frac{T_1 - T_2}{T_1} \times 100$$

Here,

T_1= Papaya plant are covered with fine net and imidacloprid (Admire) 200 SL @ 1 ml/L of water sprayed at 15 days interval

T_2 = Artificial infestation of papaya mealybug on papaya plant (100 nymph of papaya mealybug were released per plant)

3.4 Statistical analysis

The recorded data on various parameters were statistically analyzed using SPSS statistical package program.

CHAPTER IV

RESULTS AND DISCUSSION

The present study was conducted to assess the damage of a papaya in the field after infestation of papaya mealybug and also studied the biology of papaya mealybug (*P. marginatus*). The results of the experiment are presented below and discussed with other findings:

4.1 Biology of Papaya Mealybug

4.1.1 Eggsac

The papaya mealybug (*P. marginatus)* laid eggs in an eggsac. Each female laid one eggsac (Table 1) after laying the eggs female was died. Eggsac was made of whitish cottony layer (plate 4.1).

4.1.2 Egg

Adult female lays (97-150) eggs per sac (Table 1). Eggs were yellowish color and oval shape (plate 4.2). The length of egg was 0.35±0.01 mm (Table 3) and the breadth was 0.14±0.008 mm (Table 3). The average incubation period of the eggs was 4-7 days (Table 2). The oviposition period of a female was 5-8 days (Table 2). Chellappan *et al.* (2006) reported that the length of egg was 0.34±0.01 mm and the breadth was 0.15±0.01 mm which is also confirmed the present study. They also reported that incubation period was 8.5±0.85 days and oviposition period 7.8±0.63 days is also close to the present study. Females usually lay 150-600 eggs in an ovisac. The results of the present study are lying between the ranges of these findings. Egg laying usually occurs over the period of 3-4 days, which is lower than the present study. Egg hatch in about ten

days which is lower than the present study. However, this variation might be due to the environmental condition (Jithu *et al*., 2016). The adult female of *P. marginatus* laid about 150 to 200 eggs inside the ovisacs which are close to the present study (Al-hilal *et al.*, 2012). Suganthy *et al.* (2011) reported that the period of egg was 6.33±0.58 days and this finding is lying between the present studies. Females usually lay 100 to 600 eggs. Eggs are greenish yellow and are laid in an ovisac and these findings are similar to the present study but they also reported that egg laying usually continues over a period of one to two weeks and eggs hatch in about 10 days, these results are somewhat different to the present study. This variation might be occurred due to environmental condition or host species (Tanwar *et al.*, 2010).

Plate 4.1 Egg Sac (30X)

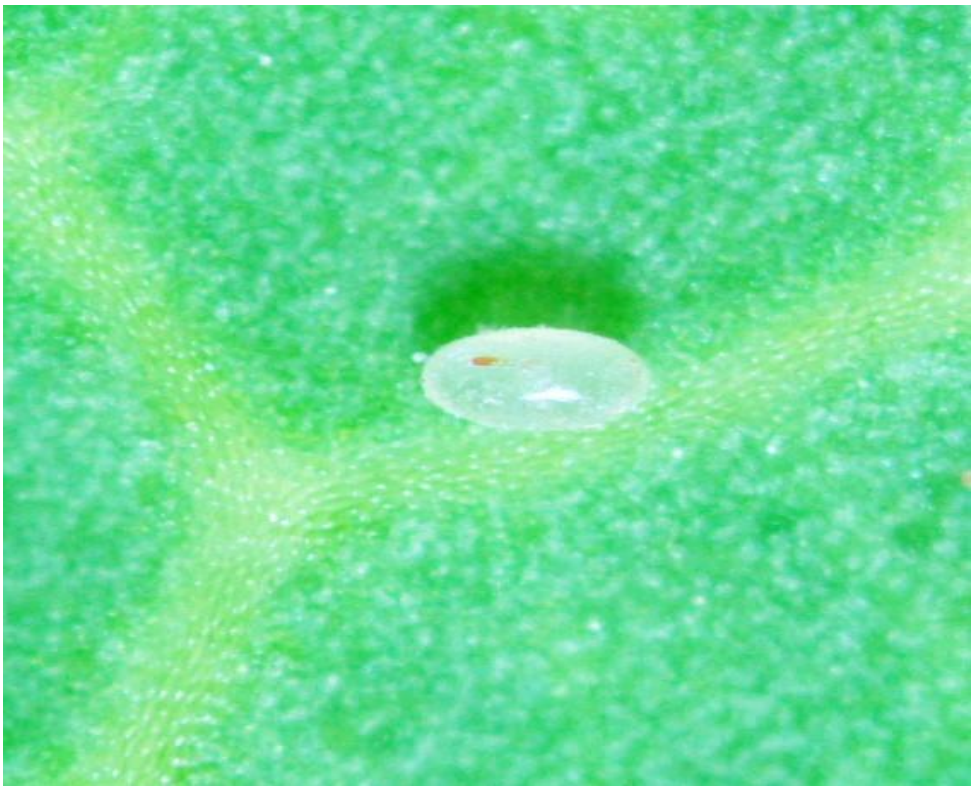

Plate 4.2 Egg (90X)

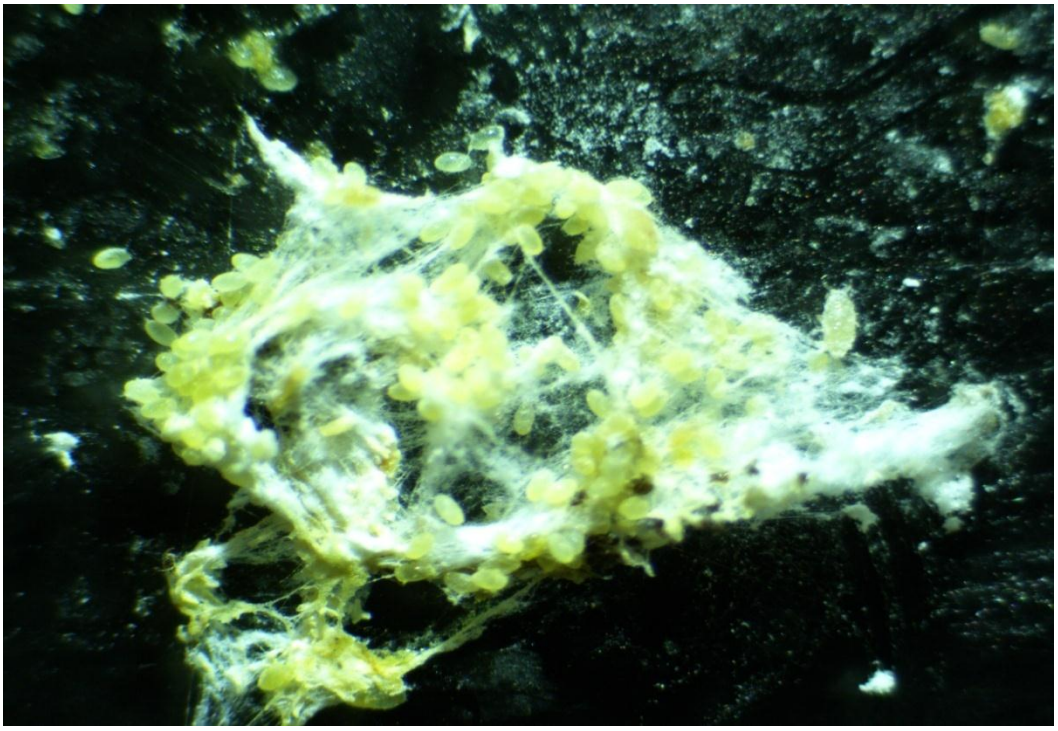

Plate 4.3 A mass of eggs (30X)

Plate 4.4 A mass of 1st Instar Nymph (30X)

Table 1: Number of eggs per sac laid per female

Observations	Egg number
1	97.0
2	120.0
3	118.0
4	130.0
5	150.0
Mean± SD	123±19.52

4.1.3 Nymph

Females have three instars nymphs whereas males have four instars (Table 2).

Al-hilal *et al.* (2012) observed that in case of *P. marginatus*, generally three and four nymphal instars took place in case of female and male mealybug, respectively, this finding is same as the present result.

4.1.3.1. First instar nymph

At this stage male and female could not be distinguished (Plate 4.5). First instar nymph were very active. The length of the nymph was 0.41±.08 mm (Table 3) and the breadth was 0.25±0.03 mm (Table 3). The average duration of 1st instar nymph was 4-6 days (Table 2). The first instar nymph is yellowish color (Plate 4.6). Miller and Miller (2002), reported that in 1st instar gender could not be determined and nymph is yellow color which is similar to the present findings. They also reported that the length and breadth of nymph was 0.4 mm and 0.2 mm which is close to

the present findings. 1st instar nymph was 4.6±0.52 days this result is accordance with the present result (Chellappan *et al.*, 2006). Seni and Sahoo (2014), studied the biology of *P. marginatus* on sprouted potato throughout the year revealed that the duration of first instar nymphs, ranged from 3-17 days and the present study finding is also lying between the ranges of this findings. The sexes of which could not be distinguished and this finding is same as the present result. The length of first instar nymph was 0.42±0.074 mm and 0.024±0.27 mm in width. This instar appears yellowish in color which is similar to the present findings (Al-hilal *et al.*, 2012). Suganthy *et al.* (2011) reported that the period of first instar nymph was 4.00±1.00 days and this finding is lying between the present studies.

4.1.3.2. Second instar nymph

The 1st instar nymph was moulted to 2nd instar nymph and casted their exuvae. The 2nd instar female was yellowish color (Plate 4.6) and male was pink color (Plate 4.7) Female length was 0.69±0.03 mm and breadth was 0.44±0.02 mm and the male was 0.70±.065 mm long and 0.38±0.04 mm wide (Table 3). Average duration of 2nd instar female nymph was 3-5 days and the 2nd instar male nymph was 3-4 days (Table 2). Miller and Miller (2002), reported that the 2nd instar female was yellowish color and male was pink color which is similar to the present study. They also reported that 2nd instar female length and breadth was 0.7 mm and 0.04 mm which is close to the present study. But the 2nd instar male nymph 0.4 mm long and 0.02 mm wide which is somewhat different to the result. Chellappan *et al.* (2006) confirmed the present result according to them 2nd instar male nymph 0.75±0.02 mm long and 0.44±0.02 mm wide. They

also observed that 2nd instar female nymph average duration was 4.2±0.63 days and 2nd instar male nymph average duration was 4.3±0.67 days. Al-hilal *et al.* (2012) observed the length of second instar female nymph was 0.6±0.054 mm and 0.089±0.4 mm in width. Body color appeared yellow in field conditions. Length of second instar male nymph was 0.62±0.044 mm and 0.09±0.3 mm in width. Body looks like yellow in color during field observation. The length of second instar male and female is close to the present result but the width showed different result and this might be due to the environmental condition or host species. The period of second instar nymph was 3.67±0.58 days and this finding is lying between the present studies (Suganthy *et al.*, 2011).

Plate 4.5 1st instar nymph (30X)

Plate 4.6 2nd Instar nymph female (30X)

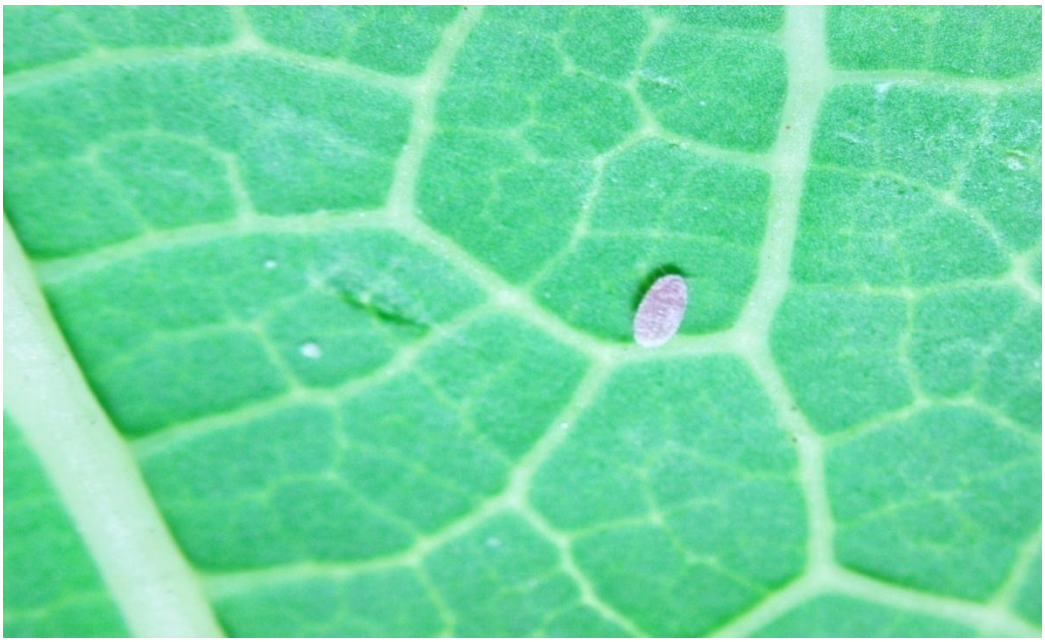

Plate 4.7 2nd Instar nymph male (30X)

Plate 4.8 3rd Instar nymph female (30X)

Plate 4.9 3rd Instar nymph male (30X)

Plate 4.10 Pupa (30X)

Table 2: Duration of different life stages of *Paracoccus marginatus*

Life stage	observation	Period in Days Average ±SD
Oviposition	5	6.00±1.22
Incubation period	5	5.80±1.09
1st instar (gender not identified)	5	4.80±0.83
2nd instar female	5	4.20±0.83
3rd instar female	5	3.40±0.54
Adult female	5	10.0±2.00
2nd instar male	5	3.60±0.54
3rd instar male	5	2.80±0.83
Pupa	5	3.60±0.54
Adult male	5	2.40±0.54
Total lifespan male	5	17.2±2.86
Total lifespan female	5	22.4±3.70

4.1.3.3 Third instar nymph

The 2nd instar female moulted after 3-4 days and male was moulted after 2-4 days into 3rd instar nymph (Table 2). The 3rd instar male was pink color (Plate 4.8) and the female was yellowish color (Plate 4.9). Female length was 1± 0.14 mm and breadth is 0.72±0.05 mm and male 3rd instar nymph was 0.85± 0.02 mm long and 0.41±.02 mm wide (Table 3). Miller and Miller (2002), reported that the 3rd instar female was yellowish color and male was pink color which is confirmed the present study. They also reported that 3rd instar female length and breadth was 1.1 mm and 0.7 mm and male was 0.9 mm and 0.4 mm which is similar to the present

result. Studies made by Chellappan *et al.* (2006) observed that 3rd instar female and male average duration were 5.1±0.32 days and 2.6±0.52 days confirmed the present study. Al-hilal *et al.* (2012) observed the length of third instar nymph was 0.89±0.11 mm and it was 0.12±0.51 mm in width. Body appears yellow in color during field observation. Length of third instar male nymph was 1.05±0.23 mm and 0.156±0.59 mm in width. Body looks like yellow in color during field observation. This is result somewhat different from the present result and this might be due to the environmental condition or host species. The period of third instar nymph was 5.00±1.00 days and this finding is higher than the present study. This variation might be due to the environmental condition or host species (Suganthy *et al*., 2011).

Table 3: Measurement of different stages of *Paracoccus marginatus*

Stage	**Length (mm) Average ±SD**	**Breadth (mm) Average ±SD**
Egg	0.35±0.03	0.14±0.01
1st instar (gender not identified)	0.41±0.08	0.25±0.03
2nd instar female	0.69±0.03	0.44±0.02
3rd instar female	1± 0.14	0.72±0.05
Adult female	1.94±0.27	1.38±0.05
2nd instar male	0.7±0.06	0.38±0.04
3rd instar male	0.85±0.02	0.41±.02
Pupa	0.94±.04	0.26±0.03
Adult male	0.98±.03	0.26±0.01

4.1.3.4. 4th instar nymph

The 4th instar nymph occurred only in case of male *P. marginatus*. It is the pupal stage. The duration of this stage is 3-4 days (Table 2). The length of pupa was 0.94 ±.04 mm and breadth was 0.26±.03 mm (Table 3). Pupal stage occurred in a cocoon. The cocoon was made of whitish cotton like thread. The color of pupa was pink (Plate 4.10). The pupa was pink color and length and breadth of pupa was 1.0 mm and 0.03 mm which is accordance with the present result (Miller and Miller, 2002). Average duration of pupa was 4.2±0.63 days were almost similar to that determined by (Chellappan *et al.*, 2006). Al-hilal *et al.* (2012) observed that the length of fourth instar nymph was 0.98±0.075 mm and 0.02±0.49 mm in width. Body color appeared pink but occasionally yellowish. Only width is different from the present result but length and color shows similar result as present study.

4.1.3.5 Adult female

Body is yellowish color, dusted with mealy wax not thick enough to hide body color, (Plate 4.11) without discrete bare areas on dorsum, with many short waxy filaments around body margin. Body was 1.94±0.27 mm long and 1.38±0.05 mm wide (Table 3). The antennal segment of this adult female was 8. The average duration of adult female was 8-13 days (Table 2). The adult female was yellow color and 2.2 mm long and 1.4 mm wide which are close to the present findings (Miller and Miller, 2002). Chellappan*et al.* (2006) studied that the average duration of adult female was 17.6 ± 0.84 days somewhat different to the present result. The length of adult female was 2.08±0.354 mm and it was 1± 0.063 mm in width. Body is yellow in color during field observation. The length of this finding is close to the present finding but the width is less than the present finding (Al-hilal *et al.*, 2012). Suganthy *et al.* (2011) reported adult longevity of females was 20.33±1.53 days which is higher than the present finding. This variation might be due to the environmental condition or host species.

Plate 4.11 Adult female (60X)

Plate 4.12 Adult Male (90X)

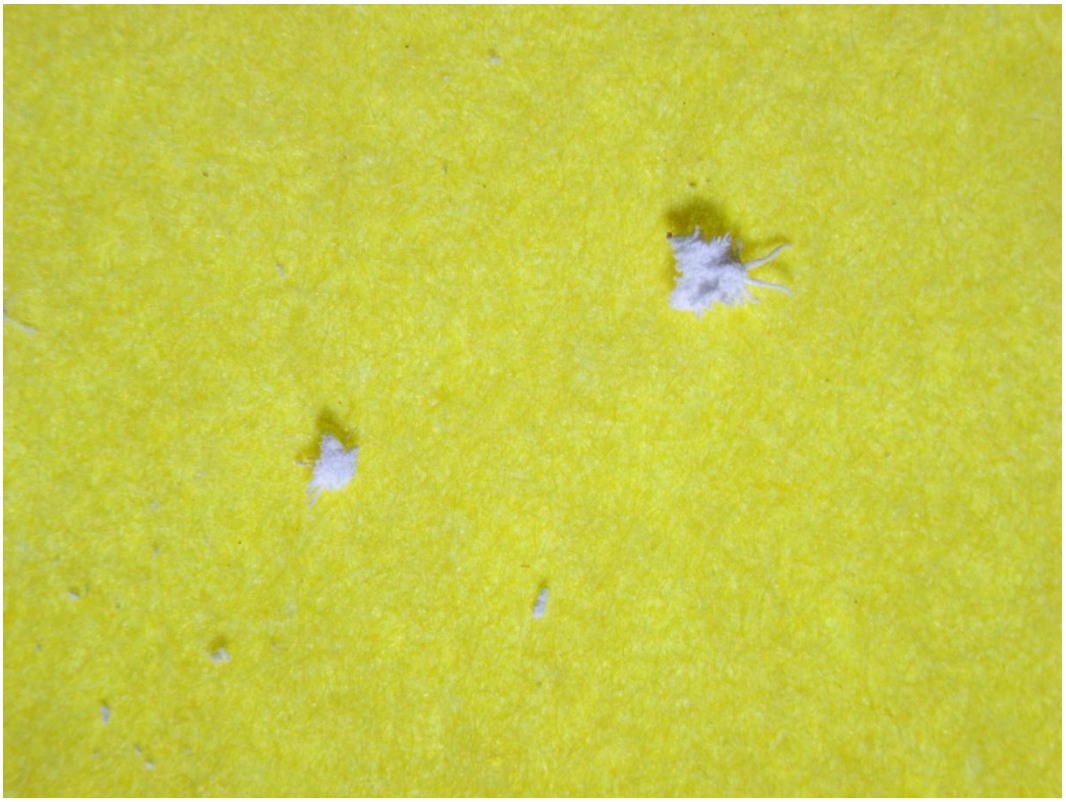

Plate 4.13 Casted exuviae (60X)

4.1.3.6 Adult male

Adult male was winged (Plate 4.12). Antennae 10 segmented. The length of the adult male was 0.98 ±0.03 mm and the breadth 0.26±0.01 mm (Table 3). The wings are white color. The longevity of adult male was 2-3 days (Table 2).

Miller and Miller (2002), reported that the adult male was winged and length and breadth of male was 1.0 mm and 0.03 mm which is close to the present findings. Chellappan *et al.* (2006) observed that the average duration of adult male was 2.7±0.48 days which are accordance with the present result. The length of adult male was 1.5 mm and 0.5 mm in width. Body color appeared pink, but occasionally yellowish, these findings different from the present findings. This variation might be due to the environmental condition or host species (Al-hilal *et al.*, 2012). Suganthy *et al.* (2011) reported adult longevity of males was 1.67±1.15 days and this finding is close to the present study.

4.2 Damage Assessment of papaya field after infestation papaya mealybug

4.2.1 Plant Height

The result indicated that papaya plant height increased progressively with the advancement of time and growth stages. At early stage, average plant height was 49.6 cm in T_1 and 23.80 cm in T_2. At middle stage, T_1 showed 83.6 cm per plant and T_2 showed 48.20 cm per plant. At later stage, average height of T_1 per plant was 114.70 cm and average height of T_2 per plant was 75.30 cm. The result indicated that T_1 showed the higher plant height and T_2 became stunted. This result indicate that in early, mid and late stage plant height reduced 52.01%, 42.6%, 34.35% respectively due to infestation of papaya mealybug (Fig: 4.5).

Table 4: Average plant height

Treatment	Number of observation	Stage	Height (cm)	Standard deviation	Standard error
T_1	10	Early	49.60	4.05	1.28
	10	Mid	83.60	4.97	1.57
	10	Late	114.70	11.64	3.68
T_2	10	Early	23.80	2.34	0.74
	10	Mid	48.20	2.69	0.85
	10	Late	75.30	7.49	2.37

[T_1= Papaya plant are covered with fine net and imidacloprid (Admire) 200 SL @ 1 ml/L of water sprayed at 15 days interval,

T_2 = Artificial infestation of papaya mealybug on papaya plant (100 nymph of papaya mealybug were released per plant)]

Plate 4.14 Managed papaya plant

Plate 4.15 Infested papaya plant

4.2.2. Leaf number

In early stage in case of T_1 plant leaf number was 10.5 and in case of T_2 plant which was infested with mealybug showed lower number of leaf that is 3.2. In mid stage T_1 plant leaf number was increasing that was 21 rapidly but T_2 plant showed very poor number of leaf that was 2.8. In late stage T_1 plant also showed leaf number increasing that was 23 on the other hand leaf number of T_2 plant was 3.1 which was very lower than that of T_1 plant. This result indicated that in early, mid and late stage leaf number reduced 69.5%, 86.6%, 86.08% respectively due to infestation of papaya mealybug (Fig: 4.5).

Table 5: Average leaf number per plant.

Treatment	**Number of observation**	**Stage**	**Leaf number**	**Standard deviation**	**Standard error**
T_1	10	Early	10.50	1.58	0.50
	10	Mid	21.00	3.91	1.23
	10	Late	23.10	6.36	2.01
T_2	10	Early	3.20	1.47	0.46
	10	Mid	2.80	1.22	0.38
	10	Late	3.10	1.44	0.45

[T_1= Papaya plant are covered with fine net and imidacloprid (Admire) 200 SL @ 1 ml/L of water sprayed at 15 days interval,

T_2 = Artificial infestation of papaya mealybug on papaya plant (100 nymph of papaya mealybug were released per plant)]

4.2.3. Petiole Length

At early stage, average petiole lengthofT_1 was 16.65 cm and the average petiole length of T_2 was 7.52 cm. At middle stage, petiole length in T_1 was 35.85 cm and 15.17 cm in T_2. At later stage, average petiole length of T_1 was 55.61 cm and average petiole length of T_2 was 25.96 cm. The result indicated that T_1 showed longer petiole length than T_2. This result indicated that in early, mid and late stage petiole length reduced 54.83%, 57.68%, 53.31% respectively due to infestation of papaya mealybug (Fig: 4.5).

Table 6: Average petiole length per plant.

Treatment	**Number of observation**	**Stage**	**Petiole length (cm)**	**Standard deviation**	**Standard error**
T_1	10	Early	16.65	2.43	0.77
	10	Mid	35.85	5.18	1.63
	10	Late	55.61	9.28	2.93
T_2	10	Early	7.52	1.29	0.41
	10	Mid	15.17	2.21	0.69
	10	Late	25.96	5.42	1.72

[T_1= Papaya plant are covered with fine net and imidacloprid (Admire) 200 SL @ 1 ml/L of water sprayed at 15 days interval,

T_2 = Artificial infestation of papaya mealybug on papaya plant (100 nymph of papaya mealybug were released per plant)]

4.2.4. Flowers Number

Number of flowers in T_1 was 13.80 but T_2 showed very lower number of flowers. Average flowers number for T_2 was 1.90. This result indicated that at reproductive stage flowers number reduced 86.23% due to infestation of papaya mealybug (Fig: 4.5).

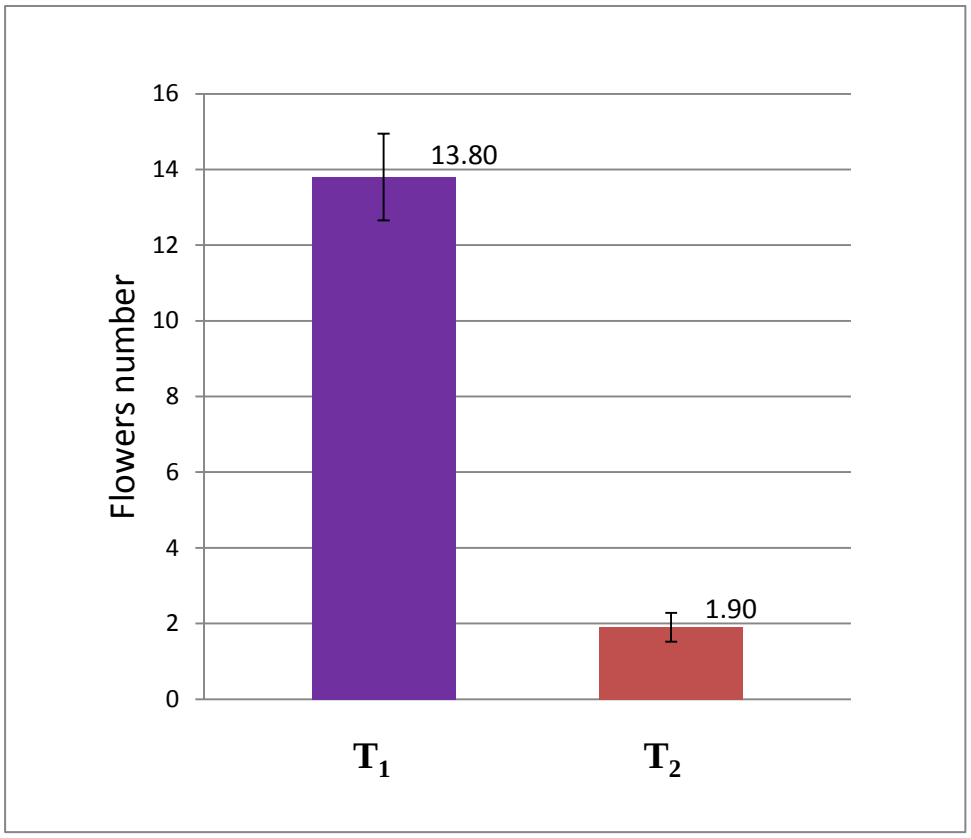

Fig: 4.1 Average numbers of flowers per plant**.**

[T_1= Papaya plant are covered with fine net and imidacloprid (Admire) 200 SL @ 1 ml/L of water sprayed at 15 days interval,

T_2 = Artificial infestation of papaya mealybug on papaya plant (100 nymph of papaya mealybug were released per plant)]

Plate 4.16 Flowers of managed plant.

Plate 4.17 Flowers of infested plant.

4.2.5. Fruit Number

In case of T_1 average number of fruits per plant recorded was 12.30. On the other hand the average number of fruits in T_2 recorded was 1.30. This result indicated that in reproductive stage fruit number reduced 89.43% due to infestation of papaya mealybug (Fig: 4.5)

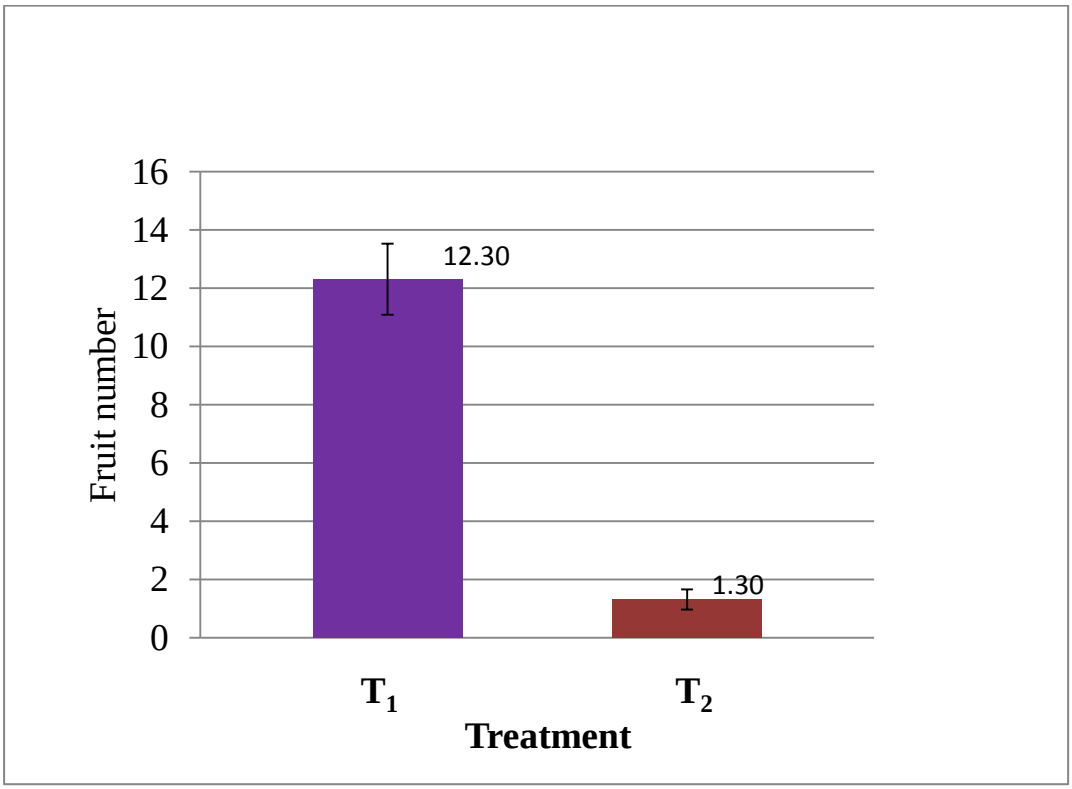

Fig: 4.2 Average numbers of fruits per plant.

[T_1= Papaya plant are covered with fine net and imidacloprid (Admire) 200 SL @ 1 ml/L of water sprayed at 15 days interval,

T_2 = Artificial infestation of papaya mealybug on papaya plant (100 nymph of papaya mealybug were released per plant)]

Plate 4.18 Fruits of managed plant.

Plate 4.19 Fruits of infested plant.

4.2.6. Average Fruit Weight

Average weight of fruit in T_1 was 559.7 g on the contrary average weight fruit was 67.1 g in T_2. This result indicated that in fruit weight reduced 89.43% due to infestation of papaya mealybug (Fig: 4.5)

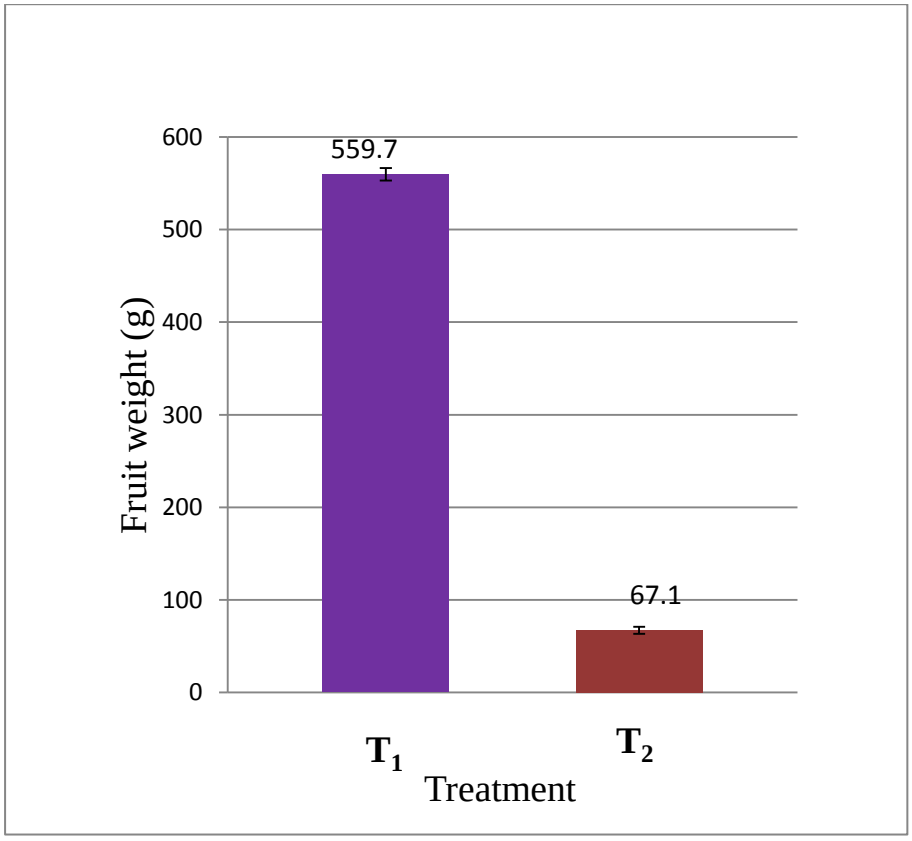

Fig: 4.3 Average weights of individual fruit per plant.

[T_1= Papaya plant are covered with fine net and imidacloprid (Admire) 200 SL @ 1 ml/L of water sprayed at 15 days interval,

T_2 = Artificial infestation of papaya mealybug on papaya plant (100 nymph of papaya mealybug were released per plant)]

4.2.7. Total fruit yield per plant

Total fruit yield per plant in T_1 was 6.88 kg on the contrary total fruit yield 0.087 kg in T_2. This result indicated that total fruit yield per plant reduced 98% due to infestation of papaya mealybug (Fig: 4.5).

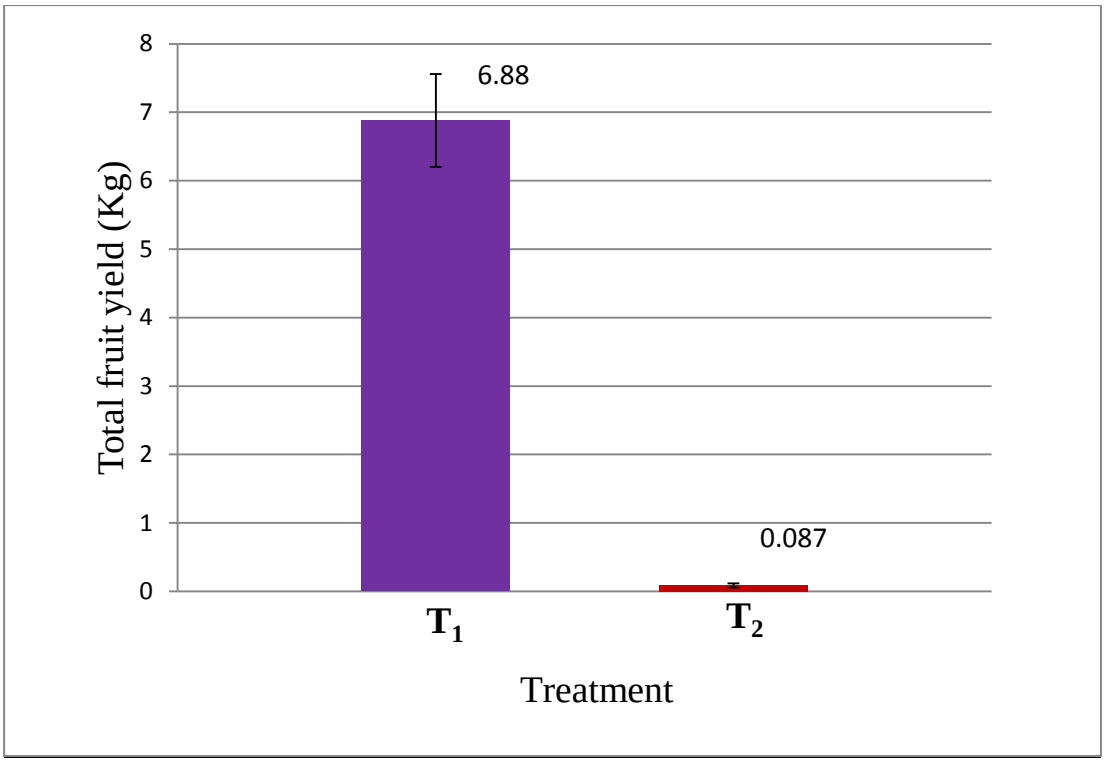

Fig: 4.4 Total fruit yield per plant.

[T_1= Papaya plant are covered with fine net and imidacloprid (Admire) 200 SL @ 1 ml/L of water sprayed at 15 days interval,

T_2 = Artificial infestation of papaya mealybug on papaya plant (100 nymph of papaya mealybug were released per plant)]

4.2.8 Percent reduction of flowers, fruits, weight of individual fruit, total fruit yield per plant by mealybug

Due to infestation of mealybug, number flowers, number of fruits, weight of individual fruit, fruit yield were reduced into 86.23%, 89.43%, 88.01% and 98% respectively per plant.

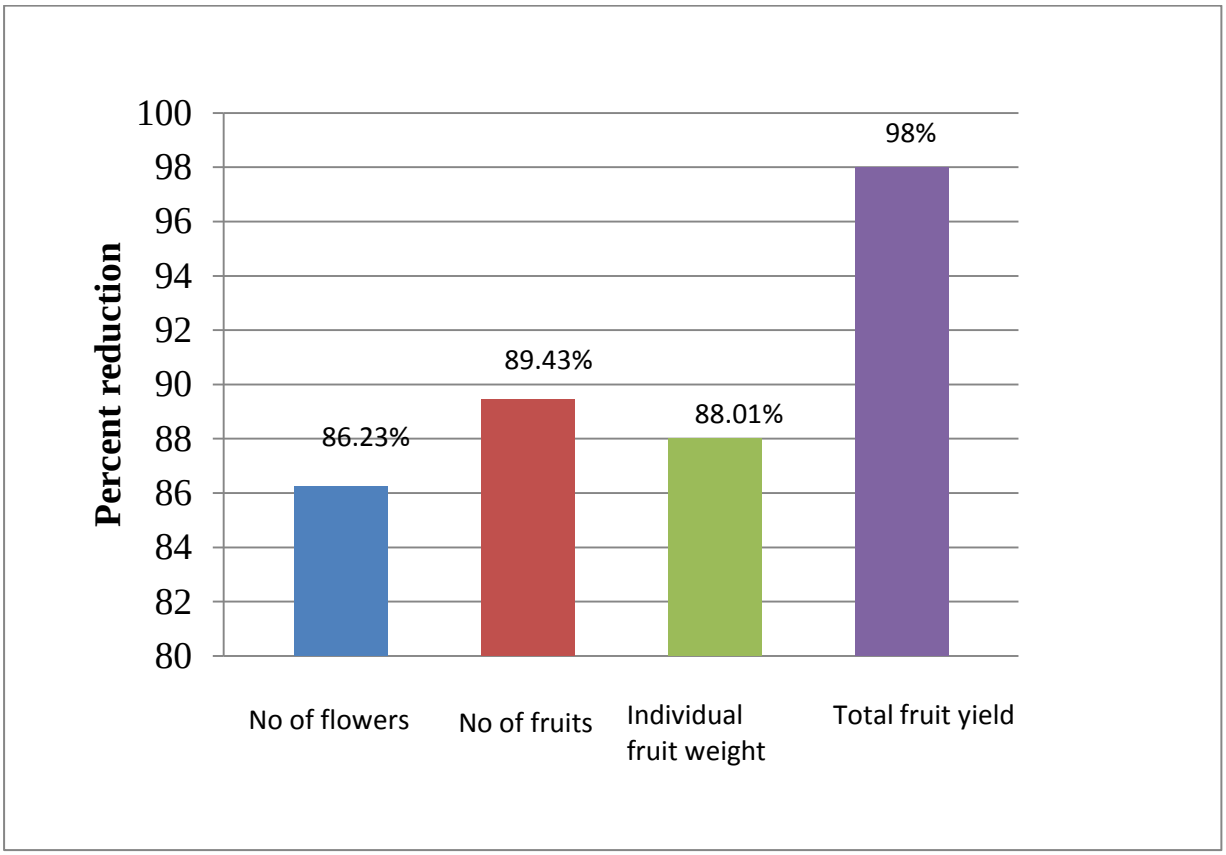

Fig: 4.5 Percent reduction of number flowers, number of fruits, weight of individual fruit, total fruit yield per plant by mealybug.

CHAPTER V

SUMMARY AND CONCLUSION

The experiment was conducted in the Entomology lab of Sher-e-bangla Agricultural university and Farm of Sher-e-Bangla Agricultural University and, Sher-e-Bangla Nagar, Dhaka during the period from June, 2017 to august, 2018 to study the biology and damage assessment of papaya mealybug (*P. marginatus*).

In the entomology lab, the biology of papaya mealybug was studied. In this experiment the characteristics of eggs, nymph, pupae and adult were studied. During oviposition period a female mealybug laid on an average of 97-150 eggs in a whitish cottony egg sack. Eggs were yellowish color and oval shaped. The average length and breadth of the eggs were 0.34 mm and 0.15 mm. The average incubation period of the eggs was 4-7 days. Females have three instars nymph and males have four instars nymph. Newly hatched nymphs were very minute and yellowish color and at this stage male female cannot be distinguished. The average length and breadth of 1st instar nymph was 0.41±0.3 mm, and 0.25±0.03 mm. The average duration of 1st instar nymph was 4-6 days. The 2nd instar and third instar female nymph was yellowish color and male was pink color. 2nd instar female nymph average length was 0.69±0.03 mm and breadth 0.44±0.02 mm and the 2nd instar male nymph was 0.70±0.06 mm long and 0.38 ±0.04 mm wide. Average duration of 2nd instar female nymph was 3-5 days and the 2nd instar male nymph was 3-4 days. The 3rd instar female nymph average length was 1±0.14 mm and breadth was 0.72±0.05 mm and duration was 3-4 days. The 3rd instar male nymph average length and breadth was 0.85±0.02 mm and 0.41 ±0.02 mm. The

average duration of 3rd instar male nymph was 2-4 days. The 4th instar male was the pupal stage the average duration of this stage was 3-4 days. The average length of 4th instar nymph was 0.94 ±0.04 mm and breadth was 0.26±0.03 mm. 4th instar nymph is also pink in color. Pupal stage is occurred in a cocoon. The cocoon was made of whitish cotton like thread. Adult female is yellowish color, dusted with mealy wax with many short waxy filaments around body margin. The adult female average length was 1.94±0.27 mm and breadth was 1.38±0.05 mm. The average duration of adult female was 8-13 days. The length of the adult male was 0.98±0.03 mm and the breadth 0.26±0.01 mm. The average longevity of adult male was 2-3 days.

Damage assessment of papaya mealybug was studied in Farm of Sher-e-Bangla Agricultural University. In this experiment two treatments were considered. Here T_1 is treated with fine net and imidacloprid and T_2 was infested by the papaya mealybug. In early, mid and late stage plant height was 49.6 cm, 83.6 cm and 114.70 cm respectively in T_1 and 23.80 cm, 48.20 cm and 75.30 cm respectively in T_2. Due to infestation of papaya mealybug plant height was reduced to 52.01%, 42.6%, and 34.35% respectively. Similarly leaf number in early, mid and late stage was 10.5, 21 and 23 respectively in T_1 and 3.20, 2.80 and 3.10 respectively in T_2. Leaf number was reduced to 69.5%, 86.6%, and 86.08% due to the infestation of mealybug. In early, mid and late stage petiole length was 16.65 cm, 35.85 cm and 55.61 cm respectively in T_1 and 7.52 cm, 15.17 cm and 25.96 cm in T_2 and 54.83%, 57.68%, 53.31% respectively reduced in early, mid and late stage due to infestation of papaya mealybug. In reproductive stage flowers number was 13.80 in T_1 and 1.90 in T_2 and fruit number was 12.30 in T_1 and 1.30 in T_2. Flowers number and fruits number were reduced to 86.23% and 89.43% respectively due

to infestation of papaya mealybug. Fruit weight was 559.7 g in T_1 and 67.1 g in T_2 and weight also reduced to 89.43% due to infestation of papaya mealybug. Total fruit yield per plant was 6.88 kg in T_1 and 0.087 kg in $T_{2.}$ Total fruit yield reduction percentage was 98%. This experiment revealed that due to infestation of papaya mealybug field was severely damaged thus it caused great losses in production.

Recommendations:

Considering the situation of the present experiment, further studies in the following areas may be conducted:

1. Biology of the papaya mealybug may be studied in the growth chamber in control environment.
2. Damage assessment may be studied in farmer's field.

CHAPTER VI

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APPENDICES

Appendix I: Results of data analysis of different parameters such as flowers number, fruit number and fruit weight.

Flowers number per plant

Treatment	Flowers number	Number of observation	SD	SE
T_1	13.80	10	3.61	1.14
T_2	1.90	10	1.19	0.37

Fruits number per plant

Treatment	Fruits number	Number of observation	SD	SE
T_1	12.30	10	4.38	1.21
T_2	1.30	10	1.25	0.34

Individal Fruit weight

Treatment	Fruit weight	Number of observation	SD	SE
T1	559.7	10	21.52	6.80
T2	67.1	10	12.16	3.84

AppendixII: Results of morphological, mechanical and chemical analysis of soil of the experimental plot

Morphological Characteristics

Morphological features	Characteristics
Location	Agronomy Farm, SAU, Dhaka
AEZ	Modhupur Tract (28)
General Soil Type	Shallow redbrown terrace soil
Land Type	Medium high land
Soil Series	Tejgaon
Topography	Fairly leveled
Flood Level	Above flood level
Drainage	Well drained

Mechanical analysis

Constituents	Percentage (%)
Sand	28.78
Silt	42.12
Clay	29.1

Chemical analysis

Soil properties	Amount
Soil pH	5.8
Organic carbon (%)	0.95
Organic matter (%)	0.77
Total nitrogen (%)	0.075
Available P (ppm)	15.07
Exchangeable K (%)	0.32
Available S (ppm)	16.17

Source: Soil Resource Development Institute (SRDI)