SEASONAL ABUNDANCE, INFESTATION INTENSITY OF PAPAYA MEALYBUG IN DHAKA AND ITS CHEMICAL CONTROL

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This is to certify that thesis entitled, "SEASONAL ABUNDANCE, INFESTATION INTENSITY OF PAPAYA MEALYBUG IN DHAKA AND ITS CHEMICAL CONTROL" submitted to the Faculty of Agriculture, 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 NUSHRAT JAHAN DIGONTY bearing Registration No. 18-09026 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, as has been availed of during the course of this investigation has duly been acknowledged.

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Dedicated To
My BelovedParents

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SEASONAL ABUNDANCE, INFESTATION INTENSITY OF PAPAYA MEALYBUG IN DHAKA AND ITS CHEMICAL CONTROL

ABSTRACT

The survey was conducted in five locations (Agargaon, Sher-e-Bangla Agricultural University, Mirpur-1, Mirpur-2 and Kallyanpur) of Dhaka, Bangladesh and the experiment was conducted at the laboratory and field of SAU during the period from February, 2019 to December, 2019 to study the seasonal abundance, infestation intensity of papaya mealybug and its chemical control. Highest leaf infestation (48.10 %) and highest branch infestation (61.29 %) were found in SAU. Highest stem infestation (83.33 %) was found in Mirpur-2 and Mirpur-1 had moderate twig infestation (63.33 %) but highest inflorescence infestation was 84.85 %. Highest fruit infestation (75.00 %) was found in Kallyanpur. It was observed that the infestation was highest during March in all the locations. The infestation decreased during the month of November in all the locations. Regarding chemical control the experiment consisted of seven chemical insecticides treatments tested against papaya mealybug both in laboratory and field viz. T_1 = Abamectin 1.8 EC, T_2 = Chlorpyrifos (Dursban Pro), T_3 = Dimethoate 30 EC, T_4 = Imidacloprid 200 SL, T_5 = Fipronil (Regent), T_6 = Spinosad 2.5 SC and T_7 = Bioneem Plus (Azadiractin). Among all the applied chemical insecticides Fipronil showed the best performance on control of the mealybug of papaya in laboratory and Bioneem Plus showed the best performance in both laboratory and field. In laboratory after 72 hr of spray, highest mortality was found in spraying of Fipronil (99.50 %) which was statistically similar to Bioneem Plus (99.50 %), Imidacloprid (98.50 %) and Spinosad (97.50 %). Lowest mortality was found in spraying of Abamectin (95.50 %) which was similar to spraying of Chlorpyrifos (95.50%). In field at seedling stage of papaya plant after 72 hr of spray, highest mortality was found in spraying of Bioneem Plus (94.92 %) which was statistically similar to Fipronil (94.83 %) and Imidacloprid (93.68 %). Lowest mortality was found in spraying of Abamectin (86.67 %). In field at mature stage of papaya plant after 72 hr of spray, highest mortality was found in spraying of Bioneem Plus (90.91 %) which was statistically similar to Abamectin (88.77 %), Spinosad (88.33 %) and Imidacloprid (87.60 %). Lowest mortality was found in spraying of Fipronil (84.18 %). Similar trend was observed after 24 hr of spray at mature stage of papaya plant but after 72 hr of spray Bioneem Plus gave the best result. No relation was observed in the infestation of leaf, branch, stem, twig, inflorescence and fruit at different locations.

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LIST OF ABBREVIATIONS AND ACRONYMS

AEZ	=	Agro-Ecological Zone
BARI	=	Bangladesh Agricultural Research Institute
BBS	=	Bangladesh Bureau of Statistics
ppm	=	Parts per million
et al.	=	And others
N	=	Nitrogen
TSP	=	Triple Super Phosphate
MP	=	Muriate of Potash
RCBD	=	Randomized complete block design
ha^{-1}	=	Per hectare
G	=	gram (s)
Kg	=	Kilogram
µg	=	Micro gram
SAU	=	Sher-e-Bangla Agricultural University
SRDI	=	Soil Resources and Development Institute
No.	=	Number
Wt.	=	Weight
LSD	=	Least Significant Difference
^0C	=	Degree Celsius
mm	=	millimeter
Max	=	Maximum
Min	=	Minimum
%	=	Percent
cv.	=	Cultivar
NPK	=	Nitrogen, Phosphorus and Potassium
CV%	=	Percentage of coefficient of variance
Hrs	=	Hours
T	=	Ton
viz.	=	Videlicet (namely)

CHAPTER I

INTRODUCTION

The papaya (*Carica papaya* L.) is one of the important, delicious and popular fruit crops grown throughout Bangladesh. It is originated in Mexico and spread to almost all the corners of the tropical and subtropical parts of the world. It is a short duration and year round fruit in Bangladesh. It is usually cultivated in homestead area but presently farmers commercially cultivate in different regions of Bangladesh. As a raw fruit, it is popularly used as vegetable in cooking and some preparations. Papaya fruit is a rich source of vitamins, minerals and enzymes. The papaya is an amazingly rich source of the proteolytic enzymes. These are the chemicals that enable the digestion of protein. Papain, which is the most important of these enzymes in the papaya, is extracted and dried as a powder for use to aid the digestion and it is often used as a meat tenderizer, the enzyme partially breaking down the meat fibers.

In recent years, the production of papaya is greatly hindered by a nuisance insect pest, papaya mealybug in Bangladesh. Recently the papaya mealybug caused heavy infestation and reduced yield of papaya and devastated the crop throughout the country.

The papaya mealybug, *Paracoccus marginatus* is a hemipteran insect and belongs to the family Pseudococcidae. It is polyphagous (Miller and Miller, 2002) in nature and sucks the sap from different parts of the plant. All infested plant parts become crinkled , yellowish, wither and dropped from the plants. The mealybug also injects a toxin as it feeds on leaves and fruits which results in chlorosis (yellowing), stunting, deformation. The honey dew excreted by the bug is a good growing media of a sooty mold which impairs photosynthetic efficiency of the affected plants. Heavily attacked plants were killed (Walker *et al*., 2003; Hue *et al*., 2007). Mealybug also transmits viruses to the plant.

It is a noxious insect pest attacking papaya and other agricultural plants of economic importance (Miller & Miller, 2002). It assumed the status of a major pest in India in 2009 when it caused severe damage to economically important crops and huge losses to farmers in Coimbatore, Europe, Tiruppur and Salem districts of Tamil Nadu (Tanwar *et al*., 2010).

Papaya mealybug is an alien pest in Bangladesh. It was first observed in Bangladesh in 2006 (Muniappen *et al.,* 2006). No intensive work has been found regarding this pest in Bangladesh. Miller and Miller (2002) listed 35 plant species as host plants for *P. marginatus*. Whereas Meyerdirk *et al*. (2004) reported that papaya mealybug has a wide host range of over 60 species of plants including economically important plants and heavy infestations on papaya in Guam in 2002.

The papaya mealybug is a polyphagous pest and its host range includes more than 60 species of plants including papaya, hibiscus, avocado, citrus, cotton, tomato, eggplant, peppers, beans, peas, sweet potato, mango, cherry and pomegranate. In Sri Lanka, *P. marginatus* was said to be reported in about 30 families of host plants. However, papaya had been observed as the most preferred host while Manioc (*M. utilissima*) and temple trees (*Plumeria acuminata*) as the next preferred (Muniappen *et al.,* 2009; Thangamalar *et al.,* 2010).

The infestation of papaya mealybug appears on above ground parts on leaves, stems and fruits as clusters of cotton-like masses. Both nymph and adult of mealybug suck 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 (Meyerdirk *et al.,* 2004; Muniappen *et al.,* 2009; and Tanwar *et al.,* 2010).

Effect of temperature on the life history of the mealybug, *P. marginatus* was investigated in the laboratory. *P. marginatus* developed and completed its life cycle at 18, 20, 25 and 30 ± 1^0 C. Females passed through three instars whereas males had four instars. Males have longer developmental time (27-30 days) than those of females (24-26 days) at 25 ± 1^0 C, 65 ± 2% RH and 12 : 12 (L:D) Photoperiod (Tanwar *et al.,* 2010). Temperature showed significant influence on the reproduction and multiplication of this mealybug. It also had pronounced effect on the seasonal abundance of the pest. The fluctuation and seasonal abundance of *P. marginatus* is presented. According to the estimated minimum temperature thresholds for the adult males and females were 14.5 and 13.9^{o}C respectively. For adult males, the estimated optimum and maximum temperature thresholds were 28.7 and 31.9^{o}C and for adult females, they were 28.4 and 32.1^{o}C, respectively. The ability of *P. marginatus* to develop, survive and reproduce successfully between 18 and 30^{o}C suggests that it has the capability to develop and establish in areas within this temperature range. With rapid development, high survival rate and enormous reproductive capacity, *P. marginatus* population could potentially reach a high level. Thus, temperature and humidity (65-70% R.H.) it fovoured the seasonal abundance and reproductive potential of *P. marginatus.* Papaya mealybugs are most active in warm and dry weather. The wax, which sticks to each ovisac and nymphs, also facilitate passive dispersal by equipments, animals or human beings. The female mealybug is not active and unable to fly. In fact, human beings greatly facilitate in the transport of these mealybugs. Long-distance movement is aided through transport of infested planting material and fresh fruits and vegetables from one end of a farm to the other or even across the country.

Control 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. For control of mealybugs, it is important to know the species present as control programs for the various mealybugs may differ. Control of mealybug involves monitoring and scouting to detect early presence of the mealybug, pruning of infested branches and burning them, removal and burning of crop residues, avoiding the movement of planting material from infested areas to other areas, control of ant, etc. Moreover, biological control agents like lady bird beetles, lace wings, hoverflies play an important role in reducing the population of mealybugs (Meyerdirk, 2001; Muniappen *et al.* 2006; Tanwar *et al*. 2010).

Within a short period of time, the newly introduced papaya mealybug spreads out many parts of Bangladesh and emerges as a major threat to papaya along with different crops (Karim *et al*. 2011). Papaya mealybug is a major insect pest in our country and comprehensive research on papaya mealybug has not yet been undertaken in Bangladesh. So it is justifiable to undertake a research on the seasonal abundance, infestation intensity and chemical control of this pest.

Objectives

Keeping the above points in view, present work was designed with the following objectives:

- To study the seasonal abundance and infestation level of papaya mealybug in Dhaka.
- To know the efficiency of different chemicals against papaya mealybug.

CHAPTER II

REVIEW OF LITERATURE

2.1 Bioecology of papaya mealybug

2.1.1 Taxonomy

Paracoccus marginatus probably originated in Central America. It was not recorded in the Caribbean islands before 1994, but has been extending its range in the region ever since. It was first recorded in the USA (Florida) in 1998 (Miller *et al.*, 1999), and has been extending its range ever since, now reaching countries as far as 30º north or south of the equator on all the major continents in the tropics. Its distribution will probably be limited by its cold tolerance (Mendel *et al.*, 2016; García Morales *et al.*, 2019), but as the planet warms, it is likely that *P. marginatus* will extend its range to countries further away from the equator.

2.1.2 Systematic position

Kingdom: Animalia
Phylum: Arthropoda
Subphylum: Uniramia
Class: Hexapoda
Order: Hemiptera
Suborder: Sternorrhyncha
Super family: Coccoidea
Family: Pseudococcidae
Genus: *Paracoccus*
Species: *Paracoccus marginatus*

2.1.3 Distribution

The papaya mealybug, *Paracoccus marginatus* is a hemipteran insect belonging to the family Pseudococcidae. The first specimen of this devastating mealybug was collected in Mexico during 1955. It was described in 1992 in the Neotropical region occupying Belize, Costa Rica, Guatemala, and Mexico (Williams and Willink, 1992).

Walker *et al.* (2003) stated that *Paracoccus marginatus* was recorded in the following 14 Caribbean countries i.e. St Martin, Guadeloupe, St Barthelme, Antigua, Bahamas, British Virgin Island, Cuba, Dominican Republic, Haiti, Puerto Rico, Montserrat, Nevis, St Kitts and the U.S. Virgin Islands since 1994.

Muniappan *et al.* (2009) first reported the papaya mealybug *Paracoccus marginatus* in Indonesia (Java) and India (Tamil Nadu). He also worked on the incidence and damage potential of this noxious pest.

The papaya mealybug is believed to be native to Mexico and/or Central America. It has never gained status as a serious pest there, probably due to the presence of an endemic natural enemy complex. 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 Willink, 1992). When the papaya mealybug invaded the Caribbean region, it became a pest there; since 1994 it has been recorded in the following 14 Caribbean countries: St. Martin, Guadeloupe, St. Barthelme, Antigua, Bahamas, British Virgin Islands, Cuba, Dominican Republic, Haiti, Puerto Rico, Montserrat, Nevis, St. Kitts, and the U.S. Virgin Islands. More recently, specimens have turned up in the Pacific regions of Guam and the Republic of Palau.

Specimens also have been intercepted in Texas and California, and it is expected that papaya mealybug could rapidly establish throughout Florida and through the Gulf states to California. It is possible that certain greenhouse crops could be at risk in areas as far north as Delaware, New Jersey and Maryland. It has already been identified on papaya plants in the Garfield Conservatory in Chicago, Illinois in late August of 2001. A biological control program was implemented in December of 2001 with very successful results.

2.1.4 Biology

Details on the biology and life cycle of the papaya mealybug are lacking. In general, mealybugs have piercing-sucking mouthparts and feed by inserting their mouthparts into plant tissue and sucking out sap. Mealybugs are most active in warm and 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 in an ovisac, although some species of mealybugs give birth to live young. Egg-laying usually occurs over the period of one to two weeks. Egg hatch occurs in about 10 days, and nymphs, or crawlers, begin to actively search for feeding sites. Female crawlers have four instars, with a generation taking approximately one month to complete, depending on the temperature. Males have five instars, the fourth of which is produced in a cocoon and referred to as the pupa. The fifth instar of the male is the only winged form of the species capable of flight. Adult females attract the males with sex pheromones. Under greenhouse conditions, reproduction occurs throughout the year, and in certain species may occur without fertilization.

According to Walker *et al.* (2003) Papaya mealybug infestations are typically observed as clusters of cotton-like masses on the above ground portions of plant, the adult female is yellow and covered with a white waxy coating. Adult females are approximately 2.2 mm long (1/16 inch) and 1.4 mm wide. A series of short waxy caudal filaments less than $1/4^{th}$ the length of the body exist around the margin. Adult males are approximately 1.0 mm long, with an elongate-oval body which is widest at the thorax (0.30mm). Adult males have ten segmented antennae and well developed wings.

Tanwar *et al.* (2010) worked on the incidence and damaging value of papaya mealybug and its management strategies. Papaya mealybug is most active in warm and temperature weather. An individual female usually deposits 100 to 600 eggs. Eggs are greenish yellow and are laid in an ovisac which is about three to four times the body length and entirely covered with white wax. Eggs generally hatch at nearly 10 days and nymph or crawlers pass their times in search of feeding locations. Males have longer developmental time (27-30 days) than females (24-26 days) at 25± 1°C 65±2% RH and 12:12 (L:D) photoperiod.

Aitken (1984) described papaya mealybug (*P. marginatus*), as an invasive pest from Central American countries. This mealybug has caused havoc in agricultural and horticultural crops in India ever since its first report from Coimbatore during 2007. The authors have reported that the adult females of *P. marginatus* laid eggs (approximately about 150 to 200 eggs) inside the egg-sacs. Eggs are pink colored, grain like measuring 0.120 cm in diameter.

Indra *et al.* (2008) carried out research work on *P. marginatus*. The female mealybug usually laid up to 600 eggs enclosed in an ovisac. *P. marginatus* was observed to complete the life cycle on papaya (*Carica papaya* L.) in 26 days and the life cycle was found to vary from 15 days to 32 days depending on the host plant species. It has the ability to develop, survive, and reproduce successfully between 18 to 30 °C which suggests that it has the ability to develop and establish in areas within these temperature range.

2.1.5 Host plants

The papaya mealybug is polyphagous and has been recorded on >55 host plants in more than 25 genera. Economically important host plants of the papaya mealybug include papaya, hibiscus, avocado, citrus, cotton, tomato, eggplant, peppers, beans and peas, sweet potato, mango, cherry, and pomegranate (Walker *et al.*, 2003). The main host is papaw (Williams and Willink, 1992).

Miller and Miller (2002) worked on the incidence and developmental stage of *P. marginatus* in different host plants in USA. The genus *Paracoccus* includes some 79 species of varied distribution from the "Austro-Oriental, Ethiopian, Madagascan, NeoArctic, Neotropical, Newzealand, Pacific, Palearctic and oriental regions" (Ben Dov, 1994). Although most assigned species have not been recognized as major economic pest there are two notable exceptions. *P. marginatus* is a polyphagous insect; it has recorded on about 55 host plants in more than 25 general.

Food is a component of the environment and may influence an animal's chance to survive and multiply by modifying its fecundity, longevity or speed of development (Andrewartha and Birch, 1954). The economically important host range of the papaya mealybug includes papaya, hibiscus, acalypha, plumeria, avocado, citrus, cotton, tomato, eggplant, pepper, beans and peas, sweet potato, mango, cherry and pomegranate (Miller and Miller, 2002). In addition, weed species such as *Parthenium hysterophorus* L. are also recorded as host plants of papaya mealybug (Miller and Miller, 2002). Infestations of papaya mealybug have been observed on papaya, plumeria, hibiscus and jatropha in Hawaii with the favored hosts appearing to be papaya, plumeria, and hibiscus (Heu *et al*., 2007).

However, insects may settle, lay eggs, and severely damage plant species that are unsuitable for development of immature (Harris, 1990). There is no specific information about the life history of papaya mealybug on different host plant species. Although, papaya is the dominant host plant species of papaya mealybug, it is important to find out how it can develop on popular ornamental plants such hibiscus, acalypha, and plumeria as well as on a commonly found invasive annual weeds such as parthenium.

Hibiscus, which is believed to be native to China, is a popular ornamental and landscape shrub, and widely grown in the tropics and subtropics (Ingram and Rabinowitz, 2004). Different hibiscus species are grown in many areas of the US (USDA, 2007). Hibiscus has been grown in Florida for many years (Ingram and Rabinowitz, 2004), and its potential planting range in the US includes some areas of Texas and California (Gilman, 1999). Hibiscus is widely grown in Hawaii. Hibiscus is sold nationwide as potted flower plants, and maintained in greenhouses around the country. Pink hibiscus mealybug, *Maconellicoccus hirsutus* (Green) (Hemiptera: Pseudococcidae) is another important mealybug species that was introduced to Florida in 2002, and has been identified as one of the most important insect pests of hibiscus (Goolsby *et al*., 2002; Hoy *et al*., 2006).

2.1.6 Damage

The papaya mealybug feeds on the sap of plants by inserting its stylets into the epidermis of the leaf, as well as into the fruit and stem. 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. Papaya mealybug has only been recorded feeding on areas of the host plant that are above ground, namely the leaves and fruit.

Walker *et al.* (2003) conducted on the different ecological aspects *P. marginatus.* The papaya mealybug feeds on the sap of plants by inserting its stylets of beaks into the epidermis of the leaves, as well as into the unripe fruits and stems. In doing so, it infects a toxic or harmful substance into the leaves. The results are chlorosis, plant stunting, leaf deformation, early leaf and fruit drop, a heavy buildup of honeydew, and death of host plants. Heavy infestations are capable of rendering fruit inedible due to the aggregation of thick white waxy appearance. Papaya mealybug has only been recorded feeding on the areas of the host plant above ground parts including leaves and fruits of different host plants.

2.1.7 Factors responsible for high population buildup

Indra *et al.* (2008) stated that with rapid development, high survival rate, and enormous reproductive capacity, *P. marginatus* population could potentially reach a high level. Wax layer and waxy fibers over the ovisac and body of mealybug nymphs and adult females protect them from adverse environmental conditions and routine chemical pesticides. Availability of alternate hosts/weeds around fields not cared by cultivators, movement of crawlers through air, irrigation water or farm equipment helps in fast spread of the mealybug from infested field to healthy fields. No phytosanitation: free movement of infested fruits, vegetables and other material, Intensive cropping system. Wider acceptability of hosts by papaya mealybug and its subsequent adaptability on them. Ant association providing protection from parasitoids and predators and aiding in dispersal of the pest. In certain crops, stems which often carry mealybug infestation are stocked in the farm for propagation or other purposes. These stocks, near the newly planted crop act as reservoirs of papaya mealybug. Healthy plants can be infested from mealybug infested plants as juvenile mealybugs can crawl from an infested plant to another plant. Small ‘crawlers’ get readily dispersed by wind,

rain, irrigation water, birds, ants, clothing, and vehicle, etc. The wax, which sticks to each ovisac and nymphs, also facilitates passive dispersal by equipment, animals or human beings. The female mealybug is not active and unable to fly. In fact, human beings greatly facilitate in the transport of these mealybugs. Long-distance movement is aided through transport of infested planting material and fresh fruits and vegetables from a farm to the other or even across the country. Ants, attracted by the honeydew, have been seen carrying mealybugs from plant to plant.

Mealybugs are known to offer ants with their sugary excretion (honeydew) and in return ants help in spreading the mealy bugs and provide protection from predator ladybird beetles, parasites and other natural enemies. Species of ant, *Oecophylla smaragdina* has been found attending papaya mealybug, feeding on honeydew on papaya and other plants.

2.1.8 Seasonal abundance of papaya mealybug

Suganthy et al., (2012) stated that the biological studies of the mealybug, 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) 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 occoured within

the cocoon at the age 7 to 21, 10 to 26 and 14 to 34 days respectively. The developmental period was prolonged during winter months due to low temperature. The most favourable period for their development was observed at May month and they completed their development at the age of 7-10 (8.78±1.29), 11-14 (12.25±1.29), 16-18 (17.2±1.00) days respectively for second, third and fourth instars at 23 to 36°C and 50 to 90% R. H.

During the biological studies it is found that their sex ratio (M:F) varies during different seasons. It is varied from 1:1.20 in January month to 1:3.41 in July month. 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. Low temperature adversely affected fecundity and oviposition period. Sahoo et al. 1999 studied the biology of Planococcus minor mealybug on sprouted potato and found that they completed ten generations in a year, eight during February-November and two during November-January.

Suganthy et al., (2012) studied the biology of P. marginatus on sunflower and found that the egg, first, second and third instar nymphal periods were 6.33±0.58, 4.00±1.00, 3.67± 0.58 and 5.00±1.00 days, respectively. Further this, they also studied the longevity of adult males and females and found that females took 20.33±1.53 day to complete their adult life, whereas, male took 1.67± 1.15 days to complete their adult period. Total life cycle of female P. marginatus was 39.33±2.53 days and for male it was 24.00±1.73 days. The oviposition period was 7.33±0.58 days and fecundity was 329.33±20.03 eggs on sunflower seedlings. In the present study fecundity rate of P. marginatus was from 140-324. Similar findings were reported by Amarasekare et al. (2008) who observed that the fecundity of P. marginatus was an average of 300 eggs at 25°C and Walker et al., 2011 who reported that the females of P. marginatus usually laid 100 to 600 eggs in an ovisac. As, there were striking differences present in male and female ratio in different generation. No doubt temperature has certain

role behind that but it is not clear the main factor which are responsible. For this, details physiological study is very important to entangle that mystery.

For the studies to know the mode of reproduction, it was found that the five isolated females on sprouted potato were died at the age of 34-41 days, without laying any eggs. Thus, the species reproduces entirely sexually. Further this, as the sex ratio was female biased, it again confirm its sexual mode of reproduction. This life history information of P. marginatus will help us to understand the developmental period of different instars and which will further help in implementing a suitable integrated pest management (IPM) program.

2.2 Control of papaya mealybug

Papaya mealybug, *Paracoccus marginatus,* the invasive pest from Central American countries has caused havoc in agricultural and horticultural crops in India ever since its first report from Coimbatore during 2007. The search for the effective parasitoids in India is still elusive. Attention has been focused on the conservation of native predators of the pest. *Spalgius epius* was recorded as a potential predator of different species of mealybugs and scales. As mulberry ecosystem provides a suitable niche for colonization of the predator owing to limited use of chemicals, investigations were taken up to explore the utility of this Lycaenid as a biological control agent of *P. marginatus* in mulberry. Photomicrograph aided investigations have thrown light on the peculiar feeding behaviour of the predatory larvae. Ex situ confinement studies have shown that the fifth instar larvae consumed as much as 18 to 26 (22.33±3.21) ovisacs and 112 to 132 (121.66 ± 8.86) nymphs and adults of the mealy bugs. During the whole larval period the predatory larvae devoured about 42 to 53 (48.15±4.08) ovisacs and 196 to 222 (210.99 ± 10. 77) nymphs and adults of *P.marginatus* (Thangamalar *et al*., 2010).

A hitherto unrecorded species of mealybug was discovered in early 2008 in the western provincial districts Colombo and Gampaha in Sri Lanka, infesting a large number of plant

species. Investigations were done to identify the pest and to study its host range, nature of damage and distribution, and to design and implement control measures. The pest was identified as papaya mealybug, *Paracoccus marginatus* (Hemiptera: Pseudococcidae), an invasive alien species originating from Mexico and/or Central America.

The mealybug found to heavily infest more than 40 plant species including papaw, the major host, and several horticultural and floricultural crops like *Plumeria*, manioc, bread fruit, *Alstonia macrophylla* and *Jatropha* spp. By 2009 the pest had spread to other parts of the country including the North Western, Saba-ragamuwa, Southern, North Central, Central and Eastern provinces. As an immediate control measure, Imidacloprid 200SL, thiamethoxam 25%WG and Mineral oil were recommended for the control of this pest until biological control agents could be introduced (Galanihe *et al*., 2010).

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 1g per liter; Imidacloprid 200g/l SL at the rate of 1ml per liter; and Mineral oil (Sparrow oil) at the rate of 5ml per liter (Galanihe, 2010).

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, *Cryptolaemus montrouzieri* 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 Agricultural Research Service (ARS) in 1999: *Acerophagus papayae* Noyes and Schauff, *Anagyrus loecki* Noyes, *Anagyrus californicus* (Compere), *Pseudaphycus* sp. and *Pseudleptomastix mexicana* Noyes & Schauff (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% (Kauffman *et al.,* 2001; 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). According to Muniappan (2008), classical biological control approach of *P. marginatus* in an exotic or introduced pest in Asia and it is suitable for the classical biological control approach of releasing species-specific parasitoids. This approach has been successfully implemented against PMB (papaya mealybug) in several countries in the Caribbean, some islands in the pacific and in the states of Florida and Hawaii in the United States.

Organophosphate and carbamate insecticides such as dimethoate, malathion, carbaryl, chlorpyrifos, diazinone and acephate (Walker *et al*., 2003) were commonly used insecticides to control mealybugs. Currently neonecotinoid insecticides such as acetamiprid, clothianidin, dinotefuran, Imidacloprid, thiamethoxam, and insect growth regulators (IGR) such as pyriproxyfen are used to control scale insects and mealybugs (Buss and Turner, 2006). However, there is no specific insecticide currently registered for control of papaya mealybug (Walker *et al*., 2003).

Tanwar et al. (2010) cited that efficacy of all chemical insecticides and botanical oils were increased with the progress of post treatment time and application frequency. Instant mortality was achieved within 1 day for the application of Sevin 85 SP and Dimethoate 40 EC, where the mortality percentage was 88 and 96, respectively. Among the four chemical insecticides, Sevin 85 SP and Dimethoate 40 EC provided 100% control while Deltamethrin 2.5 EC provided moderate control. The chemical insecticide Fipronil 50 SC did not control

papaya mealybug successfully and no statistical difference was found compared to control plant. Among the botanical oils, Neem provided moderate control while Mahogany and Karanja oil were less effective.

Mealybugs are generally difficult to control chemically due to their thick waxy secretion covering the body, and their ability to hide in the damaged buds and leaves without being exposed to the insecticide. The adult mealybugs were more difficult to control than the young and repeated applications of chemicals targeting immatures were required in suppressing *P. madeirensis* (Townsend *et al*., 2000). However, other management systems of papaya mealybug give results slowly; chemical management gives results fastly. So, chemical control was identified as a preferred method to control the papaya mealybug.

CHAPTER III

MATERIALS AND METHODS

3.1 Survey on abundance and infestation of papaya mealybug

The survey was conducted in five locations in Dhaka city namely Agargaon, Sher-e-Bangla Agricultural University (SAU), Mirpur-1, Mirpur-2 and Kallyanpur during the period from February, 2019 to December, 2019. Three nurseries or home garden were selected from one location for the determination of infestation intensity of papaya mealybug. For determination of infestation intensity, number of infested plants, leaves, branches, twigs, stems, inflorescences and fruits were counted. Percent infestation was recorded in the month of March and November of selected five locations for determination of seasonal abundance.

Regarding management the experiments were conducted at the laboratory and central farm of SAU during the period from February, 2019 to December, 2019. For the determination of mortality percentage of papaya mealybug, observation was made in laboratory of Entomology Department and Central Farm of SAU.

3.2 Selection of Insecticides

Seven insecticides namely, Abamectin, Chlorpyriphos, Dimethoate, Imidacloprid, Fipronil, Spinosad, Bioneem Plus and untreated control were tested for their efficacy against papaya mealybug in laboratory of Entomology and Agronomy field of SAU (Table 1).

Table 1. Insecticides with doses used against papaya mealybug

Common name	Trade name	Doses used
Abamectin	Vertimec 1.8 EC	1ml/L
Chlorpyrifos	Dursban Pro	1ml/L
Dimethoate	Dimegro 30EC	1ml/L
Imidacloprid	Admire	1ml/L
Fipronil	Regent	1ml/L
Spinosad	Tracer 2.5SC	1ml/L
Bioneem Plus	Azadiractin	1ml/L

3.3 Evaluation of insecticides in laboratory

3.3.1 Collection of insects

Papaya mealybugs were collected from infested plants at early in the morning in a jar with the help of an aspirator (for small ones) and brought to the laboratory as experimental materials. Fresh papaya leaves were provided in the jars as food source for the mealybugs.

3.3.2 Bioassay of selected insecticides

To evaluate the efficacy of seven selected chemical insecticides against papaya mealybug, foliar spray bioassay method was followed under laboratory condition. Each insecticide solution was prepared by mixing with distilled water at their field recommended dose (Table 1). Exact amount of each insecticide was taken in 500 ml volumetric flask marked for each insecticide, 200 ml distilled water was added to each flask. The flasks were shaken five minutes for proper mixing of insecticides with water. After shaking, the volume was made up to the mark by adding more distilled water. Only 500 ml distilled water was taken in a flask marked for untreated control.

3.3.3 Foliar spray method

Fresh papaya leaves equal to the size of Petri dish (12cm x 2cm) were sprayed with each insecticide solution with a hand sprayer and only water was sprayed for untreated control. After air drying, the treated leaves were placed in the Petri dishes containing moistened filter paper to avoid desiccation of the leaves. The insects were released on treated leaves in each Petri dish with the help of camel hair brush. 50 insects were released in each Petri dish. Petri dishes were placed in the laboratory following completely randomized design (CRD) with four replications.

Data on mortality of the insects were recorded at 24, 48 and 72 after insecticide application. The moribund insects were considered as dead.

$$\% \text{ Corrected mortality} = \frac{\text{Treatment mortality} - \text{Control mortality}}{100 - \text{Control mortality}} \times 100$$

$$\% \text{ Mortality} = \frac{\text{Number of dead insect}}{\text{Total number of insect}} \times 100$$

3.4 Evaluation of insecticides in field

3.4.1 Experimental site

The experiment was carried out in the central Farm of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka, Bangladesh and which is situated in 23º74´´N latitude and 90º35´´E longitude and an elevation of 8.2 m from sea level. Appendix-I.

3.4.2 Climate

The climate is subtropical in nature with moderate temperature and scanty rainfall. The soil of the experimental land belongs to the Madhupur tract and was silty clay in nature having pH ranging from 5.5 to 6.2. Details of the meteorological data during the period of the experiment were collected from the Bangladesh Meteorological Department, Agargoan, Dhaka.

3.4.3 Characteristics of soil

The soil of the experimental area belongs to the Modhupur Tract under AEZ No. 28.

It had shallow red brown terrace soil. The selected plot was medium high land and the soil series was Tejgaon. Details of the recorded soil characteristics were presented in Appendix-II.

3.4.4 Design of experiment

The experiment was laid out in a randomized complete block design (RCBD) with four replications. The unit plot size was 2m × 2m. The distance between plots and blocks was 1m. Two pits were made in each plot.

3.4.5 Plant materials

Papaya was considered as test crop under the present study. Seedlings of Red Lady variety was used for the experiment. It was an advanced winter variety. It was collected from Krishibid Upakaran Nursery, Sher-e-Bangla Nagar, Dhaka.

3.4.6 Land preparation and fertilization

The experimental plot was ploughed thoroughly by a tractor drawn disc plough followed by harrowing. The land was then labeled prior to transplanting. 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.

3.4.7 Transplanting of seedlings

Thirty days old healthy and uniform sized seedlings were transplanted into the experimental field on 27 March, 2019 in the afternoon and light irrigation was given around each seedling for their better establishment.

3.4.8 Intercultural operation

When the seedlings established in the beds it was always kept under careful observation. Various intercultural operations, thinning, weeding, top dressing was accomplished for better growth and development of papaya seedlings.

3.4.8.1 Gap filing

Dead, injured and weak seedlings were replaced by new vigor seedling from the stock kept on the border line of the experiment.

3.4.8.2 Weeding

Weeding was done three times in these plots where it was necessary.

3.4.8.3 Irrigation

Light irrigation was given just after transplanting the seedlings. A week after transplanting the requirement of irrigation was envisaged through visual estimation. Several numbers of irrigation were given with a hosepipe until the entire plot was properly wet.

3.4.8.4 Insect and pest control

The experimental crop was infested with mealy bug. They attacked at the seedling to mature stage of papaya plant. Seven insecticides and untreated control were given to the seedling to mature stage of papaya plant.

3.4.8.5 Procedure of spray application

Selected insecticides for seedling and mature plant were sprayed in assigned plots and dosages by using Knapsack sprayer to control the mealybug.

3.4.9 Data collection and analysis

The effectiveness of each treatment was evaluated on the basis of mortality percentage of papaya mealybug at 24, 48 and 72 hrs after insecticide application.

3.4.9.1 Mortality percentage of mealybug in seedling stage of papaya plant

Mortality percentage of papaya mealybug was observed in seedling stage of papaya plant at 24, 48 and 72 hrs after insecticide application.

Plate 1. Mealybug infested seedling of papaya

3.4.9.2 Mortality percentage of mealybug at mature stage of papaya plant

Mortality percentage of papaya mealybug was observed in mature stage of papaya plant at 24, 48 and 72 hours after insecticide application.

$$\% \text{ Corrected mortality} = \frac{\text{Treatment mortality} - \text{Control mortality}}{100 - \text{Control mortality}} \times 100$$

$$\% \text{ Mortality} = \frac{\text{Number of dead insect}}{\text{Total number of insect}} \times 100$$

Plate 2. Mealybug infested plant of papaya

Plate 3. Mealybug infested leaf of papaya

Plate 4. Mealybug infested fruit of papaya

3.5 Statistical analysis

The data obtained from experiment on various parameters were statistically analyzed in MSTAT-C computer program. The mean values for all the parameters were calculated and the analysis of variance for the characters was accomplished by Duncan's Multiple Range Test (DMRT) at 5 % levels of probability (Gomez and Gomez, 1984).

CHAPTER IV

RESULTS AND DISCUSSIONS

The experiment was conducted to study the seasonal abundance, infestation intensity of papaya mealybug in Dhaka and its management. The results have been presented by using different tables and discussed with possible interpretations under the following headings and sub headings:

4.1 Survey of papaya mealybug at five different locations in Dhaka

Survey was done at five different locations in Dhaka. The locations are Agargaon, Sher-e-Bangla Agricultural University (SAU), Mirpur-1, Mirpur-2 and Kallayanpur.

4.1.1 Infestation intensity of papaya mealybug

Three places of each location were selected to find the infestation percentage of papaya mealybug. The table 2 includes No. of observed plant, No. of infested plant and infestation percentage of each location. Highest infestation (65.28 %) was found in Mirpur-1 followed by Agargaon (58.87 %). Statistically same result was found in Kallyanpur (57.97 %). Lowest infestation (49.25 %) was found in SAU.

Table 2. Infestation intensity of mealybug at five different places of Dhaka

Locations	No. of observed plants	No. of infested plants	Infestation (%)
Agargaon	124	73	58.87 b
SAU	67	33	49.25 d
Mirpur-1	72	47	65.28 a
Mirpur-2	88	45	51.14 c
Kallyanpur	69	40	57.97 b
$LSD_{(0.05)}$	**_**	**_**	**1.23**
CV (%)	**_**	**_**	**1.29**

[Infestation (%) in a column, numeric value represents the mean of 3 replications; in a column means having similar letters are statistically identical at 0.05 level of probability]

4.1.2 Incidence of papaya mealybug on leaf and branch of papaya plant

Table 3 reveals the leaf infestation and branch infestation of papaya plant. Highest leaf infestation (48.10 %) was found in SAU which was statistically similar to Mirpur-1 (46.61 %). Lowest leaf infestation (38.55 %) was found in Mirpur-2. Highest branch infestation (61.29 %) was also found in SAU followed by Mirpur-2 (48.00 %), Kallyanpur (45.71 %) and Agargaon (45.45 %). Lowest infestation (41.94 %) was found in Mirpur-1.

Table 3. Incidence of papaya mealybug on leaf and branch of papaya plant in different locations

Locations	**Leaf observations**			**Branch observations**		
	No. of observed leaves	**No. of infested leaves**	**Infestation (%)**	**No. of observed branches**	**No. of infested branches**	**Infestation (%)**
Agargaon	87	39	44.83 bc	33	15	45.45 c
SAU	79	38	48.10 a	31	19	61.29 a
Mirpur-1	118	55	46.61 ab	31	13	41.94 d
Mirpur-2	83	32	38.55 c	25	12	48.00 b
Kallyanpur	82	37	45.12 b	35	16	45.71 c
$LSD_{(0.05)}$	**_**	**_**	**2.71**	**_**	**_**	**2.26**
CV (%)	**_**	**_**	**3.32**	**_**	**_**	**2.58**

[Infestation (%) in a column, numeric value represents the mean of 5 plants for each location; in a column means having similar letters are statistically identical at 0.05 level of probability]

4.1.3 Incidence of papaya mealybug on stem and twig of papaya plant

Table 4 includes the stem infestation and twig infestation of papaya plant. Highest stem infestation (83.33 %) was found in Mirpur-2 followed by Mirpur-1 (76.92 %), Kallyanpur (61.11 %) and Agargaon (47.37 %). Lowest infestation (38.10 %) was found in SAU. Highest twig infestation (75.51 %) was found in Kallyanpur followed by SAU (68.18 %). Lowest infestation (59.26 %) was found in Mirpur-2.

Table 4. Incidence of papaya mealybug on stem and twig of papaya plant in different locations

Locations	Stem observations			Twig observations		
	No. of observed stems	No. of infested stems	Infestation (%)	No. of observed twigs	No. of infested twigs	Infestation (%)
Agargaon	19	9	47.37 d	31	20	64.52 c
SAU	21	8	38.10 e	22	15	68.18 b
Mirpur-1	13	10	76.92 b	30	19	63.33 c
Mirpur-2	18	15	83.33 a	27	16	59.26 d
Kallyanpur	18	11	61.11 c	49	37	75.51 a
$LSD_{(0.05)}$	**_**	**_**	**3.70**	**_**	**_**	**1.47**
CV (%)	**_**	**_**	**3.31**	**_**	**_**	**1.22**

[Infestation (%) in a column, numeric value represents the mean of 5 plants for each location; in a column means having similar letters are statistically identical at 0.05 level of probability]

4.1.4 Incidence of papaya mealybug on inflorescence and fruit of papaya plant

Table 5 reveals the inflorescence infestation and fruit infestation of papaya plant. Highest inflorescence infestation (84.85 %) was found in Mirpur-1 followed by Agargaon (75.00 %) which was statistically similar to Mirpur-2 (74.07 %). Lowest infestation (62.07 %) was found in Kallyanpur. Highest fruit infestation (75.00 %) was found in Kallyanpur followed by Mirpur-2 (66.04 %), SAU (58.70 %) and Agargaon (47.06 %). Lowest infestation (41.27 %) was found in Mirpur-1. Kallyanpur had lowest inflorescence infestation and highest fruit infestation.

Table 5. Incidence of papaya mealybug on inflorescence and fruit of papaya plant in different locations

Locations	Inflorescence observations			Fruit observations		
	No. of observed inflorescences	No. of infested inflorescences	Infestation (%)	No. of observed fruits	No. of infested fruits	Infestation (%)
Agargaon	40	30	75.00 b	85	40	47.06 d
SAU	54	36	66.67 c	46	27	58.70 c
Mirpur-1	33	28	84.85 a	63	26	41.27 e
Mirpur-2	27	20	74.07 b	53	35	66.04 b
Kallyanpur	29	18	62.07 d	68	51	75.00 a
$LSD_{(0.05)}$	**_**	**_**	**3.52**	**_**	**_**	**1.93**
CV (%)	**_**	**_**	**2.62**	**_**	**_**	**1.84**

[Infestation (%) in a column, numeric value represents the mean of 5 plants for each location; in a column means having similar letters are statistically identical at 0.05 level of probability]

4.1.5 Comparative infestation level of papaya mealybug at different parts of papaya plant

The table 6 includes infested leaf (%), infested branch (%), infested stem (%), infested twig (%), infested inflorescence (%) and infested fruit (%) of five different locations in Dhaka. Highest leaf infestation (48.10 %) and highest branch infestation (61.29 %) were found in SAU. Highest stem infestation (83.33 %) was found in Mirpur-2. Mirpur-1 had moderate twig infestation (63.33 %) but highest inflorescence infestation (84.85 %). Highest fruit infestation (75.00 %) was found in Kallyanpur. No relation was observed in the infestation of leaf, branch, stem, twig, inflorescence and fruit at different locations.

Table 6. Comparative infestation level of papaya mealybug in different parts of papaya plant

Locations	Leaf infestation (%)	Branch infestation (%)	Stem infestation (%)	Twig infestation (%)	Inflorescence infestation (%)	Fruit infestation (%)
Agargaon	44.83 bc	45.45 c	47.37 d	64.52 c	75.00 b	47.06 d
SAU	48.10 a	61.29 a	38.10 e	68.18 b	66.67 c	58.70 c
Mirpur-1	46.61 ab	41.94 d	76.92 b	63.33 c	84.85 a	41.27 e
Mirpur-2	38.55 c	48.00 b	83.33 a	59.26 d	74.07 b	66.04 b
Kallyanpur	45.12 b	45.71 c	61.11 c	75.51 a	62.07 d	75.00 a
$LSD_{(0.05)}$	**2.71**	**2.26**	**3.70**	**1.47**	**3.52**	**1.93**
CV (%)	**3.32**	**2.58**	**3.31**	**1.22**	**2.62**	**1.84**

[Infestation (%) in a column, numeric value represents the mean of 5 plants for each location; in a column means having similar letters are statistically identical at 0.05 level of probability]

4.1.6 Seasonal abundance of papaya mealybug on papaya plant at five different locations in Dhaka

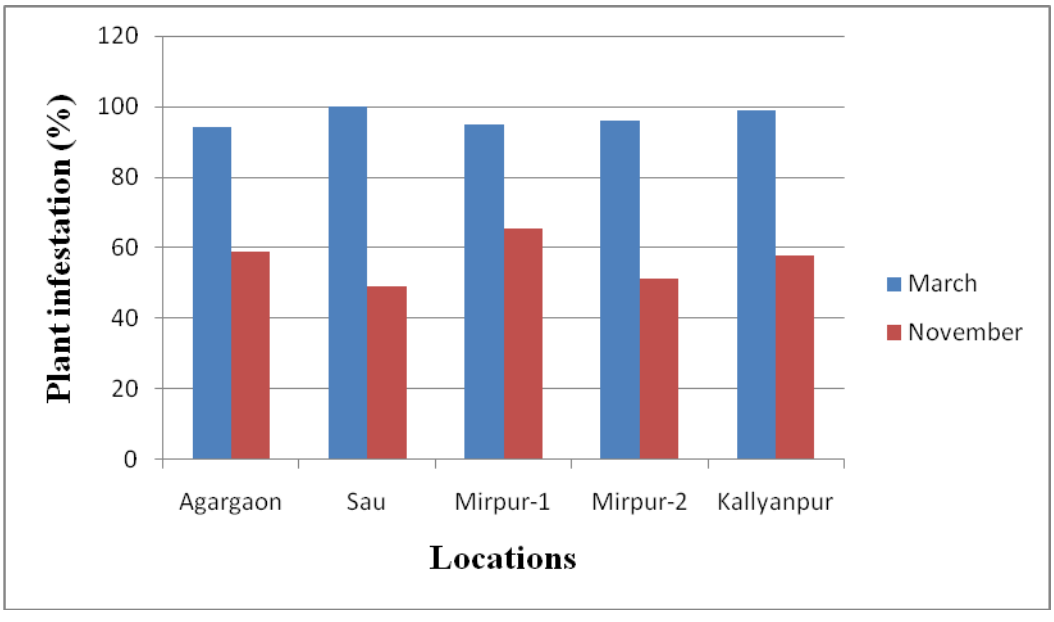


Figure 1. Population variations of papaya mealybug in March and November

In the month of March, the infestation percentage of papaya mealybug was highest (100 %) in SAU which was statistically similar to Kallyanpur (99 %), Mirpur-2 (96 %) and Mirpur-1 (95 %). Lowest infestation (94 %) was found in Agargaon. In the month of November, highest infestation (65.28 %) was found in Mirpur-1 followed by Agargaon (58.87 %) which was statistically similar to Kallyanpur (57.97 %). Lowest infestation (49.25 %) was found in SAU. It was observed that the infestation was highest during the month of March in all the locations. The infestation was decreased during the month of November in all the locations. The data has been presented in Appendix III.

4.2 Effect of insecticides on mortality of papaya mealybug in laboratory

Table 7 reveals the mortality (%) of papaya mealybug at 24 hr after spray, 48 hr after spray and 72 hr after spray in laboratory. The effect of some chemical insecticides on infestation of papaya mealybug has been presented in this table. Significant difference was found among different insecticides.

After 24 hr of spray, highest mortality was found in spraying of Fipronil (84.50 %) followed by spraying of Spinosad (71.00 %) which was statistically similar to Dimethoate (68.00 %), Imidacloprid (68.50 %) and Bioneem Plus (68.00 %). Lowest mortality was found in spraying of Abamectin (48.50 %). Similar trend was found in after 48 hr of spray. After 72 hr of spray, highest mortality was found in spraying of Fipronil (99.50 %) which was statistically similar to Bioneem Plus (99.50 %), Imidacloprid (98.50 %) and Spinosad (97.50 %). Lowest mortality was found in spraying of Abamectin (95.50 %) which was similar to spraying of Chlorpyrifos (95.50%).

The order of effectiveness of seven chemical insecticides (72 hr after spray) used in this experiment was Fipronil = Bioneem Plus> Imidacloprid> Spinosad> Dimethoate> Abamectin = Chlorpyriphos. These results indicate that Fipronil and Bioneem Plus were the most effective insecticides and Abamectin and Chlorpyriphos were the least effective insecticides for mortality percentage of papaya mealybug. Spinosad gave intermediate level of mortality percentage of papaya mealybug.

Table 7. Mortality of papaya mealybug by insecticides in laboratory

Treatments	Mortality (%)		
	24 hr after spray	48 hr after spray	72 hr after spray
T_1	48.50 d	76.50 d	95.50 c
T_2	65.00 c	83.50 c	95.50 c
T_3	68.00 bc	86.50 bc	97.00 bc
T_4	68.50 bc	88.00 b	98.50 ab
T_5	84.50 a	94.50 a	99.50 a
T_6	71.00 b	88.00 b	97.50 a-c
T_7	68.00 bc	87.50 b	99.50 a
$LSD_{(0.05)}$	**5.05**	**3.92**	**2.25**
CV (%)	**4.93**	**3.00**	**1.52**

[Mortality (%) in a column, numeric value represents the mean of 4 replications for each treatment ; in a column means having similar letters are statistically identical at 0.05 level of probability]
[T_1: Spraying of Abamectin @ 1ml/L of water at; T_2: Spraying of Chlorpyrifos @ 1ml/L of water; T_3: Spraying of Dimethoate @ 1ml/L of water; T_4: Spraying of Imidacloprid @ 1ml/L of water; T_5: Spraying of Fipronil @ 1ml/L of water; T_6: Spraying of Spinosad @ 1ml/L of water; T_7: Spraying of Bioneem Plus @ 1ml/L of water]

4.3 Effect of insecticides on mortality of papaya mealybug at seedling stage of papaya plant

Table 8 reveals the mortality (%) of papaya mealybug at 24 hr after spray, 48 hr after spray and 72 hr after spray at seedling stage. The effect of some chemical insecticides on infestation of papaya mealybug has been presented in this table. Significant difference was found among different insecticides. After 24 hr of spray, highest mortality was found in spraying of Bioneem Plus (52.54 %) which was statistically similar to Abamectin (50.48 %). Lowest mortality was found in spraying of Dimethoate (35.14 %) which was statistically similar to Chlorpyrifos (35.06 %).

After 72 hr of spray, highest mortality was found in spraying of Bioneem Plus (94.92 %) which was statistically similar to Fipronil (94.83 %) and Imidacloprid (93.68 %). Lowest mortality was found in spraying of Abamectin (86.67 %).

The order of effectiveness of seven chemical insecticide (72 hr after spray) used in this experiment was Bioneem Plus= Fipronil= Imidacloprid> Spinosad> Dimethoate> Chlorpyriphos> Abamectin. These results indicate that Bioneem Plus, Fipronil, Imidacloprid were the most effective insecticides and Abamectin was the least effective insecticide for mortality percentage of papaya mealybug at seedling stage. Dimethoate gave intermediate level of mortality percentage of papaya mealybug.

Table 8. Mortality of papaya mealybug by insecticides at seedling stage of papaya plant

Treatments	**Mortality (%)**		
	24 hr after spray	**48 hr after spray**	**72 hr after spray**
T_1	50.48 a	71.43 bc	86.67 c
T_2	35.06 c	64.94 e	88.31 bc
T_3	35.14 c	65.77 de	89.19 bc
T_4	40.00 b	69.47 cd	93.68 a
T_5	43.10 b	75.00 ab	94.83 a
T_6	42.55 b	71.63 bc	90.07 b
T_7	52.54 a	78.81 a	94.92 a
$LSD_{(0.05)}$	**3.61**	**4.02**	**3.30**
CV (%)	**5.59**	**3.74**	**2.39**

[Mortality (%) in a column, numeric value represents the mean of 4 replications for each treatment ; in a column means having similar letters are statistically identical at 0.05 level of probability]

[T_1: Spraying of Abamectin @ 1ml/L of water at; T_2: Spraying of Chlorpyrifos @ 1ml/L of water; T_3: Spraying of Dimethoate @ 1ml/L of water; T_4: Spraying of Imidacloprid @ 1ml/L of water; T_5: Spraying of Fipronil @ 1ml/L of water; T_6: Spraying of Spinosad @ 1ml/L of water; T_7: Spraying of Bioneem Plus @ 1ml/L of water]

4.4 Effect of insecticides on mortality of papaya mealybug at mature stage of papaya plant

Table 9 reveals the mortality (%) of papaya mealybug at 24 hr after spray, 48 hr after spray and 72 hr after spray on papaya plant. The effect of some chemical insecticides on infestation of papaya mealybug has been presented in this table. Significant difference was found among different insecticides.

After 24 hr of spray, highest mortality was found in spraying of Dimethoate (42.10 %) which was statistically similar to Abamectin (40.46 %), Fipronil (38.78 %) and Imidacloprid (38.40 %). After 72 hr of spray, highest mortality was found in spraying of Bioneem Plus (90.91 %) which was statistically similar to Abamectin (88.77 %), Spinosad (88.33 %) and Imidacloprid (87.60 %). Lowest mortality was found in spraying of Fipronil (84.18 %).

The order of effectiveness of seven chemical insecticides (72 hr after spray) used in this experiment was Bioneem Plus> Abamectin> Spinosad> Imidacloprid> Dimethoate> Chlorpyriphos> Fipronil. These results indicate that Bioneem Plus was the most effective insecticide and Fipronil was the least effective insecticide for mortality percentage of papaya mealybug on papaya plant. Imidacloprid gave intermediate level of mortality percentage of papaya mealybug.

Table 9. Mortality of papaya mealybug by insecticides at mature stage of papaya plant

Treatments	Mortality (%)		
	24 hr after spray	**48 hr after spray**	**72 hr after spray**
T_1	40.46 a	68.77 a	88.77 ab
T_2	35.29 bc	66.86 a-c	84.71 cd
T_3	42.10 a	65.52 bc	85.33 b-d
T_4	38.40 ab	69.80 a	87.60 a-d
T_5	38.78 ab	65.05 c	84.18 d
T_6	32.49 c	68.45 ab	88.33 a-b
T_7	33.72 c	68.62 a	90.91 a
$LSD_{(0.05)}$	**4.36**	**3.10**	**3.82**
CV (%)	**7.71**	**3.02**	**2.90**

[Mortality (%) in a column, numeric value represents the mean of 4 replications for each treatment ; in a column means having similar letters are statistically identical at 0.05 level of probability]

[T_1: Spraying of Abamectin @ 1ml/L of water at; T_2: Spraying of Chlorpyrifos @ 1ml/L of water; T_3: Spraying of Dimethoate @ 1ml/L of water; T_4: Spraying of Imidacloprid @ 1ml/L of water; T_5: Spraying of Fipronil @ 1ml/L of water; T_6: Spraying of Spinosad @ 1ml/L of water; T_7: Spraying of Bioneem Plus @ 1ml/L of water]

CHAPTER V
SUMMARY AND CONCLUSION

SUMMARY

The survey was conducted in five locations in Dhaka city namely Agargaon, Sher-e-Bangla Agricultural University (SAU), Mirpur-1, Mirpur-2 and Kallyanpur during the period from February, 2019 to December, 2019. The experiments of chemical management were conducted at the laboratory and central farm of SAU during the period from February, 2019 to December, 2019. The study was conducted to determine the seasonal abundance, infestation intensity of papaya mealybug in Dhaka and its chemical control.

Highest leaf infestation (48.10 %) and highest branch infestation (61.29 %) were found in SAU. Highest stem infestation (83.33 %) was found in Mirpur-2. Mirpur-1 had moderate twig infestation (63.33 %) but highest inflorescence infestation (84.85 %). Highest fruit infestation (75.00 %) was found in Kallyanpur. Regarding seasonal abundance it was observed that the infestation was highest during the month of March in all the locations. The infestation decreased during the month of November in all the locations. In the month of March, the infestation percentage of papaya mealybug was highest (100 %) in SAU which was statistically similar to Kallyanpur (99 %), Mirpur-2 (96 %) and Mirpur-1 (95 %). Lowest infestation (94 %) was found in Agargaon. In the month of November, highest infestation (65.28 %) was found in Mirpur-1 followed by Agargaon (58.87 %) which was statistically similar to Kallyanpur (57.97 %). Lowest infestation (49.25 %) was found in SAU. No relation was observed in the infestation of leaf, branch, stem, twig, inflorescence and fruit at different locations.

Regarding chemical management which was evaluated against papaya mealybug the experiment was consisted of seven treatments both in laboratory and field viz. T_1 = Abamectin 1.8 EC, T_2 = Chlorpyrifos (Dursban Pro), T_3 = Dimethoate 30 EC, T_4 = Imidacloprid 200 SL, T_5 = Fipronil (Regent), T_6 = Spinosad 2.5 SC and T_7 = Bioneem Plus (Azadiractin). The experiment was laid out in Completely Randomized Design (CRD) single factor with four replications in laboratory. The experiment was laid out in Randomized Complete Block Design (RCBD) single factor with four replications in field.

In laboratory after 72 hr of spray, highest mortality was found in spraying of Fipronil (99.50 %) which was statistically similar to Bioneem Plus (99.50 %), Imidacloprid (98.50 %) and Spinosad (97.50 %). Lowest mortality was found in spraying of Abamectin (95.50 %) which was similar to spraying of Chlorpyrifos (95.50%). In field at seedling stage of papaya plant after 72 hr of spray, highest mortality was found in spraying of Bioneem Plus (94.92 %) which was statistically similar to Fipronil (94.83 %) and Imidacloprid (93.68 %). Lowest mortality was found in spraying of Abamectin (86.67 %). In field at mature stage of papaya plant after 72 hr of spray, After 72 hr of spray, highest mortality was found in spraying of Bioneem Plus (90.91 %) which was statistically similar to Abamectin (88.77 %), Spinosad (88.33 %) and Imidacloprid (87.60 %). Lowest mortality was found in spraying of Fipronil (84.18 %). Similar trend was observed after 24 hr of spray at mature stage of papaya plant but after 72 hr of spray Bioneem Plus gave the best result. Among all the applied chemical insecticides in this study, Fipronil showed the best performance on management the mealybug of papaya in laboratory and Bioneem Plus showed the best performance in both laboratory and field.

CONCLUSION

From the above results, it could be concluded that no relation was observed in the infestation of leaf, branch, stem, twig, inflorescence and fruit at different locations. Highest infestation (65.28 %) was found in Mirpur-1 followed by Agargaon (58.87 %). Statistically same result was found in Kallyanpur (57.97 %). Lowest infestation (49.25 %) was found in SAU. Regarding seasonal abundance it was observed that the infestation was highest during the month of March in all the locations. The infestation decreased during the month of November in all the locations. Among all the applied chemical insecticides in this study, Fipronil showed the best performance on the control of the mealybug of papaya in laboratory and Bioneem Plus showed the best performance in both laboratory and field.

RECOMMENDATIONS

The following recommendations may be suggested from the present study-

1. Infestation intensity and seasonal abundance of papaya mealybug may be studied in different locations and different seasons of Dhaka City.
2. Bioneem Plus @ 1.0 ml/L water may be applied for the management of papaya mealybug at seedling stage and mature stage of papaya plant in field.

CHAPTER VI
REFERENCES

Aitken, E.H. (1984). The larva and pupa of *Spalgis epius*, Westwood. *J. Bombay Nat. Hist. Soc.* **8**:485-487.

Andrewartha, H.G., and Birch, L.C. (1954). The Distribution and Abundance of Animals. Chicago Press. Chicago University, Chicago, IL.

Amarasekare, K.G., Chong, J.H. Epsky., N.D. and Mannion, C. M. (2008). Effect of temperature on the life history of the mealybug *Paracoccus marginatus* (Hemiptera: Pseudococcidae). *J. Econ. Entomol.* **101:** 1798- 1804.

Buss, E.A. and Turner, J.C. (2006). Scale Insects and Mealybugs on Ornamental Plants. EENY-323. Featured Creatures. Entomology and Nematology Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL.

Galanihe, L.D. (2010). Chemical Control of Papaya Mealybug, *Paracoccus marginatus* Williams and Granara de Willink in Sri Lanka. CropLife Sri Lanka's Plant Protection Industry Journal. 05-December 2010:27-30.

Galanihe, L.D., Jayasundera, M.U.P., Vithana, A., Asselaarachchi, N. and Watson, G.W. (2010). Occurrence, distribution and control of papaya mealybug, *Paracoccus marginatus* (Hemiptera: Pseudococcidae), an invasive alien pest in Sri Lanka. *Tropic. Agric. Res. Ext.* **13**(3): 2010

Goolsby, J.A., Kirk, A.A. and Meyerdirk, D.E. (2002). Seasonal phenology and natural enemies of *Maconellicoccus hirsutus* (Hemiptera: Pseudococcidae) in Australia. *Florida Entomol*. **85**: 494- 498.

Harris, P. (1990). Environmental impact of introduced biological control agents. In: M. Mackauer, L. E. Ehler and J. Roland (eds.), Critical Issues in Biological Control. Intercept Ltd, Andover, Hants, UK. pp. 295-303.

Heu, R.A., Fukada, M.T. and Conant, P. (2007). Papaya Mealybug, *Paracoccus marginatus* Williams and Granara de Willink (Hemiptera: Pseudococ-cidae). State of Hawaii New Pest Advisory. Department of Agriculture, No. 04-03.

Hoy, M.A., Hamon, A. and Nguyen, R. (2006). Pink Hibiscus Mealybug, *Maconellicoccus hirsutus* (Green). EENY-29. Featured Creatures. Entomology and Nematology Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL.

Indra W., Shanila J. and Buddhi, M. (2008). *Paraciccus marginatus* Williams ans Granara, de Willink (Hemipter: Pseusococcidae)- an Invasive Mealybug, p.1.

Ingram, D.L., and Rabinowitz, L. (2004). Hibiscus in Florida. ENH-44. Environmental Horticulture Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL.

Kauffman, W.C., Meyerdirk, D.E., Miller, D., Scahauff, M., Hernandez, H.G. and Villanueva, J.A. (2001). Papaya mealybug biological control in Puerto Rico and Dominican Republic. Presented 11 December 2001 at the ESA Annual Meeting, San Diego, CA. Quoted in Walker A, Hoy M, and Meyerdirk DE 2003 Papaya Mealybug. Univ. Florida Featured Creatures.

Gomez, K.A. and Gomez, A.A. (1984). Statistical Procedure of Agricultural Research. John Wiley and Sons. p. 28.

Gilman, E.F. (1999). *Hibiscus rosa-sinensis*. Fact Sheet. FPS-254. Florida Cooperative Extension Service, Institute of Food and agricultural Sciences, University of Florida, Gainesville, FL.

Meyerdirk, D.E. and Kauffman, W.C. (2001). Status on the development of a biological control program for *Paracoccus marginatus* Williams, papaya mealybug. Internal USDA, APHIS, PPQ Report. Walker A, Hoy M, and Meyerdirk DE 2003. Papaya Mealybug. Univ. Florida Featured Creatures.

Meyerdirk, D.E., Muniappan, R., Warkentin, R., Bamba, J. and Reddy, G.V.P. (2004). Biological control of the papaya mealybug, *Paracoccus marginatus* (Hemiptera: Pseudococcidae). *Plant Protec*. **19**(3): 110-114.

Miller, D.R. and Miller, G.L. (2002). Redescription of *Paracoccus marginatus* Williams and Granara de Willink (Hemiptera: Coccoidea: Pseudococ-cidae), including descriptions of the immature stages and adult male. Proceedings of the Entomological Society of Washington. pp **104**: 1-23.

Muniappen, R., (2008). Invasion of papaya mealybug in Asia. *Virginia Tech*. Muniappan, R., Meyerdirk, D.E., Sengebau, F.M., Berringer, D.D. and Reddy, G.V.P. (2006). Classical biological control of the papaya mealybug, *Paracoccus marginatus* (Hemiptera: Pseudococcidae) in the republic of Palau. *Florida Entomologist*. **89** : 212-217.

Muniappen, R., Shepard, B.M., Watson, G.W., Carner, G.R., Sartiami, D., Rauf, A. and Hammig, M.D. (2009). First report of the papaya mealybug, *Paracoccus marginatus* (Hemiptera: Pseudococcidae), in Indonesia and India. *J. Agric. Urban Entomol*. **25**(1): 37-40.

Tanwar, R.K., Jeyakumar, P. and Vennila, S. (2010). Papaya mealybug and its management strategies .Technical Bulletin 22. National Centre for Integrated Pest Management, New Delhi.

Tanwar, R.K., Jeyakumar, P. and Monga, D. (2007). Mealybugs and Their Management, Technical Bulletin 19, August, 2007, National Centre for Integrated Pest Management, New Delhi.

Thangamalar, A., Subramanian, S. and Mahalingam, C.A. (2010). Bionomics of papaya ealybug, *Paracoccus marginatus* and its predator *Spalgius epius* in mulberry ecosystem. *Karnataka J. Agric. Sci.,* **23**(1): 39-41.

Townsend, M.L., Oetting, R.D. and Chong, J.H. (2000). Management of the mealybug *Phenacoccus madeirensis*. Proc. South. Nurs. Assoc. Res. Conf. **45**: 162-166.

USDA. (2007). Hawaii Papayas. National Agricultural Statistics Service, Honolulu, HI.

Walker, A., Hoy, M. and Meyerdirk D.E. (2003). Papaya Mealybug. Univ. Florida Featured Creatures.

Williams, D.J. and Granara de Willink M.C. (1992). Mealybugs of Central and South America. CAB International, Wallingford, England. 635p.

García Morales, M., Denno, B. D., Miller, D. R., Miller, G. L., Ben-Dov, Y., Hardy, N. B., 2019. ScaleNet: A literature-based model of scale insect biology and systematics. In: ScaleNet: A literature-based model of scale insect biology and systematics . http://scalenet.info/

Miller DR, Williams DJ, Hamon AB, 1999. Notes on a new mealybug (Hemiptera: Coccoidea: Pseudococcidae) pest in Florida and the Caribbean: the papaya mealybug, *Paracoccus marginatus* Williams and Granara de Willink. Insecta Mundi, **13(3/4):**179-181.

Mendel Z, Watson, G.W, Protasov, A, and Spodek M. (2016). First record of the papaya mealybug, *Paracoccus marginatus* Williams & Granara de Willink (Hemiptera: Coccomorpha: Pseudococcidae), in the Western Palaearctic. Bulletin OEPP/EPPO Bulletin, 46(3):580-582.http://onlinelibrary.wiley.com/journal/10.1111/(ISSN)1365-2338

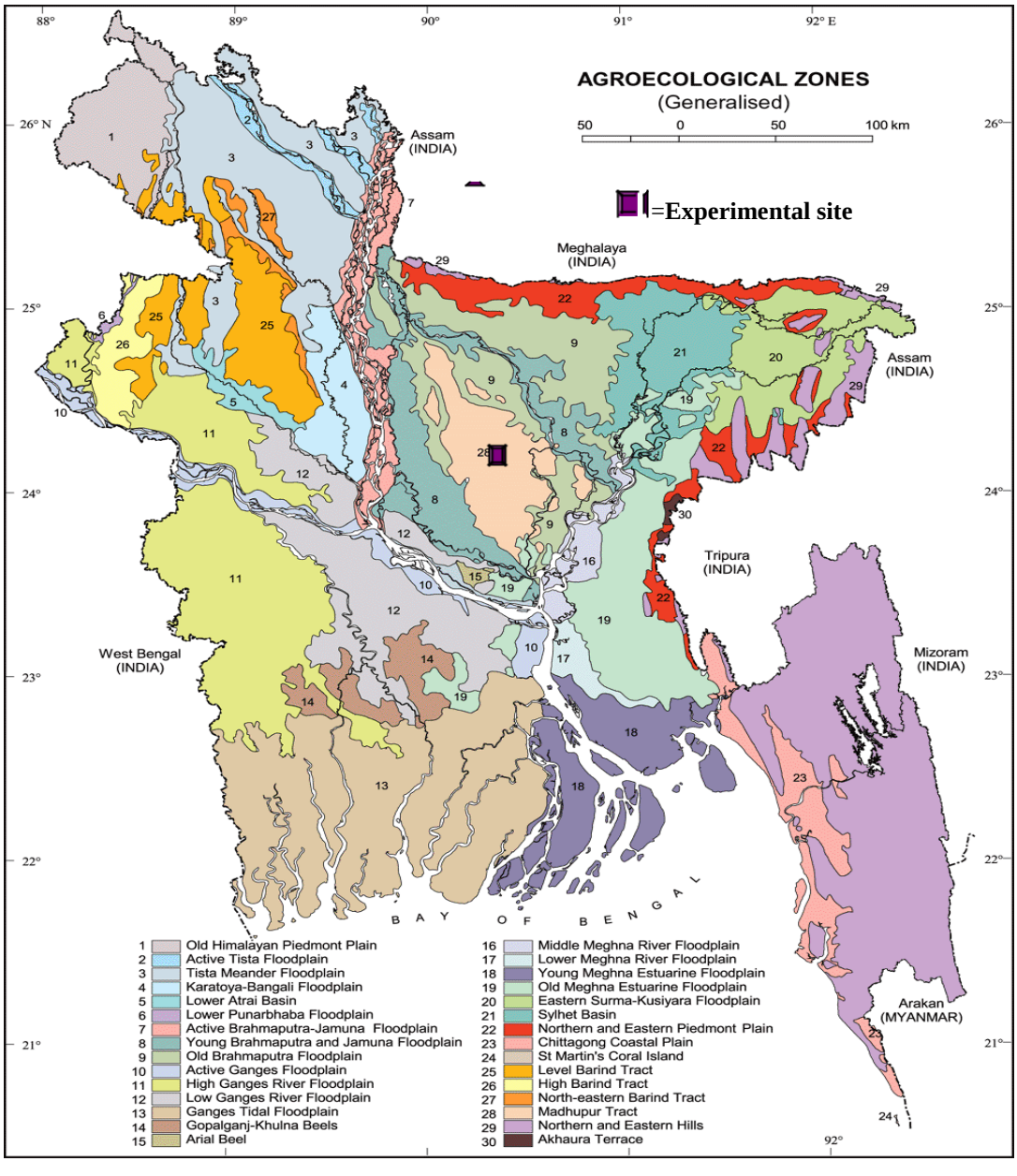
Sahoo, A.K., Ghosh, A.B. Mandal, S.K. and Maiti, D.K. (1999). Study on the biology of the mealybug, *Planococcus minor* (Maskell) Pseudococcidae: Hemiptera. *Journal of Interacademicia* **3(1):** 41-48.

Suganthy, M., Janaki., I. and Sakthivel, P. (2012). Biology of Mealy Bugs, *Paracoccus marginatus* (Williams and Granara de Willink) and Phenacoccus solenopsis (Tinsley) on Sunflower under Greenhouse and Laboratory. *Madras Agric. J.* **99(4):** 371-373.

Tanwar, R.K., Jeyakumar, P. and Vennila, S. (2010) Papaya mealybug and its management strategies, Technical Bulletin **22:** 20.

APPENDICES

Appendix I. Experimental location on the map of Agro-ecological Zones of Bangladesh



Appendix II. The physical and chemical characteristics of soil of the experimental site as observed prior to experimentation

Constituents	Percentage (%)
Sand	26
Silt	45
Clay	29
Textural class	Silty clay

Chemical composition:

Soil characters	Value
Organic carbon (%)	0.45
Organic matter (%)	0.78
Total nitrogen (%)	0.07
Phosphorus	22.08 µg/g soil
Sulphur	25.98 µg/g soil
Magnesium	1.00 meq/100 g soil
Boron	0.48 µg/g soil
Copper	3.54 µg/g soil
Zinc	3.32 µg/g soil
Potassium	0.30 µg/g soil

Source: Soil Resources Development Institute (SRDI), Khamarbari, Dhaka

Appendix III. Seasonal abundance of papaya mealybug on papaya plant at five different locations in Dhaka

Locations	Months	
	March (Infestation %)	November (Infestation %)
Agargaon	94 b	58.87 b
SAU	100 a	49.25 d
Mirpur-1	95 ab	65.28 a
Mirpur-2	96 ab	51.14 c
Kallyanpur	99 ab	57.97 b
$LSD_{(0.05)}$	**5.52**	**1.23**
CV (%)	**3.13**	**1.29**

[Infestation (%) in a column, numeric value represents the mean of 3 replications; in a column means having similar letters are statistically identical at 0.05 level of probability]