BIO-ECOLOGY AND MANAGEMENT OF PAPAYA MEALYBUG ON MULBERRY

by

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THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"Bio-ecology and Management of Papaya Mealybug on Mulberry"** is a bona fide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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LIST OF ABBREVIATIONS

BMB	Breadfruit mealybug
BSV	Banana streak virus
DAC-ELISA	Direct antigen coating- ELISA
DAT	Days after treatment
EC	Emulsifiable concentrates
g	Gram
h	Hours
ha	Hectare
HAT	Hours after treatment
kg	Kilogram
mg	Milligram
MT	Metric tonne
L	Litre
NSKE	Neem seed kernel extract
PHMB	Pink hibiscus mealybug
PMB	Papaya mealybug
ppm	Parts per million
rpm	Revolutions per minute
SCBMV	Sugarcane bacilliform mosaic virus
SE	Standard error
Viz.	Namely

Introduction

1. INTRODUCTION

Silk, the most precious natural fibre has got its own importance in the world and it has been rightly designated as the 'Queen of textiles'. Though the demand for silk is in the increasing trend, its production and quality have been found to encounter many challenges. India has the unique distinction of cultivating all four commercially known varieties of silk namely, mulberry, tasar, eri, and muga silk, of which mulberry silk contributes to 86 per cent of the total raw silk produced in the country.

The total raw silk production in the world was about 1, 31,479 MT (2011). China is the largest producer of raw silk followed by India. The raw silk production in India is 23,060 MT and it contributes to 17.54% of the global silk production. Sericulture is a highly labour intensive agro-industry and provides employment to approximately 7.63 million people, most of them being small and marginal farmers (CSB, 2013).

Mulberry (*Morus alba* L.) is also an important commercial crop in India with an area of 81089 hectares having an annual production of 18,272 MT mulberry silk. Karnataka has the largest area (70,958 ha) followed by Andhra Pradesh (40,314 ha), Tamil Nadu (14,593 ha) and West Bengal (13,557 ha) Karnataka ranks first in production (7796.00 MT) followed by Andhra Pradesh (6446.64 MT) and WestBengal (1923.78 MT) (CSB, 2013).

Earlier Sericulture Federation and recently Rural Development Department of Government of Kerala mandated by the Central Silk Board (CSB) have explored the possibilities of mulberry cultivation in the state. In Kerala, mulberry is grown in an area of 51 ha with an annual production of 5 MT of raw silk. Victory-1 (V1) is the most widely cultivated variety in mulberry gardens of Kerala.

Mulberry is the sole food plant of the silkworm, *Bombyx mori* L. The quantity of leaves produced from the mulberry garden directly influences the silkworm rearing capacity (Sakthivel and Qadri, 2010) whereas the healthy growth of the silkworm and the economic traits influenced largely by the nutritional status of the leaves fed to the silkworm. The incidence of various pests and diseases in mulberry therefore causes both quantitative and qualitative losses that affect silk productivity.

Mulberry crop is damaged by more than 300 insect pests and non insect pests (Kotikal and Devaiah, 1987; Birader, 1989).Though a number of pests have been recorded on mulberry, only a few cause serious threat to its production like tukra mealybug, *Maconellicoccus hirsutus* (Green) causing crop loss up to 4500 kg $ha^{-1}year^{-1}$ (Muralikumaran and Baskaran, 1992 a, b) and thrips, *Pseudendrothrips mori* Niwa (Sakthivel and Qadri, 2010).

Of late, the infestation of papaya mealybug has posed a threat to the cultivation of mulberry in Agali, Sholayur and Puthur panchayats in Palakkad district, considered as the most potential areas for sericulture in Kerala. The infestation was found 60 to 80 per cent in the standing mulberry crops in these regions (Krishnakumar and Rajan, 2009).

Papaya mealybug feeds on the sap of plants by inserting its stylets into the epidermis of the leaves resulting in curling, crinkling, rosetting, twisting and general leaf distortion. When the infestation proceeds, yellowing of leaves followed by drying and shedding takes place. Sooty mould also occurs in the upper surface of leaves, that make them unfit for silkworm feeding.

Considering the widespread occurrence of the pest, its habitat and damage caused to mulberry cultivation in Kerala, it is essential to conduct a detailed study on identification of mealybugs, biology, collateral hosts, natural enemies, role in disease transmission and population dynamics to evolve an integrated pest management strategy with following objectives.

- To conduct survey for the assessment of population of mealybugs.
- To identify the different species of mealybugs in mulberry and study their biology.
- To identify the natural enemies of the mealybugs.
- To study the role of mealybugs as vectors in disease transmission.

- To study the study of predation of mealybug by commercially available predators.
- To study the efficacy of chemical pesticides and also the combination of chemicals and botanicals against the pest.
- To study the effect of promising treatments on silkworm rearing.
- To evolve an integrated mealybug management in mulberry.

Review of Literature

2. REVIEW OF LITERATURE

Papaya mealybug, *Paracoccus marginatus* (Williams and Granara de Willink) is an invader of agricultural and horticultural crops and is a serious economic threat to agriculture all over the world. In India it has been reported from Tamil Nadu. The pest has also invaded agricultural crops of Kerala, especially mulberry in Palakkad district. The information regarding the distribution, host range, description, biology, population dynamics, natural enemies, collateral hosts, symptom of infestation and the management of the pest are reviewed here.

2.1. MEALYBUGS OF MULBERRY

Mulberry was recorded as one among the many host plants for the bread fruit mealybug, *Icerya aegyptiaca* (Douglas) (Ayyar, 1919; Glover, 1935 and Rao, 1950). Siddappaji *et al.* (1984) reported the incidence of bread fruit mealybug as a new pest of mulberry in India. They reported that the mealybugs were situated along the midribs and larger veins on the lower surface of mulberry leaves. The large quantities of sap removed by this mealybug, cause immature leaves and stems to dry up and die.

The mealybug, *Maconellicoccus* sp. belongs to family Pseudococcidae and has been reported as a pest of mulberry in India, Bangladesh and Indonesia and identified the species as *M. hirsutus* (Green) (Chatarjee and Sarkar, 1993; Baskaran *et al.*, 1994; Bindroo and Dhar, 1996).

Muralikumaran and Baskaran (1992a, b) reported that seasonal incidence, transmission and severity of pink mealybug incidence in mulberry and the dreadful tukra disease, causing crop loss up to 4500 kg/ha/year. Tewari *et al.* (1994) reported it as a major pest of mulberries.

According to Manjunath *et al.* (2006), mulberry mealybug, *M. hirsutus* was a minor pest but later it was recorded as a serious polyphagous pest feeding voraciously on mulberry leaves and this statement was supported by Mala *et al.* (2007).

Shekhar and Qadri (2009) reported that papaya mealybug *P.marginatus* was found infesting severely, the mulberry gardens of Coimbatore and Erode districts of Tamil Nadu. According to them, an area of 1500 acres of mulberry plantations were destroyed by this pest and farmers were not able to rear silkworms as the quantity and quality of leaves were very much affected by *P. marginatus* (Mahalingam *et al.*, 2010).

In Kalimpong and Sikkim hills, root mealybug, *Paraputo* sp was causing considerable damage to mulberry plantations. It was found in the root zone and adjacent stump portion of mulberry below the soil surface up to 20 cm deep.The pest sucks sap and secretes honey dew and perpetuating fungal infection in severely infested plants. Growth of mulberry become stunted and normal growth of the plant ceases, leaves become yellow and appeared to be wilting. This pest caused severe damage in nursery gardens resulted in the mortality of young seedlings (Mukhopadhyay *et al.*, 2010)

Incidence of long tailed mealybug, *Pseudococcus longispinus* (Targioni-Tozzetti) on mulberry was first recorded by Sakthivel *et al.* (2011) in the mulberry farm of Farmers Training Centre (FTC), at Manikandam, Trichi in March 2011. They also observed that the infestation hampered the vigorous growth of plants and reduced the yield and quality of mulberry leaves.

2.2. STATUS OF PAPAYA MEALYBUG

2.2.1. Worldwide Distribution

Mealybugs (Hemiptera: Pseudococcidae) are important plant pests worldwide (Mckenzie, 1967; Williams, 1985; Williams and Granara de Willink, 1992; Miller *et al.*, 2005). About 630 species of coccids have been recorded from India, approximately 10% of world's known scale insect species. In the current decade, the trend of increased build up of various mealybug species in crop and wild plants was observed mainly due to certain abiotic changes in climate and environment (Tanwar *et al.*, 2007)

Papaya mealybug, a native of Mexico and Central America (Miller *et al.*, 1999), was first described in1992 (Williams and Granara de Willink, 1992) and later redescribed by Miller and Miller (2002). It was then reported in St. Martin in the Caribbean islands in 1995 and since then it has spread to 13 countries in the Caribbean, Florida in the US and three countries in South America by 2000 (Miller *et al.*, 1999; Matile-Ferrero *et al.*, 2000). In the early part of 2002, heavy infection of *P. marginatus* were observed on papaya in Guam (Meyerdirk *et al.*, 2004; Walker *et al.*, 2006), then it became established in the Republic of Palau in 2003 (Muniappan *et al.*, 2006; Walker *et al.*, 2006) and in Hawaiian islands in 2004 (Heu *et al.*, 2007). Papaya mealybug was reported infesting a large number of plant species in Columbo and Gampaha districts of Sri Lanka for the first time in 2008 (Galanihe *et al.*, 2010).

2.2.2. India

Incidence of papaya mealybug was first reported in the campus orchards of Tamil Nadu Agricultural University in July 2008 (Muniappan, 2009).

Subsequently, this mealybug assumed the status of a major pest in 2009, (Shekhar and Qadri, 2009) when it has caused severe damage to economically important crops including mulberry gardens (Ronald, *et al.*, 2007; Muniappan, *et al.*, 2008; Tanwar *et al.*, 2010). Surveys conducted during May 2009 between latitude and longitude ranges from 10^0.56'-11^0.16' north and 76^0.46'-77^0.10' east respectively in Coimbatore district of Tamil Nadu registered heavy infestations of *P. marginatus* (Anonymous, 2009).

The occurrence of papaya mealybug in Karnataka was reported by Shekhar *et al.* (2011) during the first week of June 2010, while conducting a routine survey for insect pests of mulberry in Hanahalli village, Chamarajanagar. The first case of papaya mealybug infestation in mulberry gardens of Andhra Pradesh was reported by Prasad *et al.* (2012) in the mulberry field of Thallapalli village of Palamaner area in Chittoor district.

2.2.3. Kerala

During July 2009, the papaya mealybug was found infesting the mulberry gardens in Agali, Sholayur and Puthur, panchayats in Palakkad district of Kerala state (Krishnakumar and Rajan, 2009).

2.3. HOST RANGE

Papaya mealybug is highly polyphagous. Ben-Dov (1994) listed *Carica papaya* L. (Caricaceae): *Parthenium hysterophorus* L.(Compositae): *Acalypha* sp., *Manihot chloristica* L. and *Manihot esculenta* L. (Euphorbiaceae): *Mimosa pigra* L. (Mimosaceae) and *Hibiscus* sp. and *Sida* sp. (Malvaceae) as its host plants.

Miller *et al.* (1999) collected specimens of papaya mealybug from a wide variety of host plants *viz*; papaya, *Hibiscus*, avocado, citrus, cotton, tomato, egg plant, peppers, beans and peas, sweet potato, mango, cherry and pomegranate in Central America, in the Caribbean islands and in U. S. In Cuba, Angeles *et al.* (2000) reported that *P. marginatus* caused significant damage to cassava and papaya when it was found for the first time in1999. It was also found on a variety of other plants but no economic damage was observed on major economic crops so far.

Miller and Miller (2002) listed 35 plant species as host plants for *P.marginatus*. The host plants were either annuals or perennial field crop plants, plantation crops, shrubs or trees, fruit trees, ornamental plants or weeds.

Meyerdirk *et al.* (2004) reported that papaya mealybug has a wide host range of over 60 species including economically important plants. They have also reported heavy infestation on papaya in Guam in 2002. Infestations of papaya mealybug were also reported in Palau in 2003 (Muniappan *et al.*, 2006) and Heu *et al.* (2007) in Hawaii. According to them, heavy infestation of papaya mealybug was observed on papaya, *Plumeria*, *Hibiscus* and *Jatropha*.

Ben-Dov (2008) reported the presence of papaya mealybug in 22 plant families. Surveys conducted during May 2009, in Coimbatore district of Tamil Nadu registered heavy infestations of papaya (*C. papaya* ; Caricaceae), mulberry (*Morus alba* L.; Moraceae), jatropha (*Jatropha curcus* L.; Euphorbiaceae) and tapioca (*M. esculenta* ; Euphorbiaceae) besides moderate to low infestations on shoe flower (*Hibiscus rosa-sinensis* L.; Malvaceae), guava (*Psidium guajava* L.; Myrtaceae), brinjal (*Solanum melenogena* L.; Solanaceae) and tomato (*Lycopersicon esculentum* L.; Solanaceae) (Anonymous, 2009). Regupathy and Ayyasamy (2010) reported about 50 hosts of papaya mealybug including field and horticultural crops, herbaceous perennials, climbers, trees, ornamentals and several weed hosts. According to them, weed species like Parthenium, Abutilon, Sida etc., also provided a green bridge for the successful perpetuation of this mealybug throughout the year.

An extensive survey conducted during 2009-2011 revealed the presence of *P. marginatus* on 133 plant species belonging to 48 families including pulses, oilseeds, fibre crops, narcotics, green manures, vegetables, fruit trees, tuber crops, flower plants, ornamentals, plantation crops, medicinal and aromatic plants, biofuel crops, tree species and weeds. Plants from Malvaceae, Solanaceae, Asteraceae and Euphorbiaceae were generally found preferred hosts of this mealybug species (Sakthivel *et al.*, 2012).

2.4. MEALYBUGS IN MULBERRY

2.4.1. Papaya Mealybug

Mealybugs are small, soft bodied plant sap-sucking insects that constitute the second largest family of scale insects (Hemiptera: Coccoidea), with more than 2,000 described species (Downie and Gullan, 2004; Ben-Dov, 2006). Scale insects (Coccoidea), infests a wide variety of host plants and no plant is free from attack of one or the other of these insects (Suresh, 2000).

When the mealybug specimens are placed in alcohol, they turn to blue-black in colour, which is characteristic of species in this genus (Williams, 1986). Williams and Granara de Willink (1992) gave a detailed description and illustration of papaya mealybug. They also provided descriptions and keys for the 21 species of *Paracoccus* occurring in Central and South America. According to him, the eggs were greenish yellow in colour and were laid in ovisac. The ovisac was placed ventrally on the adult female and was entirely covered with white wax. Adult males tend to be coloured pink especially during the prepupal and pupal stages but appeared yellow in the first and second instar.

Miller and Miller (2002) gave a complete description of all instars of both sexes of the papaya mealybug from other closely related species. According to them, the second instar, males are usually pink in colour and occasionally yellow and in first instar gender cannot be determined. The first instar mealybugs are approximately 0.4 mm long and 0.2 mm wide and the second instar measures 0.6 mm long and 0.3 mm wide. The third instar male is also called prepupa having a length of 0.9 mm and width of 0.4 mm. Adult males were approximately 1.00 mm long with an elongate oval body that is widest at the thorax (0.3 mm). They have ten segmented antenna, a distinct aedeagus, lateral pore clusters, a heavily sclerotized thorax and head well, and by having well developed wings. Adult females are approximately 2.2 mm long and 1.4 mm wide. A series of short waxy caudal filaments less than one fourth length of the body exist around the margin. The adult female can be distinguished from all other instars by having multilocular pores, translucent pores on hind coxa and a vulva. The body colour of the third instar female is yellow and length and width approximately 1.1 mm and 0.7 mm respectively. The body colour of second instar female is light yellow and length and width approximately 0.7 mm and 0.4 mm respectively.

The second instar females lack oral collar tubular ducts and multilocular pores and have 5 setae on the third antennal segment.

Two characters that are important in distinguishing *P. marginatus* adult females from all other species were the presence of oral rim tubular ducts dorsally restricted to marginal areas of the body and the absence of pores on the hind tibia (Miller and Miller, 2002)

2.4.2. Bread Fruit Mealybug

Descriptions and illustrations were given on different instars of *I. aegyptiaca*, by Azab *et al.* (1969). Eggs are yellowish orange, oval and measure 0.65 mm width. Crawlers were bright orange coloured with six segmented antenna. The second instar larvae also possess six segmented antenna and were yellow to orange in colour, oval in shape approximately 1.43 mm length and 0.98 mm width. They were covered with white mealy secretions and fringed with 21 snow white waxy processes. Third instar larvae were 2.2 mm x 1.5 mm in size. They were also yellow to orange coloured and covered with white mealy secretions and their 21 stout, tapering, snow white processes were about 2.5 mm long. Deep orange coloured adult was broadly oval with an average size of 3.1 mm - 2.2 mm or 5-7 mm x 3-4 mm (Rao, 1950). The legs were found to be blackish in colour with 11 segmented antenna.

2.4.3. Pink Hibiscus Mealybug

Eggs were pink in colour. Crawlers were 0.3 mm long. Immature and newly matured females were greyish pink in colour dusted with white mealy wax. Adult females were 2.5 to 4 mm long, soft bodied, elongate oval and slightly flattened. Slide mounted females show the combination of 9 segmented antennae, anal lobe bars, numerous dorsal oral rim ducts on all parts of the body except limbs and long flagellate dorsal setae. Males have one pair of very simple wings, long antennae, white wax filaments projecting posteriorly and no mouthparts (OEPP/EPPO, 2006).

2.5. BIOLOGY OF MEALYBUGS

2.5.1. Papaya Mealybug

Life history of mealybug, *P. marginatus* on three ornamental plants (*H. rosa-sinensis*, *Acalypha wilkesiana* (Muell-Arg) and *P. rubra*) and one weed species (*P. hyserterophorus*) was studied under laboratory conditions by Amarasekare *et al.*, (2008b). According to them, developmental period of the mealybug in days were in acalypha, egg (8.60 ± 0.10), first (5.90 ± 0.10), second [male (6.50 ± 0.10); female (3.80 ± 0.10)], third [male (2.80 ± 0.10); female (6.30 ± 0.10)] and fourth [male (4.50 ± 0.10)]; in *Hibiscus*, egg (8.40 ± 0.10), first (6.20 ± 0.10), second [male (6.80 ± 0.10); female (3.50 ± 0.10)], third [male (2.30 ± 0.10); female (5.90 ± 0.10)] and fourth [male (3.90 ± 0.10)]; in parthenium, egg (8.80 ± 0.10), first (5.80 ± 0.10), second [male (5.60 ± 0.10), female (5.20 ± 0.10)], third [male (3.40 ± 0.10); female (4.70 ± 0.10)] and fourth [male (4.10 ± 0.10)] and in *Plumeria*, egg (8.50 ± 0.10), first (6.60 ± 0.10), second [male (9.60 ± 0.10); female (5.30 ± 0.10)], third [male (2.70 ± 0.10); female (5.10 ± 0.10)] fourth [male (2.60 ± 0.10)]. The females reared on *Plumeria* laid a lower number of eggs (186.30 ± 1.80), *Hibiscus* (230.20 ± 5.30), Acalypha (235.20 ± 3.50) and parthenium (230.20 ± 5.30). The mean pre-oviposition (6.3 ± 0.1) and oviposition (11.20 ± 0.10) days were not affected by the host species.

The studies on effect of temperature on the life history of the mealybug, *P. marginatus* by Amarasekare *et al.* (2008a) revealed that the mealybug was able to develop and complete its life cycle at 18, 20, 25 and 30 ± 1°C. At 15, 34 and 35°C, the eggs hatched after 27.5, 5.9 and 5.5 days of incubation, respectively but found that further development of the first instar nymphs was arrested. The highest fecundity was at 25°C with each female producing an average of 300 eggs. For adult males, the estimated optimum and maximum temperature thresholds were 28.7 and 31.9°C and for adult females, they were 28.4 and 32.1°C respectively. The ability of *P. marginatus* to develop, survive and reproduce successfully between 18 and 30°C suggests that it has the capability to develop and establish in areas within this temperature range.

According to Shekhar and Qadri (2009), in female life cycle of papaya mealybug, there were 3 stages (egg, nymph and adult) and in male, there were 5 stages (egg, nymph, prepupa and adult). Female laid about 400-500 eggs, which hatched in one or two days. The females lived for about 30-60 days depending upon the environmental conditions.

According to Walker *et al.* (2006) and Tanwar *et al.* (2010) the females of papaya mealybug laid 100-600 eggs and egg laying continued over a period of one or two weeks. The eggs hatched in about 10 days. The males had longer developmental time (27-30 days) than females (24-26 days) at 25 ± 1°c, 65 ± 2% RH and 12:12 (L: D) photoperiod.

A laboratory experiment was conducted to study the biology of papaya mealybug, *P. marginatus*, revealed that the adult mealybug laid 197 to 436 eggs inside the ovisac and the mean incubation period was 4.8 ± 0.9 days. Female crawlers had three instars and males had four and took 11-15 and 17-23 days respectively to become mature. Female lived longer than males (6.40 ± 1.70 and 2.40 ± 0.70 days respectively). Egg laying occurred over the period of one to two weeks. Eggs hatched in 5-6 days. The developmental period for first, second, third and fourth instars were 2.60 ± 0.50, 4.80 ± 0.80, 5.50 ± 0.40 and 6.30 ± 0.90 respectively (Mishra, 2011).

2.5.2. Pink Hibiscus Mealybug

Misra (1919) has given brief notes on the life history of *M. hirsutus* on mulberry in India. According to him, eggs were bright pink, laid loosely in the ovisac. The average number of eggs laid per female was 232. Incubation period ranged from five to eight days. During March-October, the life cycle was completed in 24-29 days.

In Egypt, Hall (1921) studied the life history of this mealybug on *Hibiscus* sp. The adult female was reddish, sparsely covered with white wax and deposited 150 to 300 pink eggs in a loose cottony ovisac. These eggs hatched in 6 to 9 days. According to him, parthenogenesis was the main mode of reproduction but sexual reproduction was also observed. One generation occupied about five weeks during summer. Dutt *et al.* (1951) studied the biology of *M. hirsutus* on roselle. Incubation period was for seven days. He described various stages of the pest and also the mode of oviposition.

Life history of *M. hirsutus* was studied on mesta by Singh and Ghosh (1970). According to them, incubation period occupied six to seven days. Nymphal stage occupied 22 days. Pre-oviposition period lasted for 3-5 days. Only parthenogenetic reproduction was observed. Oviposition continued for 4-5 days.

Ghose (1972) made detailed investigations on *M. hirsutus* on roselle. The female had three nymphal instars while the male had four. The nymphal development in male and female was completed in 10 to 19 and 11 to 17 days respectively. Life cycle occupied 23 to 29 days. Females, reared from different host plants, laid 84 to 654 eggs.

Mani (1986) recorded the observations on life history of grape mealybug, *M. hirsutus* at 24 to 28°C temperature. A female laid eggs in a range of 350 to 500. Average incubation period was 5.15 days. Three nymphal instars in female and four nymphal instars in male were observed. The developmental period of female was 26 to 31 days while, it was 24.85 days in male. Total life cycle was completed in a month.

Ali and Ahmed (1990) gave a preliminary report on the mealybug, *M. hirsutus*. Reproduction was parthenogenetic with 100 to 200 eggs being laid in a sac. The life cycle was completed within 25 to 30 days.

Jadhav (1993) recorded observations on life history of grape mealybug, *M. hirsutus* on sprouted potatoes at different temperatures in laboratory (21.5°C), glass house (25.0°C) and BOD incubator (30.0°C). A female laid on an average of 385, 352 and 277 eggs and incubation period varied from 5-7, 4-6 and 3-5 days with mean of 6.10, 4.70 and 3.93 days at 21.5, 25.0 and 30.0°C respectively. The duration of nymphal period of female was 26-31, 25-27 and 23-26 days while for male it was 0, 21-23, and 20-21 days under 21.5, 25.0 and 30.0°C, respectively. No males were formed under laboratory conditions. The total life span of female was 48-58, 43-49 and 38-43 days at 21.5, 25.0 and 30.0°C, respectively. While in case of male, it was 27-34 and 25-29 at 25.0 and 30.0°C, respectively.

Verghese (1997) studied the colony number and size of settled nymphs of pink hibiscus mealybug on pumpkin (*Cucurbita moschata* Duchesne) in the laboratory. The mean number of pseudococcids per colony was 81, 47, 22 and 83 during 1st, 2nd, 3rd and 4th weeks, with mean colony diameters of 0.95, 0.98, 1.16 and 1.40 mm, respectively.

2.6. NATURAL ENEMIES

The lycaenid predator, *Spalgis epius* (Westwood) was commonly associated with the natural control of *Phenacoccus iceryoides*, *Phenacoccus glomeratus*, *Psuedococcus lilacinus*, *Planococcus citri* infesting cotton, *Pithocolobium saman*, Chinese rose and *Dolichos lablab* and Sesbania (Ayyar, 1929). Pushpaveni *et al.* (1973) recorded natural control of *M. hirsutus* on mesta while Mani and Krishnamoorthy (1998) recorded *S. epius* as a natural enemy of mango green shield scale. Seasonal distribution of *S. epius* was recorded on mulberry in June-December, 2009 (Thangamalar *et al.*, 2010)

During a survey in Lucknow on the natural enemies of mango insect pests, predatory mites of the genera, *Leptus* and *Bochartia* were found preying on the nymphs and adults of mealybug *Drosicha mangiferae* Green (Tandon and Lal, 1976). Berlinger (1977) reported that coccinellids of genera *Hyperaspis* and *Scymnus* preyed on the mealybugs on grapevine in Southern Israel. According to Prakasan (1987), the coccinellid, *Pullus pallidicollis* was found preying on *P. citri* and *P. lilacinus* in Wayanad district of Kerala.

Krishnamoorthy and Mani (1989) reported three lacewings, *viz.*, *Mallada boninensis* Okamoto, *Chrysoperla lacciperda* Kimmins and *Anisochrysa basalis* Walker preying on *P. citri* in citrus orchards and the last two also recorded on *M. hirsuitus* in vineyards. They also reported that *Chrysoperla carnea* (Stephens) and *C. lacciperda* were found feeding on *Ferrisia virgata* and *P. citri* in guava orchards.

Natural enemies of papaya mealybug include the commercially available mealybug destroyer (*Cryptolaemus montrouzieri* Mulsant) lady beetles, lacewings and hover flies, which are generalist predators that have a potential impact on mealybug populations (Walker *et al.*, 2003).

2.7. ASSOCIATION OF ANTS AND MEALYBUGS

Rajagopal *et al.* (1982) stated that the ant *Monomorium* sp. was found to be attracted to the sites of infestation by *Dysmicoccus brevipes* infesting the root nodules of red gram and ground nut.

Nine species of ants were seen in association with mealybugs on coffee in Coorg district of Karnataka and Wayanad district of Kerala and the species reported are *Crematogaster* sp., *Tapinoma brunnea, Technomyrmex albipes* (Smith), *Paratrechina longicornis* (Latreille), *Acropyga* sp. and *Plagiolepis* sp. and it was suggested that the presence of *Acropyga* sp. may be a strong reason for the lower incidence of mealybugs in Coorg (Venkataramaiah and Rehman, 1989).

Ants are encouraged by the farmers in controlling mealybugs. Way and Khoo (1992) reported that seven genera of dominant ant species, *Oecophylla, Dolichoderus, Anoplolepis, Wasmannia* and *Azecta* in tropics and *Solenopsis* in the tropics and subtropics and *Formica* in the temperate environments had beneficial role in controlling mealybugs. The ants interfered with predators and parasitoids attempting to attack the mealybugs. They protected the mealybugs from natural enemies and thus interfered with biological control (Cudjoe *et al.*, 1993). According to Chakupurakkal *et al.* (1994), the population of ants increased with the mealybug population.

Ant species such as *Oecophylla smaragdina* Fabricius, *Cremetogaster* sp. and *Anoplolepis gracilipes* (Fr. Smith) were found to attend on mealybug *P. citri* on *Hibiscus* (Tanwar *et al.*, 2007).

According to Tanwar *et al.* (2010), mealybugs were known to offer ants their sugary excretion (honey dew) and in return ants helped in spreading the mealybug and provided protection from predators, parasites and other natural enemies. Ants also kept the papaya mealybug colony clean from detritus that accumulated in the secreted honey dew, which may be harmful to the colony. Species of ant, *O. smaragdina* was found to attend papaya mealybug, feeding on jatropha, papaya and other plants.

2.8. ASSOCIATION WITH OTHER SPECIES OF MEALYBUGS

Papaya mealybug on guava, teak and other plants were found associated with other species of mealybugs.

According to Tanwar *et al.* (2010), two tailed mealybug, *Ferrisia virgata* was the most common species of mealybug found associated with *P. marginatus* in Coimbatore districts of Tamil Nadu on guava and teak. In Peramblur district of Tamil Nadu, guava leaves as well as fruits were found infested with a complex of mealybugs in which, *F. virgata* was the highest followed by *P. marginatus* and *M. hirsutus.*

2.9. SEASONAL INCIDENCE

According to Misra (1919), matured females of *M. hirsutus* moved down and established themselves in leaf scars, under the bark and notches on the stem. There they remained quiescent until the winter was over. Eggs hatched after the winter and the crawlers moved and established on mulberry and cotton plants producing characteristic malformation. The predatory caterpillar, *S. epius* appeared in late October and cleared all the colonies of *M. hirsutus*. During July-September, the mealybugs were preyed by *Eublemma* sp. Life cycle of *M. hirsutus* was completed in 24-29 days during

March-October but prolonged with the advancement of cold. During winter, one of the undetermined chalcid parasitoids of the mealybug was found to hibernate in its pupal stage on the stem or leaves. The predaceous cecidomyiid, *Diadiplosis indica* (Felt) was predominant from August to November and there after hibernated in the pupal stage in the colonies of mealybugs on the shoots.

In the Mediterranean climate of Egypt, *M. hirsutus* hibernated in the egg stage (Hall, 1921). The incidence of *F. virgata* has been reported to be more severe during dry season or prolonged period of drought (Rao, 1926). Das *et al.* (1948) observed heavy build-up of *F. virgata* during July-August on jute and on garden land fruit crops during winter and early spring in Dhaka, Bangladesh.

Azam (1983) found that the active period of *M. hirsutus* was during June-August and October-March on grapes around Hyderabad. Babu and Azam (1987b) surveyed the population density of grape mealybug, *M. hirsutus* around Hyderabad during 1984-85. The pest was found infesting the vegetative parts of the crop from early June (1.7 female adults/twig) to the end of December (5.1 female adults/twig). During the first fortnight of September to second fortnight of October, the female adult population decreased largely due to pruning operation. The mealybug again become active during January (22.5 female adults/bunch) and increased as the grape cluster developed and was abundant by March (32.5 female adults/ bunch) when the fruits were at ripening stage.

Shreedharan *et al.* (1989) reported that the pest, *P. citri* was severe in summer season (March-July) and no incidence was observed in winter season (October-November) in Mandarin orange (*Citrus reticulata* Blanw.) in Shevroy hills of Tamil Nadu. The studies on association with weather factors revealed that the population of mealybug was positively correlated with the temperature and negatively with relative humidity, while it had no clear correlation with total rainfall.

The population growth pattern of the Pseudococcid, *Phenacoccus manihoti* Matile- Ferrero was studied over two population cycles in cassava fields during 1985 - 87 in Freetown, Sierra Leone. The number and rate of dispersal of the insects were higher and the damage was more severe in the dry season than in rainy season. During the rainy season, the pest population consisted of mainly adults. Although rain is an important known abiotic natural control factor for the pest, the decline in the insect number started before the rainy season (James and Fofanah, 1992).

Field studies were carried out during 1995-96 in Andhra Pradesh, India to investigate fluctuation in *M. hirsutus* populations in grapes and *Annona reticulata* L. The highest population was found on grapes during the first half of July (vegetative phase) and during the second half of March (reproductive phase) and on *A. reticulata* in June (Murthy and Babu, 1996).

The phenology of mealybug, *Planococcus vitis* Nied attack grape vines in Southern Israel was characterized by a peak occurring between mid-May and mid-June, followed by a second smaller peak between October and December. Population remained very slow during winter, which was passed beneath the bark of the trunk (Berlinger, 1977). Murray (1978) reported that the numbers of *P. citri* were lowest in September, increasing to a peak population in January-June in Australia.

According to Godfrey and Pickel (1998), *Rhizoecus kondonis* Kuwana, a subterranean mealybug pest of alfalfa, prunes and other crops in California had three generations per year with peaks in abundance in July-August, December-January and March-April. The adults of *R. kondonis* were observed in late March and April and eggs were present in mid-April, the last fortnight of July and in September-October (Huang *et al.*, 1983).

The seasonal incidence of *P. solenopsis* Tinsley population was maximum (35 insects/ 5cm) during June and decreased slowly during September and there was no incidence up to February (Suresh *et al.*, 2010) in Coimbatore, Erode and Tiruppur districs of Tamil Nadu.

2.10. ENVIRONMENT AND MEALYBUG POPULATION

Hafez and Salma (1969) conducted a study in Egypt, on the bionomics of sugarcane mealybug, *Saccharicoccus sacchari* (Ckll.). According to them, peak populations were present in August-September when the average monthly temperature was 26.6°C - 27.3°C. There were four generations a year. Salma (1969) studied the response of the females of *Planococcus vitis* to temperature, humidity, light and contact alone or in combination and the orientation mechanism. The preferred temperature range was 16 - 34°C and this preference was unaffected by the relative humidity.

Liu and Chang (1984) reported that the populations of both nymphs and adults of citrus mealybug, *P. citri* on guava were large in cool and dry months from November to April and small in warm wet months from July to September. There was negative correlation between mealybug population and temperature. Incessant rainfall and heavy pruning of the trees also had an adverse effect on populations.

According to Amarasekare *et al.* (2008a), temperature was one of the important environmental factors that could influence the distribution and abundance of *P. marginatus* in the United States. They found that the ability of *P. marginatus* to develop, survive and reproduce successfully between 18 and 30°C and they had the capability to develop and establish in areas within this temperature range.

All the meteorological parameters influenced the infestation of cotton mealybug, *P. solenopsis* in all districts of Punjab. A positive correlation existed among the per cent field infestation, number of infested rows by mealybug and temperature whereas, negative correlation was observed with relative humidity and rainfall (Dhawan, *et al.*, 2009)

Suresh *et al.* (2010) found that *P. marginatus* was positively correlated with maximum temperature on *P. alba*. However, it was positively correlated with minimum temperature on *C. papaya, J. curcas* and *P. guajava*.

2.11. PHENOL CONTENT IN MEALYBUG INFESTED PLANTS

Goodman (1986) reported that cassava variety with a high phenolic acid level in its extracellular fluids was less preferred by *P. manihoti.* According to Janaki and Suresh (2012) total phenolic content of healthy leaves of less susceptible *Solanum viarum* was significantly highter (165 mg g^{-1}) than that of susceptible variety CO 2 (150 mg g^{-1}). This result provides evidence that total phenolic content in leaves place an important role in imparting resistance against mealybug because of direct toxicity. Increased total phenols were observed in mealybug infested leaves of CO 2 and *S. viarum* (293.75 and 178 mg g^{-1} respectively) in comparison to healthy counterparts (150 and 165 mg g^{-1}).

2.12. SYMPTOMS OF INFESTATON

Tanwar *et al.* (2010) reported that infestation of mealybug appeared as clusters of cotton-like masses on the above ground portion of the plants with long waxy filaments. Immature and adult stages of *P. marginatus* sucked sap of the plant and weakened the plant. The leaves became crinkled, yellowish and withered. The honey dew excreted by the bug and the associated sooty mould formation impaired the photosynthetic efficiency of the affected plants

Mealybug infested mulberry, *Jatropha* and *Parthenium* plants showed bunchy terminals with distorted leaves.. Yellowing of leaves followed by drying and shedding was common in mulberry and *Jatropha.* Severely infested plants of mulberry were stunted and had sooty mould formations rendering the leaves unfit for silkworm rearing (Anonymous, 2009).

According to Shekhar and Qadri (2009), the pink mealybug, *M. hirsutus* infested only the apical young leaves of plants whereas the papaya mealybug infested all parts of mulberry plants such as leaves, stems bottom shoots and stocks. The attacked leaves became wrinkled, plant stunted and leaves fell off after yellowing.

2.13. INTEGRATED PEST MANAGEMENT APPROACH

With rapid development, high survival rates and enormous reproductive capacity, *P. marginatus* population could potentially reach a high level and cause significant damage to a large number of economically important crops unless suitable management practices are implemented in a timely manner (Amarasekare, *et al.*, 2009).

Integrated pest management systems, make use of all options to reduce pest populations with priority to non-chemical measures (IOBC, 2008). Accordingly, chemical treatments should not be done on a regular, preventive basis, but only when essential. Ideally, modern crop protection agents do not affect natural enemies of pests and fit well in IPM systems (Grafton-Cardwell *et al.*, 2008; Rosell *et al.*, 2008).

Since early instar mealybugs were easier to control than late instars (Townsend *et al.*, 2000), timing insecticide application during emergence of early instars using their developmental times would be helpful in implementing a suitable IPM program for *P. marginatus.*

2.13.1. Prevention of Infestation

One of the first methods of mealybug control is to use plants that are not infested with the mealybugs for planting purpose. Prevention is a key factor in the management of mealybugs, because papaya mealybug is very difficult to control, once established. Efforts should be made to prevent spread and establishment of mealybugs by either inspecting the plant materials or treating or removing the host plants from the premises or not allowing water from infested areas to drain into clean areas, as crawlers can be transported in water (Hara *et al.*, 2001).

2.13.2. Cultural Control

Various weeds may serve as hosts for mealybugs. Control of weeds is one of the components in the management of mealybugs. Weeds have to be controlled from early in the season, since they act as access routes for ants (Addis, 2005).

2.13.3. Biological Control

Rao and David (1958) found that the beetles of *C. montrouzieri* released @ 500 adults along with 500 grubs / acre (10 beetles and 10 grubs / tree) were sufficient to suppress the population of various mealybugs. When a severe outbreak of mealybugs occurred in many coffee estates in Kerala, *C. montrouzieri* was released in one estate and though it did not establish there in 1977, a large number of adults and few larvae were recovered in four infested coffee plantations about 10 km away from released site.

Development and feeding of the coccinellid predator, *C. montrouzieri* was studied on the eggs, nymphs and adults females of the grape mealybug, *M. hirsutus*. The coccinellid grub consumed a total of 881.30 eggs or 259.00 nymphs or 27.55 adult females of *M. hirsutus* under laboratory conditions (Mani and Thontadarya, 1987).

Gautam *et al.* (1988) suggested the release of *C. montrouzieri* @ 2-3 beetles per tobacco *(Nicotiana tabacum* L.) plant for effective control of *F. virgata*. In a laboratory study it was shown that, the mean daily consumption rate of eggs of the Pseudococcidae, *M. hirsutus* by larvae of *C. montrouzieri* was significantly greater at 30°C than at 20°C (Babu and Azam, 1988).

According to Hamid *et al.* (1997), biological control using *C. montrouzieri* at a prey predator ratio of 1:15 caused a significant reduction of *P. citri* in citrus orchards.

Mani and Krishnamoorthy (1990) recommended the release 10 adults of *C. montrouzieri* per guava tree for effective control of *C. psidii.* Moreover, field release of *C. montrouzieri* @ 10 to 20 adults /guava tree gave excellent control of *F. virgata* within 50 days. This was observed in presence of other natural enemies. Hamid and Michelakis (1994) conducted experiments in green houses in Greece from November 1991 to January, 1992 and assessed the effects of *C. montrouzieri* for the control of *P. citri* on potted orange trees.

Mani *et al.* (1995) reported that the release of *C. montrouzieri* at 50 beetles per mango (*Mangifera indica* L.) tree had resulted in significant reduction of *Rastrococcus iceryoides* (Green).

Mani and Krishnamoorthy (1999) recorded *M. hirsutus* from acid lime for the first time in India in January 1999, at Bangalore, Karnataka. A parasitoid and a predator were recorded, but their effect was negligible. *C. montrouzieri* was released twice at 25 individuals/plant on 29 January and 15 February 1999, which resulted in a reduction of the mealybug population from 39.40/shoot in January to 1.30/shoot in mid-March.

Goolshy *et al.* (2000) made periodic releases of a green lacewing, *Chrysoperla rufilabris* (Burmeister), which reduced populations of the long tailed mealybug, *Pseudococcus longispinus* (Targioni-Tozzetti), in the interior plantscape. *C. rufilabris* eggs mixed with eggs of the Angoumois grain moth, *Sitotroga cerealella* (Oliver), as initial food for newly eclosed lacewing larvae, were placed. Each such release of lacewing eggs kept long tailed mealybug populations below aesthetic injury levels for four weeks.

Malleshaiah *et al.* (2000) studied the feeding potential of *C. carnea* on the eggs, nymphs and adult females of *P. citri* under laboratory conditions for the first time. The grubs were found active predators on mealybugs and the predatory grub preyed on all the stages of the mealybug.

Mani and Krishnamoothry (2001) conducted a study on the biological control of the pink mealybug, *M. hirsutus* on guava by using the Australian ladybird beetle, *C. montrouzieri.* The ladybird beetle was released (@ 20/plant) in the first week of June, in 1992, in Bangalore, Karnataka, India. A mean mealybug population of 918.50 per plant was observed in the first week of June at the time of releasing the predator. There was a reduction in the mealybug population, a month after the release of the predator and a mean of 4.60 per plant was recorded by the end of August 1992 on the predator released plants compared to 781.40 on the control plants.

According to Mishra (2011), the first, second third and fourth instar grubs of *C. montrouzieri* consumed 16.8 ± 0.4, 50.1 ± 0.8, 144.6 ± 1.9 and 189.1 ± 2.2 papaya mealybugs/day.

2.13.4. Management Using Botanicals

Verghese (1997) studied the effects of 5 and 2.5 per cent neem seed kernel extracts and Azadirachtin (Econeem) 9 ppm on newly hatched and late first instar (4 day old) nymphs of *M. hirsutus* under laboratory conditions. After 24 and 48 h, mortality of early first instar nymph was greatest with five per cent neem seed kernel extract (NSKE). The mortality of late first instar nymphs after 24 and 48 h was greatest with nine ppm Azadirachtin.

The effect of neem kernel water extract (NKWE) in different concentrations on *P. manihoti* was investigated in the laboratory at 23°C and in a greenhouse on cassava. A choice test showed that, neem treated cassava leaves were less attractive to first instar nymphs than untreated leaves. Pseudococcids that started feeding on treated leaves died in the second instar.

A greenhouse experiment showed that three applications of NKWE at weekly intervals protected cassava against established early instar nymphs (Mourier, 1997).

2.13.5. Chemical Control

Snetsinger (1996) reported endrin (19.5EC @ 0.5ml L^{-1}), aldrin (5 per cent granules) and dimethoate (43.5 EC @ 1 ml L^{-1}) gave 100 per cent control of root mealybug *Rhizoecus pritchardi* on *Sainpaulia*, an ornamental plant in Pennsylvania.

Dorge and Murthy (1974) reported that, in a field test on effectiveness of various insecticides against *F. virgata* on custard apple, malathion (0.1%) applied @ 6.5 litres/tree resulted in greatest reduction in pest population. The pest can be checked by spraying the trees with diazinon or phosphamidon (0.03% each) emulsion or malathion or dimethoate (0.05% each) insecticides on citrus (Atwal, 1976).

Rao *et al.* (1977) inferred that, dichlorvos (0.15%) with combination of fish oil rosin soap (2.5%) gave 80 per cent mortality of mealybugs while dichlorvos (0.15%) alone gave 67% mortality. Butani (1978) recommended spraying with malathion (0.04%) or phosphamidon (0.03%) against young nymphs and with diazinon or monocrotophos (0.1%) against older nymphs and adults. The effectiveness based on the mortality of the mealybug was reported to be the highest for dichlorvos, followed by fenvalerate and monocrotophos. (Anonymous, 1982)

The effectiveness of ten insecticides evaluated for the control of *Planococcus pacificus* Cox. on custard apple both in laboratory and fields in Karnataka. The result showed that, dimethoate, phosphamidon, dichlorvos and monocrotophos, all at 0.05 per cent gave the best control (Shukla and Tandon, 1984).

In another study, dipping the grape bunches in fenvalerate or dichlorvos at 2 ml L^{-1} effectively controlled the mealybug. The efficacy of the treatments was increased when fish oil rosin soap was added; however, berries had brownish blotch underneath due to accumulation of the mixture (Reddy and Narayana, 1986).

Rao *et al.* (1988) tested three conventional insecticides, *viz.*, dichlorvos, monocrotophos and dimethoate each at 0.05% against grape mealybug, *M. hirsutus* on two varieties, Anab-e-Shahi and Thompson Seedless. The per cent knockdown in colonies 10 days after spraying in Anab-e-Shahi was 51 and 52 by dichlorvos and dimethoate, respectively.

Su and Wang (1988) reported that the pseudococcid, *P. citri* infesting grape vine in Taiwan was effectively controlled by the application of malathion 40 EC and dimethoate 44 EC causing 93-100 per cent mortality of the pest. Debarking of infested vines, followed by sprays of dichlorvos (0.02%) in combination with fish oil rosin soap (2.5%) helped to control *M. hirsutus* on grape vine (Mani, 1990).

In a laboratory study, Singh *et al.* (1991) observed that fensulfothion was the most toxic insecticide to adult females of mealybug, *D. mangiferae* followed by dimethoate, fenthion, fenitrothion, parathion, quinalphos, methyl demeton, phosphamidon, formothion and disulfoton.

In a field trial carried out in coffee cv. Catimor in Kerala to determine the effectivenss of soil application of dimethoate and monocrotophos at 0.05, 0.075 and 0.1 per cent against *Planococcus lilacinus*, dimethoate at 0.1 per cent was found to be most effective treatment (Kumar and Prakasan, 1992).

Beevi *et al.* (1992) tested ten insecticides as sprays in laboratory against eggs of mealybug, *M. hirsutus*. Hatching was least in eggs treated with neem oil (0.3%) followed by moncrotophos (0.04%), methyl demeton (0.04%) and fish oil rosin soap (2.5%) + dichlorvos (0.2%). Hatta and Hara (1992) reported that spraying with chlorpyriphos (0.03%) totally eliminated pseudococcids on ginger in Hawaii.

Balikai (1999) reported that, mealybug population was the lowest (1.17 and 5.90 colonies per vine at 30 and 60 days after treatment, respectively) on grapes where the pest colonies were disturbed with tooth brush and then sprayed with dichlorvos 76 EC @ 2 ml of water followed by lannate 24 L @ 2 ml + Teepol 0.5 ml L^{-1} and dichlorvos 76EC @ 2 ml L^{-1} + Neemark @ 5 ml + Teepol 0.5 ml L^{-1} of water.

Baskaran *et al.* (1999) reported that, *F. virgata* was the dominant coccid species, infesting 98 per cent of guava trees, followed by *M. hirsutus*.

Monocrotophos (0.072%), malathion (0.25%), dimethoate (0.06%) and phosalone (0.175%) were evaluated for *F. virgata* control. Dimethoate and malathion were most effective in controlling *F. virgata*. Guava leaf disks were offered to *F. virgata* after treating with phosalone (0.175%), phosphamidon (0.086%), monocrotophos (0.072%), dichlorvos (0.1%), malathion (0.25%) and dimethoate (0.06%) by leaf dipping and leaf spraying. The leaf dip assay was most effective, recording cent per cent mortality at 24 h after treatment. Patricia (1999) found that one application of imidacloprid 350 SC (Confidor) in spring through drip irrigation systems at 0.75 g a.i. plant $^{-1}$ can provide an effective control of grape mealybug during the entire season.

Hassan (1999) compared the efficacy of diazinon (60% EC), dimethoate (30% EC), malathion (50% EC), summer oil [mineral oil] (98% EC) and KZ oil [mineral oil] (95% EC) against the California red scale insect, *Aonidiella aurantii* (Maskell) and the cottony cushion scale, *Icerya purchasi* (Maskell) insect under standard laboratory conditions and the results indicated that diazinon was the most potent insecticide, followed by dimethoate, malathion, summer oil and KZ oil.

Major insecticides used against mealybugs include diazinon, dimethoate, azinfosmethyl, chlorpyriphos, parathion, pyrimifos-methyl and malathion, which were applied singly or in mixtures that include mineral oils (Vacante, 1988; Peleg and Bar-Zakay, 1995; Dreishpun, 2000).

Labanowski and Soika (2001) reported that Mospilan 20 SP (acetamiprid) and Confidor 200 SL (imidacloprid) applied as spray treatment were very effective in controlling citrus mealybug, *Planococcus citri* (Risso). Daane *et al.* (2006) suggested that IGR (buprofezin) and nicotine based insecticides (imidacloprid) could be recommended as good alternative pesticides against *M. hirsutus* in vineyards.

Suresh *et al.* (2010) evaluated efficacy of different insecticides against *P. solenopsis*. The insecticides, profenophos and methyl parathion were found to be quite effective and caused cent per cent mortality one day after treatment while imidacloprid, fish oil rosin soap and dimethoate caused cent per cent mortality after two days of the treatment imposition. All the tested insecticides were found to be quite effective upto 10 days after application.

Materials and Methods

3. MATERIALS AND METHODS

Investigations on papaya mealybug in mulberry including survey, identification and biology of the mealybugs, natural enemies, collateral hosts, effect of predators, role as a vector in disease transmission, effect of chemical treatments against mealybug and on silkworm rearing and also pest management studies were conducted in the present study.

3.1. SURVEY AND ASSESSMENT OF PAPAYA MEALYBUG INFESTATION ON MULBERRY IN KERALA

A preliminary survey was conducted districtwise to collect the information regarding the presence of the papaya mealybug on mulberry in Kerala. From the severely infested district of Palakkad, three panchayats were selected for detailed survey. A proforma for conducting the survey (Appendix 1) was prepared to collect the information about the infestation of mealybugs. From these selected panchayats, list of farmers growing mulberry in more than one acre were prepared. A simple random sample of 10 farmers from each panchayat was selected to get a total of 30 farmers. From each selected field, 50 mulberry plants were taken at random for the detailed study. Seasonal distribution of papaya mealybugs was assessed for one year at monthly intervals from October 2009 to September 2010.

3.1.1. Assessment of Papaya Mealybug Population.

The distribution of mealybug and its egg mass in mulberry was assessed from 10 centimeters of the growing tip of each of the selected 50 mulberry plants (selected from 30 mulberry plots). A total of 12 observations were recorded.

3.2. FIELD SURVEY FOR THE NATURAL ENEMIES OF PAPAYA MEALYBUG

The distribution of predators and parasitoids in mulberry was assessed from the selected panchayats by observing 10 cm growing tip of the mealybug infested plants. These observations were taken from October 2009 to September 2010 (12 observations).

3.3. COLLATERAL HOSTS

The weed and host plants grown in and around the mulberry gardens infested with mealybugs were examined for the infestation. This experiment was done throughout the study period from October 2009 to October 2012. Infestation by mealybugs was categorized on the following parameters based on visual observation. During survey, whole plants of the species were examined for occurrence and infestation levels as described by Arif *et al.* (2009)

Parameter	Infestation levels
Incidental (*)	Only a few individuals of the mealybug casually found. No breeding individuals observed.
Low (**)	All stages of mealybug found in low numbers. No adverse symptoms like deformation of leaf observed on the plant
Medium (***)	All stages of mealybug found in large numbers. Wilting and yellowing of plant leaves observed. Infested plant normally survived.
High (****)	All stages of mealybug found in very large numbers. Almost all plant parts (stem, leaves, flowers and fruits) covered with mealybug showing white appearance. Leaves, fruits and inflorescences covered with honey dew excretion and sooty mould. Excessive leaf and fruit shedding. Most of the plants died in the infested area.

3.3.1. Preference to Collateral Hosts

An area of 50 m^2 was divided in to four blocks. The weed plants in each block were observed to record the severity of infestation. The number of egg masses, mealybugs and predators were counted from the terminal 10 cm portion of these plants. Observations were recorded at bimonthly intervals for six months from June 2010 to December 2010 Data were tabulated and analyzed by Completely Randomized Design.

3.4. CROP HUSBANDRY PRACTICES

The important cultivation practices and the pest control measures followed were recorded.

3.5. CORRELATION OF PAPAYA MEALYBUG AND ITS PREDATOR POPULATION WITH WEATHER PARAMETERS

Weather parameters were collected from Attappadi Hill Area Development Society (AHADS) located in Palakkad district to study the correlation between papaya mealybug and its predator population with weather parameters.

3.6. IDENTIFICATION OF PAPAYA MEALYBUG AND ITS PREDATOR

Different stages of the mealybugs were collected in polythene bags for identification and mass multiplication in the laboratory. Adult mealybugs were collected from infested mulberry gardens at Agali, Sholayur and Puthur panchayats.They were killed and preserved in 70% alcohol in small vials (5ml capacity). The specimens were sent to the National Bureau of Agriculturally Important Insects (NBAII), Bangalore and got identified.

The predator obtained was reared to the adult stage and identified at NBAII, Bangalore.

3.7. BIOLOGY OF MEALYBUG

Biology of the mealybugs identified was studied in the insect rearing laboratory, Department of Entomology, College of Agriculture, Vellayani. The study was conducted at room temperature of approximately 28.3^{0}C ± 0.2^{0}C. The experiment was laid out in Completely Randomized Design (CRD) with ten replications.

3.7.1. Eggs

The gravid females from the colony were placed individually on newly sprouted potatoes and kept in glass troughs lined with wet tissue paper and observed regularly for egg laying. Once the egg laying was initiated, the shape and colour of eggs were observed under microscope. The size of ten freshly laid eggs was measured using a micrometer in a calibrated microscope model Leica M 165 C. Eggs collected from single female were placed on the sprouts with 10 eggs per sprouts using a camel hair brush. The sprouts were checked daily for egg hatch. The number of days taken for egg hatch and emergence were noticed. Ten replications were maintained.

3.7.2. Hatching Percentage

The number of eggs laid by 10 female mealybugs were counted and kept for emergence. Number of crawlers emerged was counted to calculate the percentage hatching.

$$\text{Hatching percentage} = \frac{\text{Number of eggs hatched in the egg mass}}{\text{Total number of eggs in the egg mass}} \times 100$$

3.7.3. Incubation Period

Once the egg laying was complete such sprouted potatoes were transferred to another glass jar and kept undisturbed. Freshly laid egg masses were observed daily for the emergence of crawlers. The incubation period was counted from the day the first egg was laid to emergence of the first crawler in the egg mass. Ten replications were maintained for study.

3.7.4. Nymphal Instars

Freshly hatched nymphs were kept in glass troughs lined with double layered wet tissue paper. Potato sprouts were provided for feeding. Dark condition was provided by covering the trough with black chart paper and observed daily for moulting.

3.7.5. Adults

The adult female mealybugs were examined under microscope to observe its colour, shape and behaviour. The length and width was measured using a micrometer in a calibrated microscope model Leica M 165 C.

3.7.6. Oviposition Period

The adult female mealybugs which started oviposition were kept separately and period of egg laying was observed. Ten replications were maintained.

3.7.7. Fecundity

After completion of egg laying, the number of eggs laid per female was counted under 10X objective of the Stereo zoom microscope.

3.7.8. Longevity

Adults were collected and ten freshly moulted adults were kept singly on potato sprouts in a glass jar covered with muslin cloth. Date of mortality of adult was recorded and thereby the adult longevity was calculated.

3.8. MASS MULTIPLICATION OF MEALYBUG

Mass rearing of mealybug was tried on different plant parts, *viz.*, papaya fruits, pumpkin fruits, sprouted potatoes and amorphophallus.

Potatoes are used as an alternative food source for rearing of mealybugs (Tsugawa, 1972; Sagarra and Vincent, 1999; Serrano and Laponite, 2002). Seed potatoes with eyes (Amarasekare *et al.*, 2009) were brought from local markets were washed and disinfected in 5% Sodium hypochlorite solution. After cleaning, the potatoes were treated with gibberlic acid 100 ppm solution for half an hour and placed under dark condition in wet gunny bags for four to five days to induce early sprouting. The tubers were then sown in plastic basins filled with moist sand. Before filling, the sand was sterilized in hot air oven at 1000°C to prevent infestation by any pathogen which might induce rotting of tubers. Crawlers collected from the field were introduced on the green sprouts when they reached a height of 15-20 cm using a camel hair brush and mass cultured continuously for several generations (Plate 1).

3.9. BIOLOGY OF THE PREDATOR

The number and duration of larval instars and pupae were recorded. The emerged adults were kept separately in cages for egg laying.

3.9.1. Feeding Efficiency of the Predator

The feeding potential of the larval instars of the predators against each stage of mealybug was studied under laboratory conditions. Known numbers of different stages of mealybugs were provided in petri dish (9 cm diameter) separately for the second, third, fourth and fifth larval instars of the predator.

Plate 1.Mass multiplication of papaya mealybug on sprouted potatoes

3.10. ESTIMATION OF PHENOL IN MULBERRY LEAVES

The estimation of phenol in mulberry leaves was done to confirm the role of microorganisms in the damage of mulberry leaves in the mealybug infested fields.

Mulberry leaves with 0, 25, 50, 75 and 100 per cent of infestation were taken from the infested mulberry gardens of Palakkad district.The phenol content was estimated following the procedure described by Bray and Thorpe (1954). One gram leaf sample was homogenized in 10 ml of 80 per cent ethanol. The homogenate was then centrifuged at 10000 rpm for 20 minutes, supernatant was saved and residue was extracted with five times the volume of 80 per cent ethanol and centrifuged as above. The supernatant was saved and evaporated to dryness in a boiling water bath. The residue was dissolved in 5 ml distilled water. An aliquot of 0.2 ml was pipetted out and made up to 3 ml with distilled water. Folin-Ciocalteau reagent (0.5 ml) was added and 2 ml of 20 per cent sodium carbonate solution was added to each tube after three minutes. This was mixed thoroughly and kept in boiling water for one minute. The reaction mixture was cooled and absorbance was measured at 650 nm against a reagent blank. Standard curve was prepared using different concentrations of catechol and expressed in catechol equivalents as mg g^{-1} of leaf tissue on fresh weight basis.

3.11. ROLE OF PAPAYA MEALYBUG AS A VECTOR IN DISEASE TRANSMISSION

3.11.1. Immunodetection of Virus Using Direct Antigen Coating-Enzyme Linked Immunosorbent Assay (DAC-ELISA)

ELISA test was conducted for the detection of any virus infecting symptomatic mulberry plants. Diseased samples were collected from the plants showing leaf curl symptoms and were tested for the reported viral diseases of mulberry. The Serodiagnosis of the virus was carried out following the procedure described by Huegenot *et al.*, 1992.

The healthy and infected leaf samples were ground separately in the coating buffer (carbonate buffer) in the ratio of 1:5 (W/V). The homogenate was centrifuged at 5000 rpm for 10 minutes at 4^0C.The treatments were replicated thrice. After incubation for 2 hrs at 37^0C the wells were washed with PSB-T, three times each for duration of three minutes. The plates were washed using a plate washer (BIORAD) to remove excess PBS-T. Blocking was done with 100 µl of 1% BSA for 30 minutes at 30^0C.After incubation blocking agent was removed, plates were washed with PBS-T as before. Antibodies specific for SMBV and BSMV were used. The antibodies at 1:10000 dilution in PBS-TPO were added and incubated overnight at 4^0C. The plates were washed with PBS-T (10^{-4}) and incubated for 2 hrs at 37^0C.Wells were washed with PBS-T as before. The substrate para Nitro Phenyl Phosphate (p-NPP) in diethanol amine buffer (1 mg ml^{-1}) was added each well (100 µl/well) and incubated for 1 hr at 37^0C. Reaction was stopped by adding 50 µl of 4% Sodium hydroxide. The absorbance was read at 405 nm in an ELISA reader (BIORAD model 680 micro plate readers).

3.12. EFFICIENCY OF COMMERCIALLY AVAILABLE PREDATORS

3.12.1. Cultures of *Chrysoperla carnea* and *Cryptolaemus montrouzieri*

The adults and grubs of *C. montrouzieri* and eggs of *C. carnea* were obtained from NBAII, Bangalore. *C. montrouzieri* was mass reared on *Maconellicoccus hirsutus* (Green) (Plate 2). The methodology as described by Babu and Azam (1987a) was followed for mass culturing of the predator. The rearing cages of 30 X 30 X 30 cm size covered on all sides with a 40 mesh and a glass pane on the top was used for the rearing of *C. montrouzieri*. The pumpkins (*Cucurbita moschata* Duchense) were treated with carbendazim (1g L^{-1}) to avoid fungal attack and the wounds were treated with wax before placing in the cages. One hundred adults and grubs of *C. montrouzieri* each were released in separate cages. Infested pumpkins with pink hibiscus mealybug, *M. hirsutus* were periodically provided for the development of the predator.

Plate 2. Mass multiplication of pink hibiscus mealybug on pumpkin

3.12.2. Feeding Potential of *C. carnea*

The feeding potential of *C. carnea* was observed in two categories, *viz*., no choice feeding and free choice feeding (Rashid *et al*., 2011). The experiment was laid out in Completely Randomized Design with four replications.

3.12.2.1. No Choice Feeding

The feeding potential of the larval instars of *C. carnea* against each stage of mealybug, *viz*., ovisac, first, second and third instars was studied under laboratory conditions. Known numbers of different stages of prey insects were provided in petri dish (9 cm diameter) separately for the first, second and third nymphal instars of *C. carnea*. Each treatment was replicated four times. The number of prey insects consumed was recorded daily. Fresh ovisacs and mealybugs were provided to the predator until they reached the next instar. In this way, the number of prey insects consumed during each larval instar was recorded.

3.12.2.2. Free Choice Feeding

In this experiment, single larva of each larval instar of the predator was introduced into petri dish (9 cm diameter) with the help of camel hair brush along with known number of mealybugs of 1-3 nymphal instars for feeding. Free choice feeding of each predator instar on each instar of prey (*P. marginatus*) was recorded daily till the completion of each instar of the predator

3.12.3. Feeding Potential of *C. montrouzieri*

The methodology of no choice and free choice feeding for *C. carnea* were followed here with the different first, second, third and fourth instar grubs and adults of *C. montrouzieri*. The number of different stages of *P. marginatus* consumed during each grub stages of the predator was recorded.

The experiment was laid out in Completely Randomized Design with four replications.

3.13. LEAF DIP BIOASSAY

The method described by Elbert and Nauen (1996) was followed. Leaf discs (45 mm diameter) were cut from medium sized papaya leaves using a sharp blade and dipped in respective solutions of botanicals and insecticides for a minute, then dried on filter paper in open air for 20 minutes. The bases of the small ventilated 50 mm diameter polythene petridishes were filled with 5 ml agar gel (12 g L^{-1}) to maintain the turgidity of leaf. The leaf discs were placed on the agar with its adaxial surface downwards. First instar nymphs and adult females were obtained from the potato culture and placed on a black cloth. Using a fine camel hair brush, 10 mealybugs (per replication) were then transferred onto the treated leaf discs and the setup was covered with a lid. Leaf discs immersed in water alone served as control. This was replicated three times and observations were made. The mortality was recorded 24 and 48 hours after the exposure to insecticides.

Insecticides used for laboratory bioassay

Sl.No	Insecticides/botanicals	
	Common name	Trade name
1	Dichlorvos	Doom 76 EC
2	Dimethoate	Rogor 30 EC
3	Imidacloprid	Confidor 17.80 SL
4	Abamectin	Dynamite 1.90 EC
5	Azadirachtin	Econeem plus 1EC
6	Neem seed kernel extract (NSKE)	

3.14. EFFICACY OF CHEMICAL PESTICIDES AGAINST PAPAYA MEALYBUG

Efficacy of selected insecticides/botanicals was evaluated against papaya mealybug by leaf dip bioassay and the most effective chemicals, first and second will be identified from this experiment. The experiment was laid out in completely randomized block design with three replications.

Details of treatments for the evaluation of chemicals against papaya mealybug

Treatments		Dose	Quantity used
T1	Dichlorvos	0.05%	0.60 ml L^{-1}
T2	Dimethoate	0.05%	1.70 ml L^{-1}
T3	Dimethoate	0.1%	3.40 ml L^{-1}
T4	Imidacloprid	0.005%	0.30 ml L^{-1}
T5	Imidacloprid	0.01%	0.60 ml L^{-1}
T6	Abamectin	0.003%	1.60 ml L^{-1}
T7	Abamectin	0.006%	3.20 ml L^{-1}
T8	NSKE	2.5%	2.50 g L^{-1}
T9	NSKE	5%	50 g L^{-1}
T10	Control (untreated)		

3.15. EFFICACY OF CHEMICALS + BOTANICALS AGAINST PAPAYA MEALYBUG

Based on the laboratory studies envisaged in the section 3.6, the two promising chemicals ranking first and second were selected. Solutions of half the quantity of each chemical ranked first and second in combination with NSKE 5% and econeem plus 2 ml L^{-1} were evaluated against papaya mealybug by using leaf dip bioassay. Mortality was recorded 24 and 48 hours after exposure to insecticides. The experiment was laid out in completely randomized block design with three replications.

	Treatments
T1	Most effective chemical (I^{st})
T2	Second most effective chemical (II^{nd})
T3	Half I^{st} + NSKE 5%
T4	Half I^{st} + Econeem plus 2 ml L^{-1}
T5	Half II^{nd} + NSKE 5%
T6	Half II^{nd} + Econeem plus 2 ml L^{-1}
T7	Control

3.16. EFFECT OF PROMISING TREATMENTS ON SILKWORM REARING

Silkworms were reared on mulberry leaves treated with most promising treatments against papaya mealybug to assess safe period for collection of leaves for feeding.

Raising Mulberry

Mulberry crop variety V-1 was raised and maintained throughout the period of investigation in the College of Agriculture, Vellayani. The mulberry crop was raised and managed following the package of practices of the Central Silk Board. The leaves were harvested daily in the morning and evening. Diseased and poor quality leaves were rejected.

Silkworm rearing

Disinfection

The disinfection was carried out two to three days prior to the incubation of eggs. The rearing equipments and the rearing rooms were cleaned properly and removed the dead larvae, leaf bits and other debris. The rearing equipments were washed with 5% bleacing powder solution and sun dried. The windows and doors in the rearing room were closed and sealed by pasting paper. The rearing room was cleaned and air dried. After room cleaning, floor, walls and the roof of the rearing rooms were disinfected with 5% bleaching powder solution. After spraying, the rooms were kept closed for 24 hrs. Then doors and windows were opened and air circulation was allowed in the room for 24 hrs for the fumes to disappear.

Eggs

Disease free layings (DFLs) were procured from Silkworm Seed Producing Centre, a unit under Central Silk Board at Kozhinjampara of Palakkad district (Plate 3).

Incubation

The silkworm eggs were incubated properly to promote uniform hatching. For this, eggs at blue head stage were covered with black paper and kept in a small wooden box on the day prior to hatching.

The loose eggs were spread on paraffin paper placed in a plastic tray and the moist foam pads were kept all around the paraffin paper so as to maintain relative humidity at 80-85 per cent. The paper and foam pads were covered by another paraffin paper and kept for incubation.

Brushing of Larvae

The next day at 8 AM, the incubated layings were exposed to diffused sunlight in the rearing room. Ninety per cent of the eggs were hatched out by 10 AM. Tender mulberry leaves were chopped into 0.5 cm^2 size and sprinkled over the layings for easy handling of worms to the rearing bed.

Feeding Silkworms

The silkworms (Plate 4) were fed with good quality mulberry leaves chopped into required size according to different larval stages to ensure their healthy and uniform growth. Four feedings were given at 6 AM, 11 AM, 3 PM and 8 PM. The quantity of leaves for each treatment was measured before feeding.

Bed Cleaning

The unconsumed leaves, faecal pellets, exuviae of moulted larvae and dead larvae were removed from the rearing bed. The bed cleaned once during the first and second instar larval stages just before setting for moult. Two cleanings were given at third instar stage. In the fourth instar stage, the rearing beds were cleaned on alternate days and the fifth instar larvae were cleaned daily before the first feed.

Nylon nets were used for bed cleaning. The nets were spread over the bed and one or two feedings were given. The nets were then lifted with fresh leaves and larvae were transferred to a new clean and disinfected tray.

Larval Spacing

The larval spacing was given for the first and third experiments were according to the Package of Practices recommendations of the Central Silk Board.

Moulting

The worms were handled with utmost care during moulting stage. The paraffin cover was removed and the rearing beds were widened and spread to facilitate uniform moulting. Once new worms came out of moult, Vijetha powder was dusted in the rearing bed and on the larvae to prevent fungal infection.

Young Age Silkworm Rearing

The rearing practices followed for the first and second instar larvae were almost similar. They were fed four times a day with tender leaves chopped to 0.5 to 1.0 cm^2 during first instar and 1 to 2 cm^2 during the second instar. The humidity requirement for these instars was 85 per cent and it was provided in the rearing bed by keeping moist foam pads and covered with paraffin papers. The temperature was maintained was 27°C for both of these instars. At moulting, the practices mentioned earlier were followed.

Late Instar Rearing

The third, fourth and fifth instars were reared in bamboo trays in which newspapers were used for spreading in the tray as support. The newspapers were changed during cleaning of each instar. The third instar larvae were fed with leaves cut to a size of 3 cm x 6 cm and for the fourth and fifth instar larvae, entire leaves were given. For all these instars four feedings per day were provided. Three bed cleanings were given for the third instar larvae and during the fourth and fifth instar larval stages, daily bed cleanings were done. Leaves of medium maturity were fed to the third and fourth larval stages and coarse mature leaves were fed to the fifth stage.

Mounting

At the end of the fifth instar, the mature worms were identified from the rearing trays and placed in the chandrike for spinning the cocoons. The density of mature worms mounted was 40-45 worms per sq.feet in the mountage.

Harvesting of Cocoons

The cocoons (Plate 5) were harvested on the sixth day from the mountage. The cocoons were weighed after cleaning by removing the faecal pellets or any other extraneous materials and also the outer floss sticking on to its surface. Samples were taken from these cocoons for recording weight of cocoons, shells and pupae.

Variety of silkworm	– Bivoltine hybrid
Treatments	- Four
Number of replications	– Six
Design of experiment	– CRD

Plate 3. Disease free layings of silkworm

Plate 4. Silkworm larvae

Plate 5. Silkworm cocoons

Observations

Total Larval Duration

Instarwise larval duration was recorded and duration for all the five instars was added to compute total larval duration.

Single Cocoon Weight

Ten cocoons from each replication of the treatments were collected at random and their weight was recorded using a Melter-electronic precision balance and from these, the average single cocoon weight was computed.

Shell Weight

The above sample cocoons were cut open, the pupa and exuviae were removed and the shell was weighed in an electronic balance. The average shell weight was computed.

Shell Ratio

The shell ratio was determined by using single cocoon weight and shell weight

Shell ratio = (Weight of single shell / Weight of cocoon) X 100

Effective Rearing Rate (ERR by number)

Effective rearing rate (ERR by number) was calculated using the formula of Rahman (1989).

$$\text{ERR (By Number)} = \frac{\text{Number of cocoons harvested}}{\text{Number of worms brushed}} \times 10{,}000$$

Effective Rearing Rate (ERR by weight)

Effective rearing rate (ERR by weight) was calculated using the formula of Rahman (1989).

$$\text{ERR (By Weight)} = \frac{\text{Number of cocoons harvested}}{\text{Number of worms brushed}} \text{ X 10,000 X (single cocoon weight)}$$

3.16.1 Larval Weight

The larval weight was recorded by weighing ten worms one day prior to setting for moulting using a top loading Melter-electronic balance for the first, second, third and fourth instars. In the fifth instar, the weight of ten full grown larvae one day prior to spinning was taken and the average was worked out.

3.16.2 Growth Rate

The growth rate of the larva at particular instar was found out by using the equation (Rahman, 1989)

Growth rate (g) =

$$\frac{\text{Weight of larvae at a particular instar} - \text{Weight of larvae at previous instar}}{\text{Weight of larvae at the previous instar}}$$

3.17. FIELD EXPERIMENT

Based on the laboratory studies envisaged in sections 3.6 and 3.7, the effective treatments were evaluated to evolve an IPM strategy against papaya mealybug. The sprayings were given on need basis. Suitable cultural and mechanical practices identified from the survey were also incorporated along with the selected chemicals and botanicals to finalize the treatments.

Field trials were carried out June – July (2012) in the farmers' fields in Agali, Sholayur and Puthur panchayats adopting randomized block design (RBD) consisting of eleven treatments including an untreated control. The experiment was replicated thrice with the plot size of 4 X 4 m^2. First round spraying were given after pruning and weeding using a knapsack hydraulic sprayer (Aspee, Mumbai) with a spray fluid volume of 500 L ha^{-1}. Five plants were randomly selected from each plot avoiding those from margin. Post treatment counts were recorded on 7, 14, 21 and 28 days after first spray. Second round spraying was taken up in the selected plots 15 days after the first spraying. A 10X hand magnifying lens was used for counting the number of mealybugs. After completion of the spraying, number of shoots and leaves damaged by the mealybugs were counted. At harvest, data on yield of leaves were also recorded.

Details of treatments in the field experiment for the management of papaya mealybug

	Treatments
T1	Pruning + weeding
T2	T1 + Dichlorvos 2 ml L^{-1}
T3	T1 + Dimethoate 1.7 ml L^{-1}
T4	T1 + Econeem plus 2 ml L^{-1}
T5	T1 + Imidacloprid 0.6 ml L^{-1}
T6	T1 + Dichlorvos 2 ml + Econeem plus 2 ml L^{-1}
T7	T1 + Dimethoate 1.7 ml + Econeem plus 2 ml L^{-1}
T8	T1 + Imidacloprid 0.6 ml + Econeem plus 2 ml L^{-1}
T9	T1 + T6 + T6
T10	T1 + T7 + T6
T11	T1 + T8 + T6
T12	Control

3.18. ASSESSMENT OF MEALYBUG POPULATION PER PLANT

The mealybug population per plant was counted after each treatment by considering all the infested shoots in the plant. The distribution of mealybug was assessed from 10 centimeters of the growing tip of each of the five selected plants and it was replicated thrice.

3.19. EFFECT OF VARIOUS TREATMENTS ON LEAF DAMAGE

The leaves crinkled and distorted by mealybug infestation per plant were counted to study the effect of various treatments on mealybug.

3.20. EFFECT OF VARIOUS TREATMENTS ON SHOOT DAMAGE

The shoots with stunted growth and rosetting per plant were counted to study the effect of different treatments on mealybug.

3.21. EFFECT OF VARIOUS TREATMENTS ON LEAF YIELD

The good quality leaves harvested per plant to be fed to the silkworm larvae were weighed separately and recorded.

3.22 ECONOMICS OF TREATMENTS

Benefit: Cost ratio for different treatments was worked out using the formula

$$\text{Benefit: Cost Ratio (BCR)} = \frac{\text{Total benefit (Rs)}}{\text{Total cost (Rs)}}$$

Statistical Analysis

Data were subjected to analysis of varience (two way classification).

Results

4. RESULTS

The results of the investigations on "Bio-ecology and management of papaya mealybug on mulberry" carried out at College of Agriculture, Vellayani and farmers' fields in selected panchayats of Palakkad district during the period from October 2009 to December 2011 are presented here.

4.1. SURVEY OF PAPAYA MEALYBUG INFESTATION

The results of the preliminary survey conducted at different districts to study the presence of papaya mealybug on mulberry in Kerala are presented in Table 1.

It was observed that mulberry was cultivated in eight districts *viz*; Alappuzha, Ernakulam, Idukki, Kollam, Palakkad, Pathanamthitta, Thrissur and Wayanad. Among those, papaya mealybug infestation was recorded from only two districts, Palakkad and Thrissur during the course of the study.

Based on the preliminary survey, three severely mealybug infested panchayats, *viz*., Agali, Sholayur and Puthur in Palakkad district were selected for assessing the papaya mealybug population. The number of egg masses, mealybugs and natural enemies were recorded at monthly intervals from the selected panchayats for a period of one year from October 2009 to September 2010 is presented in the Tables 2, 3 and 4.

4.1.1. Distribution of Egg Masses in Different Months

In Agali, the highest number of egg mass was observed in July (3.67) and June 2010 (3.61) and was statistically on par. This was followed by April (2.94) and March 2010 (2.14). The lowest number of egg masses is recorded in December (1.05) followed by November (1.07) and October 2009 (1.20). The number of egg mass was found gradually declining from October 2009 to December 2009 and then increasing and reaching its peak during June 2010 and July 2010. Again it was observed that the number of

Table 1. List of panchayats with severe infestation of papaya mealybug

Sl. No.	District	Area of cultivation (ha)	Panchayats having mulberry cultivation	Panchayats with severe infestation
1	Alappuzha	4.53	Cheriyanad, Puliyur, Pattanakkad	-
2	Ernakulam	2.02	Chembannur	-
3	Idukki	6.48	Marayur, Kanthaloor	-
4	Kollam	1.01	Ochira, Thodiyoor	-
5	Palakkad	35.22	Agali, Sholayur, Puthur, Chittur, Kozhijnambara, Kuzhalmandam	Agali, Sholayur, Puthur
6	Pathanamthitta	0.61	Kottanad	-
7	Thrissur	0.4	Mala	-
8	Wayanad	6.07	Padinjarethara, Ambalavayal, Vellamunda	-

egg masses were low in August 2010 (2.68) followed by September 2010 (1.89) (Table 2)

A similar trend was observed in Sholayur and Puthur panchayats. The highest number of egg masses was recorded in the month of July 2010 (3.82 and 3.80 respectively in Puthur and Sholayur panchayats) and the population was significantly superior compared to the remaining months. This was followed by June (3.59 and 3.57 egg masses) and May 2010 (3.29 and 3.18 egg masses) in Puthur and Sholayur panchayats respectively. The population started declining gradually from October 2009 to December 2009. Lesser number of egg masses were recorded in December 2009 (1.05) and (1.04) in Sholayur and Puthur respectively (Table 2).

The mean number of papaya mealybug egg masses observed in these panchayats followed a similar trend. Highest number of egg masses were recorded in July and June 2010 (3.76) and (3.59) respectively whereas, the lowest number of egg masses were recorded in December 2009 (1.05) (Table 2).

4.1.2. Population Dynamics of Papaya Mealybug from October 2009 to September 2010

In Agali, the highest population of papaya mealybug was recorded in July and June 2010 and was statistically on par (57.79 and 53.59 mealybugs respectively). The population was significantly superior compared to the remaining months. Higher numbers of mealybug were observed in May (47.82) and August 2010 (45.05). The population was reduced in September 2010 (25.95). The lowest population was recorded with December 2009 (1.15) followed by January 2010 (3.35), November 2009 (3.66) and October 2009 (4.36). In February 2010 also the population was still lower (6.89). A sudden increase was observed in March and April 2010 (22.53 and 35.02 respectively) (Table 3).

Similarly in Sholayur, the highest number of mealybugs was recorded in the month of July 2010 (59.46) followed by June 2010 (57.07).

Table 2. Occurrence of egg masses of papaya mealybug at different Locations in Attappadi block (from October 2009 to September 2010)

Sl. No.	Month & year	Incidence of mealybug egg mass in different panchayats*			
		Agali	Sholayur	Puthur	Mean
1	October 2009	1.20 (1.09)	1.21 (1.10)	1.18 (1.09)	1.20 (1.09)
2	November 2009	1.07 (1.04)	1.09 (1.04)	1.09 (1.05)	1.09 (1.04)
3	December 2009	1.05 (1.03)	1.05 (1.02)	1.04 (1.02)	1.05 (1.02)
4	January 2010	1.37 (1.17)	1.15 (1.07)	1.09 (1.04)	1.20 (1.10)
5	February 2010	1.41 (1.19)	1.45 (1.20)	1.35 (1.16)	1.40 (1.18)
6	March 2010	2.14 (1.46)	2.34 (1.53)	2.35 (1.53)	2.28 (1.51)
7	April 2010	2.94 (1.71)	2.69 (1.64)	3.03 (1.74)	2.89 (1.70)
8	May 2010	3.17 (1.78)	3.18 (1.78)	3.29 (1.81)	3.22 (1.79)
9	June 2010	3.61 (1.90)	3.57 (1.89)	3.59 (1.90)	3.59 (1.90)
10	July 2010	3.67 (1.91)	3.80 (1.95)	3.82 (1.95)	3.76 (1.94)
11	August 2010	2.68 (1.63)	2.75 (1.66)	2.63 (1.62)	2.69 (1.64)
12	September 2010	1.89 (1.37)	1.88 (1.37)	1.85 (1.36)	1.87 (1.37)
	CD (0.05)	0.05	0.04	0.04	0.04

* Mean of 50 observations (Number of egg masses/10 cm apical shoot)
Figures in the parentheses are square root transformed values

The population of mealybugs was high in August (51.71) and in May 2010 (49.10). The population of mealybugs was reduced in September 2010 (38.78). The gradual reduction in population was observed in October (4.48) and November 2009 (3.70) and the lowest population was observed in December 2009 (1.22). Then the number of mealybugs gradually increased in January and February 2010 (3.32 and 7.08 respectively). The population of mealybugs increased again in March (23.13) and April 2010 (34.51) (Table 3).

The highest number of mealybug was recorded in July 2010 (55.15) followed by June 2010 (51.16) in Puthur and the population was significantly superior compared to the other months. After the hike, the number of mealybugs were reduced in August (46.91) and May 2010 (44.94) as well as in September 2010 (31.91). Comparatively lower population of mealybugs was observed in October 2009 (4.37), November 2009 (3.86), January 2010 (2.55) and February 2010 (4.58). Significantly lesser number of mealybugs was reported in December 2010 (1.06). A sudden increase in population was observed in March (19.62) and April 2010 (30.76) (Table 3).

The mean number of papaya mealybug observed in these panchayats followed a similar trend. Highest mean number of mealybugs were recorded in July and June 2010 (57.47) and (53.94) respectively whereas, the lowest number of mealybugs were recorded in December 2009 (1.14) (Table 3).

4.2. POPULATION OF *S. EPIUS*, PREDATOR OF PAPAYA MEALYBUG (FROM OCTOBER 2009 TO SEPTEMBER 2010)

In Agali, the highest number of predator, *S. epius* was recorded in July (2.84) and June 2010 (2.73) and was statistically on par. Maximum incidence of predator was observed in April (2.31), May (1.83), August (1.77) and March 2010 (1.21). The population was significantly lesser in February 2010 (0.99), September 2010 (0.81), January 2010 (0.53), October 2009 (0.49) and November 2009 (0.39). The lowest population was recorded with December 2009 (0.15) (Table 4).

Table 3. Occurrence of papaya mealybug at different locations in Attappadi block (from October 2009 to September 2010)

Sl.No.	Months	Incidence of mealybug in different panchayats*			
		Agali	Sholayur	Puthur	Mean
1	October 2009	4.36 (2.09)	4.48 (2.12)	4.37 (2.09)	4.41 (2.10)
2	November 2009	3.66 (1.91)	3.70 (1.92)	3.86 (1.96)	3.74 (1.93)
3	December 2009	1.15 (1.07)	1.22 (1.10)	1.06 (1.03)	1.14 (1.07)
4	January 2010	3.35 (1.83)	3.32 (1.82)	2.55 (1.60)	3.07 (1.75)
5	February 2010	6.89 (2.62)	7.08 (2.66)	4.58 (2.14)	6.18 (2.47)
6	March 2010	22.53 (4.75)	23.13 (4.81)	19.62 (4.43)	21.76 (4.66)
7	April 2010	35.02 (5.92)	34.51 (5.87)	30.76 (5.55)	33.43 (5.78)
8	May 2010	47.82 (6.92)	49.10 (7.01)	44.94 (6.70)	47.29 (6.87)
9	June 2010	53.59 (7.32)	57.07 (7.55)	51.16 (7.15)	53.94 (7.34)
10	July 2010	57.79 (7.60)	59.46 (7.71)	55.15 (7.43)	57.47 (7.58)
11	August 2010	45.05 (6.71)	51.71 (7.19)	46.91 (6.85)	47.89 (6.92)
12	September 2010	25.95 (5.09)	38.78 (6.23)	31.91 (5.65)	33.88 (5.80)
	CD (0.05)	0.28	0.06	0.05	0.10

* Mean of 50 observations (Number of mealybugs/10cm apical shoot)
Figures in the parentheses are square root transformed values

A similar trend was observed in Sholayur. The highest number of predators was recorded in the month of July 2010 (2.88) followed by June 2010 (2.71). Comparatively higher number of predators was found in April 2010 (2.38), May 2010 (2.00), August 2010 (1.85), March 2010 (1.33) and February 2010 (1.03). Significantly lower incidence of predators was observed during September 2010 (0.81), January 2010 (0.57), October 2009 (0.41) and November 2009 (0.35). The lowest population was recorded in December 2009 (0.23) (Table 4).

The highest number of predators was recorded in July 2010 (2.81) followed by June 2010 (2.60) in Puthur and the population was significantly superior compared to the other months. The number of predators was also high in April 2010 (2.09), May 2010 (1.87), August 2010 (1.65) and March 2010 (1.15). The lowest number of predators was recorded with December 2009 (0.45). The population was significantly low in February 2010 (0.97), September 2010 (0.79), October 2009 (0.49), January 2010 (0.45) and November 2009 (0.29) (Table 4).

The mean number of predeators in these panchayats followed a similar trend. The highest number of predators was observed in July followed by June (4.32) where as the lowest number was recorded in December (0.14).

4.3. ASSOCIATION AMONG DIFFERENT MEALYBUGS

In Agali, the papaya mealybug population was highest in December 2009 (1.23) whereas the presence of pink hibiscus mealybug (1.11) and breadfruit mealybug (0.62) was the lowest during this period. The mean number of pink hibiscus mealybugs (9.47) increased during February 2010 when compared with papaya mealybugs (6.89) and breadfruit mealybugs (2.50). The population of papaya mealybug (59.89) increased and reached its peak in July 2010 whereas population of both pink hibiscus mealybug (25.92) and breadfruit mealybug (5.46) was found to decrease (Table 5).

Table 4. Occurrence of *Spalgis epius*, predator of papaya mealybug at different locations of Attappadi block (from October 2009 to September 2010)

Sl. No.	Month &year	Incidence of *Spalgis* in different panchayats*			Mean
		Agali	Sholayur	Puthur	
1	October 2009	0.49 (0.70)	0.41 (0.64)	0.49 (0.70)	0.38 (0.68)
2	November 2009	0.39 (0.63)	0.35 (0.59)	0.29 (0.54)	0.30 (0.59)
3	December 2009	0.15 (0.39)	0.23 (0.48)	0.21 (0.46)	0.14 (0.45)
4	January 2010	0.53 (0.73)	0.57 (0.75)	0.45 (0.67)	0.46 (0.72)
5	February 2010	0.99 (1.00)	1.03 (1.02)	0.97 (0.98)	1.00 (1.00)
6	March 2010	1.21 (1.10)	1.33 (1.15)	1.15 (1.07)	1.33 (1.11)
7	April 2010	2.31 (1.52)	2.38 (1.54)	2.09 (1.45)	3.35 (1.50)
8	May 2010	1.83 (1.35)	2.00 (1.41)	1.87 (1.37)	2.40 (1.38)
9	June 2010	2.73 (1.65)	2.71 (1.64)	2.60 (1.61)	4.32 (1.64)
10	July 2010	2.84 (1.69)	2.88 (1.70)	2.81 (1.68)	4.59 (1.69)
11	August 2010	1.77 (1.33)	1.85 (1.36)	1.65 (1.29)	2.26 (1.33)
12	September 2010	0.81 (0.90)	0.81 (0.90)	0.79 (0.89)	0.76 (0.90)
	CD (0.05)	0.06	0.04	0.06	0.05

* Mean of 50 observations (Number of *Spalgis*/10cm apical shoot)
Figures in the parentheses are square root transformed values

In Sholayur, the mean number of pink hibiscus mealybugs (8.57) was higher in December 2009 when compared with papaya mealybugs (1.28). Similar trend was observed in February 2010. During this period, the highest mean number of pink hibiscus mealybugs (20.64) was recorded and the number of papaya mealybugs was 7.10. In July 2010, the population of papaya mealybugs (58.57) was observed at a higher level when compared with pink hibiscus mealybug (34.96). Infestation of breadfruit mealybug was not observed in Sholayur during the study period.

In Puthur, the highest mean number of papaya mealybugs (1.06) was observed in December 2010 and during this period, the minmum number of pink hibiscus mealybugs (0.91) was recorded. The lowest number of breadfruit mealybugs (0.57) was recorded during this period. The population of pink hibiscus mealybugs (7.48) was found to increase during February 2010 and population of both papaya mealybug (4.58) and breadfruit mealybug (1.23) was found to decrease. In July 2010, the population of papaya mealybug (55.15) was found to be higher compared to the population of pink hibiscus mealybug (27.56) and breadfruit mealybug (6.08).

4.4 ALTERNATE AND COLLATERAL HOSTS OF PAPAYA MEALYBUG

The entire crop and weed species in and around the mulberry gardens infested with papaya mealybug in Attappadi block were observed for a period of two years to find out the alternate and collateral hosts. Papaya mealybug incidence was observed on 60 plant species belonging to 27 families including pulses, oilseeds, fibre crops, green manures, vegetables, fruit trees, flower plants, tuber crops, medicinal plants, biofuel plants, tree species and weeds (Plate 6 to 11). Plants from the family Asteraceae, Euphorbiaceae, Malvaceae and Solanaceae were generally found as preferred hosts of this mealybug species. Among these *P. hysterophorus* (Asteraceae), *H. rosa sinensis, S. acuta* (Malvaceae), *J. curcas, M. esculenta* (Euphorbiaceae) and *P. alba* (Apocynaceae) harboured this pest round the

Table 5. Comparison of population of different mealybugs on mulberry in Palakkad district.

Month and Year	Mealybugs*		
	Papaya mealybug	Pink hibiscus mealybug	Breadfruit mealybug
	Agali		
December 2009	1.23 (1.11)	1.11 (1.05)	0.62 (0.79)
February 2010	6.89 (2.62)	9.47 (3.08)	2.5 (1.58)
July 2010	59.89 (7.74)	25.92 (5.09)	5.46 (2.34)
CD	0.11	0.22	0.42
	Sholayur		
December 2009	1.28 (1.13)	8.57 (2.93)	0
February 2010	7.10 (2.66)	20.64 (4.54)	0
July 2010	58.57 (7.65)	34.96 (5.91)	0
CD	0.14	0.09	
	Puthur		
December 2009	1.06 (1.03)	0.91 (0.96)	0.57 (0.76)
February 2010	4.58 (2.14)	7.48 (2.74)	1.23 (1.11)
July 2010	55.15 (7.43)	27.56 (5.25)	6.08 (2.47)
CD (0.05)	0.13	0.27	0.14

* Mean of 50 observations (Number of mealybugs/10cm apical shoot)
Figures in the parentheses are square root transformed values

year and acted as a persistent source for the spread of papaya mealybug (Tables 6 and 7).

4.4.1. Weed Hosts Affinity by Papaya Mealybug

Papaya mealybugs on five selected weeds, *viz.*, *Parthenium hysterophorus, Tridax procumbens, Sida acuta, Phyllanthus niruri* and *Urena lobata* were recorded at bimonthly intervals. The observations on the number of egg masses, mealybugs and predators in 10 cm apical shoot were recorded for six months and the results are presented in Table 8.

Maximum number of egg masses were observed on *P. hysterophorus* (11.64) followed by *S. acuta* (7.50) and *U. lobata* (5.33), both belong to the same family Malvaceae. This was followed by *T. procumbens* (3.92) and the lowest in *P. niruri* (2.87). Similarly the number of mealybugs was maximum in *P. hysterophorus* (147.01) followed by *S. acuta* (117.19), *U. lobata* (84.48) and *T. procumbens* (50.55). The lowest number of mealybug was observed in *P. niruri* (36.43). The number of *S. epius* was high in *P. hysterophorus* (7.45) followed by *S. acuta* (5.44). The number of *S. epius* recorded on other weed hosts was 3.47, 2.86 and 2.61 respectively for *U. lobata*, *T. procumbens* and *P. niruri* and was on par among each other (Table 8).

4.5. MULBERRY CULTIVATION IN ATTAPADI BLOCK

Most of the muberry cultivated fields surveyed were under rainfed cultivation with 5400 plants per acre. The variety of mulberry preferred for cultivation was Victory-1. Weeding was not done properly. The crop residues were heaped near the field without any disposal. The fencing of the mulberry garden was done with *Jatropha*. Application of manures and fertilizers as recommended by SERIFED was followed by the farmers. Insecticides were regularly applied 15-20 days interval for the control of thrips and mealybugs. The insecticides used were dichlorvos, profenofos, dimethoate and botanicals like nimbecidine. Five leaf harvests were done per

Table 6. Incidence of papaya mealybug in different crops in Attappadi block

Sl. No.	Common name	Scientific name	Family	Intensity of infestation
1.	Papaya	*Carica papaya* L.	Caricaceae	****
2.	Redgram	*Cajanus cajan* L.	Fabaceae	****
3.	Brinjal	*Solanum melongena* L.	Solanaceae	****
4.	Tapioca	*Manihot esculenta* L.	Euphorbiaceae	****
5.	Groundnut	*Arachis hypogea* L.	Fabaceae	**
6.	Guava	*Psidium guajava* L.	Myrtaceae	****
7.	Tomato	*Lycopersicon esculentum* Mill.	Solanaceae	**
8.	Sugar apple	*Annona squamosa* L.	Annonaceae	***
9.	Pumpkin	*Cucurbita moschata*	Cucurbitaceae	*
10.	Pomegranate	*Punica granatum* L.	Lythraceae	***
11.	Jack	*Artocarpus heterophyllus* Lam.	Moraceae	*
12.	Water rose apple	*Syzygium samarangense* (Blume) DC	Myrtaceae	*
13.	Banana	*Musa* sp.	Musaceae	*
14.	Mango	*Mangifera indica* L.	Anacardiaceae	*
15.	Jungle flame	*Ixora coccinea* L.	Rubiaceae	**
16.	Marigold	*Tagetes erecta* L.	Asteraceae	***
17.	Zinnia	*Zinnia elegans* Jacq.	Asteraceae	**
18.	Teak	*Tectona grandis* L	Verbanaceae	**
19.	Shoe flower	*Hibiscus rosa sinensis* L.	Malvaceae	****
20.	Turkey berry	*Solanum torvum Sw.*	Solanaceae	**

Table 6. (Continued) Incidence of papaya mealybug in different crops in Attappadi block

Sl. No.	Common name	Scientific name	Family	Intensity of infestation
21.	Mulberry	*Morus alba* L.	Moraceae	****
22.	Cotton	*Gossypium hirsutum* L.	Malvaceae	****
23.	Bhendi	*Abelmoschus esculentus* (L.) Moench	Malvaceae	****
24.	Indian tree of heaven	*Ailathus exelsa* Roxb.	Simaroubaceae	*
25.	Cotton tree	*Bombax ceiba* L.	Bombacaceae	**
26.	Sappanwood	*Caesalpinia sappan* L.	Fabaceae	*
27.	Jatropha	*Jatropha curcas* L.	Euphorbiaceae	****
28.	Cowpea	*Vigna unguiculata* (L.) Walp.	Fabaceae	**
29.	Japanese lantern	*Hibiscus schizopetalus* (Mast.) Hook.f.	Malvaceae	***
30.	Tulsi	*Ocimum sanctum* L.	Lamiaceae	*
31.	Nerium	*Nerium oleander L.*	Apocynaceae	**
32.	Chinese glory bower	*Clerodendrum chinense* (Osb.) Mabb.	Lamiaceae	**
33.	Chilli pepper	*Capsicum annum* L.	Solanaceae	**
34.	Birdseye chilly	*Capsicum frutescens* L.	Solanaceae	*
35.	Bittergourd	*Momordica charantia* L.	Cucurbitaceae	*
36.	Silver oak	*Grevillea robusta* A.cunn. ex R. Br.	Proteaceae	**
37.	Rose	*Rosa chinensis* Jacq.	Rosaceae	*
38.	White frangipani	*Plumeria alba* L.	Apocynaceae	****
39.	Frangipani	*Plumeria rubra* L.	Apocynaceae	****
40.	Dahlia	*Dahlia pinnata* L.	Asteraceae	*

Table 7. Incidence of papaya mealybug in different weed plants observed in Attappadi block

Sl. No.	Common name	Scientific name	Family	Infestation intensity
1	Congress grass	*Parthenium hysterophorus* L.	Asteraceae	****
2	Coat buttons	*Tridax procumbens* L.	Asteraceae	***
3	Sambong	*Blumia* sp.	Asteraceae	**
4	Asthma weed	*Euphorbia hirta* L.	Euphorbiaceae	**
5	Sunnhemp	*Crotalaria juncea* L.	Fabaceae	**
6	Common wire weed	*Sida acuta* Burm.	Malvaceae	****
7	Caesar weed	*Urena lobata* L.	Malvaceae	****
8	Devil's thorn	*Tribulus terrestris* L.	Zygophyllaceae	*
9	Balloon vine	*Cardiospermum helicacabum* L.	Sapindaceae	*
10	Gliricidia	*Gliricidia sepium* (Jacq.) Kunth ex Walp	Fabaceae	****
11	Stonebreaker	*Phyllanthus niruri* L.	Phyllanthaceae	****
12	Indian copperleaf	*Acalypha indica* L.	Euphorbiaceae	***
13	Shaving brush	*Emilia sonchifolia* L.	Asteraceae	**
14	Goatweed	*Scoparia dulcis* L.	Scrophulariaceae	*
15	Giant sensitive plant	*Mimosa invisa* L.	Fabaceae	*
16	Touch me not	*Mimosa pudica* L.	Fabaceae	*
17	Thumbai	*Leucas aspera* (Willd)	Lamiaceae	**
18	Devil's Horsewhip	*Achyranthus aspera* L.	Amaranthaceae	*
19	Dog mustard	*Cleome viscosa* L.	Capparaceae	*
20	Devil's apple	*Datura stramonium* L.	Solanaceae	**

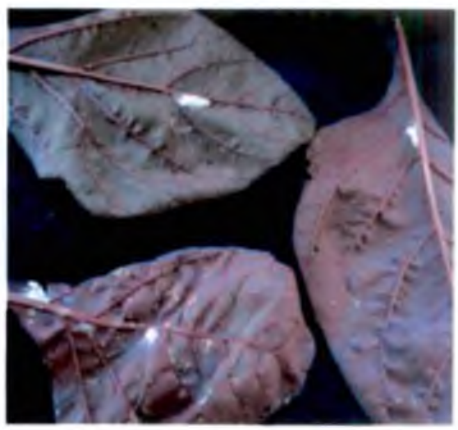
Redgram

Cucumber

Cowpea

Bhindi

Chilli



Amaranthus

Plate 6. Incidence of papaya mealybug in different crops

Banana

Pomegranate

Jack

Mango

Guava

Papaya

Plate 7. Incidence of papaya mealybug in different crops

Brinjal

Ground nut

Teak

Cotton

Nerium

Silver oak

Plate 8. Incidence of papaya mealybug in different crops

Tulsi

Hibiscus

Japanese lantern

Sappanwood

Plate 9. Incidence of papaya mealybug in different crops

Turkey berry

Devil'sap

Christmas weed

Touch me not

Sida

Congress grass

Plate 10. Incidence of papaya mealybug in different weeds

Devil's Horsewhip

Gliricidia

Giant sensitive plant

Goatweed

Devil's thorn

Shaving brush

Plate 11. Incidence of papaya mealybug in different weeds

Table 8. Population density of papaya mealybug and its predator, *Spalgis epius* on different weed hosts in Attapadi block

Sl.No.	Weed hosts	*No./10cm apical shoot		
		Egg mass of *P.marginatus*	Adult *P. marginatus*	*Spalgis*
1	*P. hysterophorus*	11.64 (3.41)	147.01 (12.12)	7.45 (2.73)
2	*T. procumbens*	3.92 (1.98)	50.55 (7.11)	2.86 (1.69)
3	*S. acuta*	7.50 (2.74)	117.19 (10.83)	5.44 2.33)
4	*P. niruri*	2.87 1.69)	36.43 (6.04)	2.61 (1.62)
5	*Urena lobata* L.	5.33 (2.31)	84.48 (9.19)	3.47 (1.86)
	CD (0.05)	0.28	0.50	0.26

* Mean of 10 observations
Figures in parentheses are square root transformed values

year. Shoot rearing was practiced by some farmers who allowed the mulberry plants to grow with 10-12 shoots and cut when it is required.

4.6. CORRELATION OF PAPAYA MEALYBUG POPULATION WITH PREDATOR POPULATION AND WEATHER PARAMETERS

Weather parameters *viz.*, maximum and minimum temperature, relative humidity, rainfall, wind speed and sunshine during different months were collected from October 2009 to September 2010 in Attapadi block and were correlated with population of papaya mealybug. The result of the correlation analysis is presented in Table 9.

It was observed that there was a significant positive correlation between papaya mealybug population and maximum temperature (+0.468), wind speed (+0.690) and sunshine (+0.257) while a negative correlation existed with minimum temperature (-0.340), rainfall (-0.463) and relative humidity (-0.108).

Similar trend was found in the case of its predator, *S. epius*. A positive correlation existed between the population of predator and maximum temperature (+0.177), wind speed (+0.553) and sunshine (+0.427) whereas the predator population was negatively correlated with minimum temperature (-0.165), rainfall (-0.485) and relative humidity (-0.113) (Table 9).

A highly significant positive correlation existed between papaya mealybug and its predator, *S. epius* population (+0.886).

4.7. IDENTIFICATION OF MEALYBUGS OF MULBERRY

Three species of mealybugs were identified *viz.*, papaya mealybug, *P. marginatus* and pink hibiscus mealybug, *M. hirsutus* and breadfruit mealybug, *I. aegyptiaca* at National Bureau of Agriculturally Important Insects, Bangalore. Among these three, heavy infestation was observed with papaya mealybug in the mulberry gardens of Palakkad district.

Table 9. Correlation between weather parameters and incidence of papaya mealybug and its predator, *S. epius* on mulberry (from October 2009 to September 2010)

Sl. No.	Parameters	Correlation coefficient	
		Papaya mealybug	*Spalgis*
1	Rainfall (mm)	-0.463	-0.485
2	Relative Humidity (%)	-0.108	-0.113
3	Maximum Temperature (^{0}C)	+0.468	+0.177
4	Minimum Temperature (^{0}C)	-0.340	-0.165
5	Wind speed	+0.690	+0.553
6	Sunshine	+0.257	+0.427
7	Mealybug		+0.886

Table 10. Details of biology of papaya mealybug reared on sprouted potato

Sl. No	Parameters	*Quantification details (Mean ±S.E)
1	Hatchability	92.26 ± 2.55 percent
2	Fecundity	361.50 ± 27.37 eggs/female
3	Oviposition period	10.50 ± 1.90 days
4	Incubation period	5.20 ± 0.83 (March-April)
		7.30 ± 1.25 (November-December)
5	Adult longevity	
	Male	3.30 ± 0.48 days
	Female	19.60 ± 1.35 days

* Mean of 10 observations

Papaya mealybug and pink hibiscus mealybug were found infesting the terminal portions of the plant where as breadfruit mealybug was found more on the lower surface of older leaves.

It was observed that papaya mealybug when pressed in between white papers produced a greenish yellow stain whereas a pink stain was formed with pink hibiscus mealybug. The important distinguishing character of papaya mealybug from the other two species are presence of oral rim tubular ducts dorsally restricted to marginal areas of the body and absence of pores on the hind tibia and possession of eight segmented antennae.

A carnivorous butterfly was found feeding on the papaya mealybug, which was identified as *S. epius* by NBAII. This insect belongs to the family Lycaenidae, under Lepidoptera.

4.8. BIOLOGY OF MEALYBUGS

Biology of the three mealybugs identified from survey *viz.*, papaya mealybug, pink hibiscus mealybug and breadfruit mealybug were studied. Among the three mealybugs, biology of papaya mealybug was studied in detail.

4.8.1. Papaya Mealybug

4.8.1.1. Eggs

Eggs (Plate 12) were elongate-oval in shape, greenish yellow in colour and were laid in an egg sac, entirely covered with white wax. The eggs were observed in masses and the average number of eggs per egg mass ranged from 102 to 482 with an average of 361.50 eggs (Table 10). On an average, an individual egg measured 0.36 mm in length and 0.26 mm in width. The length of an egg ranged from 0.32 to 0.38 mm width from 0.24 to 0.27 mm (Table 12).

4.8.1.2. Hatching

The number of crawlers emerged was counted to calculate the per cent hatching which ranged from 86.67 to 95.12. On an average, 92.26 per cent eggs hatched to crawlers during March to April 2010 (Table 10).

4.8.1.3. Incubation Period

The incubation period ranged from 5 to 7 days with an average of 5.2 days during March-April 2010 and 6 to 9 days with an average of 7.3 days during November-December 2009 (Table 10).

4.8.1.4. Nymphal Instars

Nymphal instars were identified and separated based on the morphological dimensions. Males had four nymphal instars whereas, the females had only three instars. The morphometrics of different nymphal instars are presented in Table 12

4.8.1.4.1. First Instar Nymphs

The first instar nymphs (Plate13) were the only actively moving stage called crawlers. They were light greenish yellow in color, smooth, without the white waxy coating on their body congregating together within the loose white waxy filaments for three days. The size of the crawlers ranged from 0.3 to 0.4 mm in length 0.2 to 0.3 mm in width with an average of 0.36 mm in length and 0.27 mm in width (Table 12). The first instar took an average of 6.1 days to moult to the second instar (Table 11).

4.8.1.4.2. Second Instar Nymph

From second instar onwards, the female nymphs appeared yellowish (Plate 14) with slight mealy coating whereas the male nymphs were light pink coloured (Plate 15). The female nymphs measured an average of 0.63 mm in length and 0.44 mm in width, the length ranged from 0.5 to 0.7 mm and width from 0.3 to 0.5 mm. The length of male nymph ranged from 0.6 to

0.8 mm and width from 0.2 to 0.4 mm with an average length of 0.71 mm and width of 0.33 mm (Table 12). The female and male instars took an average of 5.2 days and 6.4 days to moult to the third instar (Table 11).

4.8.1.4.3. Third Instar Nymph

The third instar female nymphs (Plate 16) were yellow in colour with mealy coating and they began to take normal shape of the adult. They measured an average of 1.29 in length and 0.78 mm in width (Table 12). The length ranged from 1.1 mm to 1.6 mm and width from 0.7 to 0.9 mm. The female took an average of 5.4 ± 0.52 to moult to the adult female (Table 11).

The third instar male nymphs (Plate 18) were called prepupa at this stage. The length ranged from 0.8 to1.0 mm and width from 0.3 to 0.4 mm. They measured an average of 0.89 mm length and 0.36 mm width (Table 12). The third instar took an average of 3.5 days to moult to the fourth instar (Table 11).

4.8.1.4.4. Fourth Instar Male

The fourth instar of the male (Plate 19) was formed in a cocoon and is known as the pupa. They measured an average of 0.93 mm length and 0.36 mm width, the length ranged from 0.8 to 1.0 mm and width from 0.3 to 0.4 mm (Table 12).

4.8.1.5. Adults

4.8.1.5.1. Adult Female

The adult females (Plate 17) were greenish yellow coloured, oval in shape dusted with mealy wax not thick enough to hide body colour, with many short waxy filaments around the body margin. They measured an average of 2.38 mm length and 1.49 mm width, the length ranged from 2.0 mm to 2.7 mm and width from 1.2 mm to 1.6 mm (Table 12).

Plate 12.Egg mass of papaya mealybug

Plate 13.First instar papaya mealybug

Plate 14. Second instar papaya mealybug (females)

Plate 15. Second instar papaya mealybug (male)

Plate 16. Third instar papaya mealybug(female)

Plate 17. Adult papaya mealybug with egg mass (female)

Plate 18. Third and fourth instars of papaya mealybug (male)

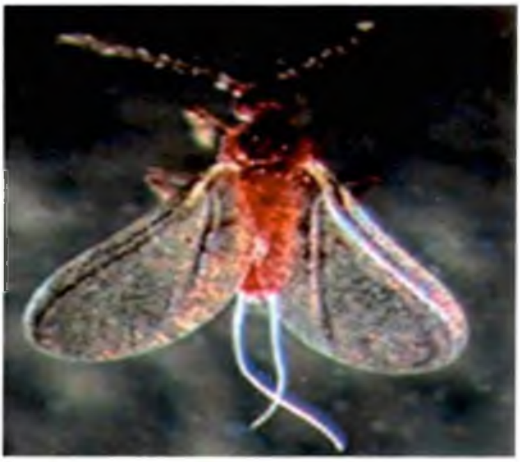


Plate 19. Adult papaya mealybug (male)

Table 11. Duration of life stages of papaya mealybug, reared on sprouted potato

Sl. No.	Stages	*Duration (days) (Mean ± S.E)	
		Male	Female
1	Ist Instar	6.1 ± 0.74	
2	IInd Instar	6.40 ± 0.52	5.20 ± 0.53
3	IIIrd Instar	3.50 ± 0.53	5.40 ± 0.42
4	IVth Instar	3.30 ± 0.48	**
Total larval duration		19.30 ± 0.97	16.70 ± 0.92

* Mean of 10 observations
** IVth instar nymph in female is absent

Table 12. Morphometrics of life stages of papaya mealybug

Sl. No.	Stages	Dimension (mm) (Mean ± S.E)			
		*Length		*Width	
1	Egg	0.36 ± 0.05		0.26 ± 0.05	
2	Ist instar nymph	0.38 ± 0.08		0.27 ± 0.05	
		Male		Female	
		*Length	*Width	*Length	*Width
3	IInd instar nymph	0.71 ± 0.09	0.33 ± 0.06	0.63 ± 0.07	0.44 ± 0.07
4	IIIrd instar nymph	0.89 ± 0.09	0.36 ± 0.05	1.29 ± 0.18	0.78 ± 0.08
5	IVth instar nymph	0.93 ± 0.07	0.36 ± 0.05	**	
6	Adult	1.06 ± 0.08	0.34 ± 0.05	2.38 ± 0.22	1.49 ± 0.13

* Mean of 10 observations
** IVth instar nymph in female is absent

4.8.1.5.2. Adult Male

Adult males (Plate 19) measured an average of 1.06 mm length and 0.34 mm width, with an elongate oval body that is widest at the thorax. The length ranged from 1.0 to 1.2 mm and width from 0.3 to 0.4 mm (Table 12). They have ten segmented antennae, a distinct aedeagus, heavily sclerotized thorax and well developed wings.

4.8.1.5.3. Adult Behaviour

It was observed that the adult female mealybug stopped feeding and settled before egg laying. Hairs grew from the wax pores and covered the body. An adult laid only one egg mass in its life period. The eggs were laid in an ovisac, surrounded with loose white waxy material, secreted by the mother before laying eggs.

4.8.1.6. Oviposition Period

The egg laying period ranged from 8 to 13 days with an average of 10.50 days (Table 10).

4.8.1.7. Fecundity

An adult female mealybug laid an average of 361.50 eggs in its life period (Table 10). The eggs were laid in a folded chain fashion and later, the chain was broken distributing the eggs within egg mass. In field, the eggs were always attached to a rough substratum, *viz.*, stem, leaves or dried plant parts.

4.8.2. Pink Hibiscus Mealybug

The duration of life cycle of pink hibiscus mealybug (Plate 20) is presented in Table 13 and 14.

Freshly laid eggs were translucent and yellowish or light orange in colour.

They were elongated and oval in shape. As incubation period advanced, the translucent eggs were found to become pinkish in colour towards hatching. The incubation period was an average of 4.1 days. The percentage of eggs hatched varied from 78.60 to 86.20 with an average of 82.26 per cent (Table 13).

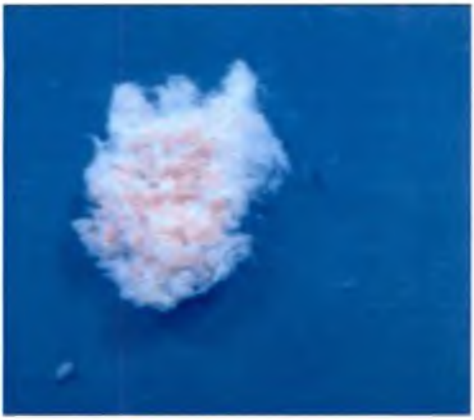
Nymphs were usually yellow to orange in colour with reddish compound eyes. Six segmented antennae were visible and held diagonally in front of the head. The neonate larvae were oval in shape and they were highly mobile. During that stage, male and female were indistinguishable. The duration of first instar nymph lasted for 6 to 8 days with a mean of 7.2 days (Table 14). As the stage advanced, colour changed from orange to pink and entered second instar.

The second instar nymphs were larger than first instar nymphs and body was pinkish in colour with appearance of white thin waxy secretions on the body. It was sluggish and become stationary at a suitable spot. The duration of second instar nymph lasted for 6 to 7 days with a mean of 6.5 days.

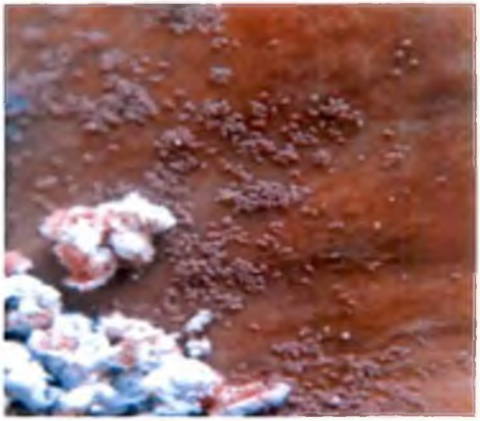
The duration of third instar nymph lasted for 7 to 8 days with a mean of 7.5 days. Total nymphal period averaged 21.2 days (Table 14).

Adult females were soft, oval and distinctly segmented. Besides head, totally 13 segments were clearly visible which comprised of three thoracic and ten abdominal segments. The head was covered with white mealy secretions. The adults were stationary. During the same season, on sprouted potato the longevity of adult female ranged between 10 to 13 days with a mean of 12.1 days (Table 13). The males of the mealybugs were not observed.

The ovipositional period ranged from 6 to 8 days with a mean of 6.9 days. The number of eggs laid by an adult female ranged from 202 to 351 with an average of 281.3 eggs in its life period (Table 13).

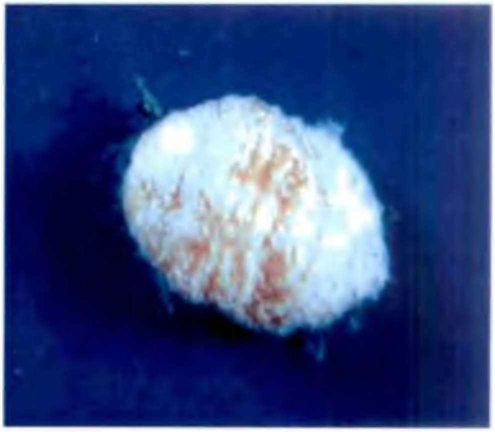


Egg mass



First instars

Second instar



Third instar

Plate 20. Life stages of pink hibiscus mealybug (female)

Table 13. Biological characters of pink hibiscus mealybug reared on sprouted potato

Sl. No	Parameters	*Quantification details (Mean ± S.E)
1	Hatchability	82.26 ± 2.46 per cent
2	Fecundity	281.3 ± 49.89 eggs
3	Oviposition period	6.90 ± 0.74 days
4	Incubation period	4.10 ± 0.88 days
5	Adult longevity (female)	12.10 ± 1.20 days

* Mean of 10 observations

Table 14. Duration of life stages of of pink hibiscus mealybug reared on sprouted potato

Sl. No.	Stages	*Duration (days) (Mean ±S.E)
1	Ist Instar	7.20 ± 0.92
2	IInd Instar	6.50 ± 0.53
3	IIIrd Instar	7.50 ± 0.53
	Total larval duration	21.20 ± 1.35

* Mean of 10 observations

4.8.3. Breadfruit Mealybug

The deatails of the biology of *I. aegyptiaca* (Plate 21) are presented in Table 15 and 16. Males were not observed in the study and adult longevity could not be worked out.

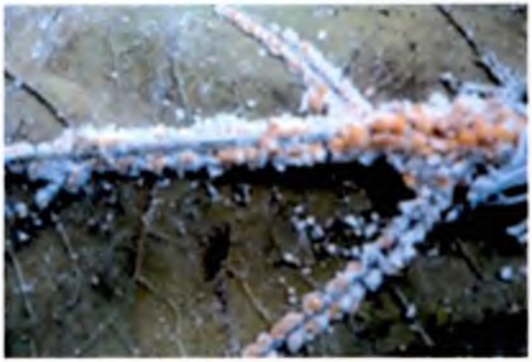
The females laid an average of 141.3 eggs into a waxy egg sac attached ventral tip of the abdomen. The eggs were oval in shape and yellowish-orange in colour. The incubation period ranged from 8 to 10 days with an average of 9.0 days.

The first instar nymphs (crawlers) were bright orange in colour and were very active. The crawlers settled within a day and the body was covered by a waxy covering within two days. A long, thread like waxy filament developed near the anus, which received droplets of honeydew as they are discharged. The duration of first instar nymph ranged from18 to 20 days with an average of 18.8 days.

The second instar larvae were oval in shape and yellow to orange in colour. Immediately after moulting, the bugs were covered with a white mealy secretion. They are fringed with 21 snow-white waxy processes. The duration of second instar larvae ranged from 9 to 10 days with an average of 9.4 days.

The duration of third instar larvae varied from 18 to 20 days with an average of 17.8 days. The yellow to orange coloured body of the larvae was covered with a white mealy secretion and 21 stout, tapering, snow-white processes.

The deep orange coloured adults were broadly oval in shape with 11 segmented antennae. The abdomen was slightly convex dorsally and flattened ventrally. The legs were black in colour. The dorsal surface is covered with cushions of white mealy secretion, mingled with granular wax. Waxy process on thorax was stouter than those present in abdominal region.



First instar **Second instar**

Third instar **Adult**

Plate 21. Life stages of breadfruit mealybug (female)

Table 15. Biological characters of breadfruit mealybug reared on sprouted potato

Sl. No	Parameters	*Quantification details (Mean ± S.E)
1	Hatchability	82.90 ± 3.18 per cent
2	Fecundity	141.30 ± 24.75 eggs
3	Oviposition period	39.60 ± 1.26 days
4	Incubation period	9.00 ± 0.82 days

* Mean of 10 observations

Table 16. Duration of life stages of bread fruit mealybug on sprouted potato

Sl. No.	Stages	*Duration (days) (Mean ±S.E)
1	Ist Instar	18.80 ± 0.91
2	IInd Instar	9.40 ± 0.52
3	IIIrd Instar	17.80 ± 3.56
	Total larval duration	47.10 ± 1.79

* Mean of 10 observations

4.9. MASS MULTIPLICATION OF PAPAYA MEALYBUG

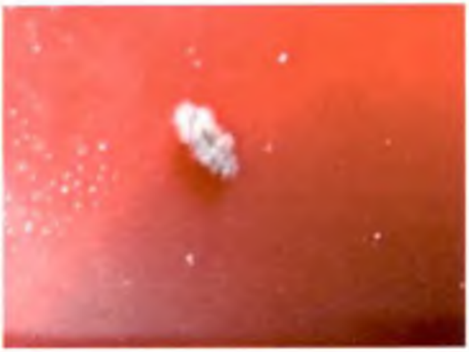
It was observed that papaya mealybugs did not feed on pumpkin fruits and amorphophallus sprouts. Although they were found feeding on papaya fruits, these mealybugs did not survive long under laboratory conditions due to rotting of the fruits by its continuous feeding. However these could be reared successfully on sprouts and plants of potato.

4.10. BIOLOGY OF THE PREDATOR

Five larval instars, pupae and adults of the predator were observed (Plate 22). The first instar larvae were pink in colour with a life span of 2.6 days and remained inside ovisac of papaya mealybug. The second instar larva was creamy white coloured and found outside the ovisac. The larvae were coated with white wax and difficult to distinguish form the mealybug. Total larval duration was observed as 10.0 days. The developmental time of each larva was 1.8, 1.4, 2.0 and 2.2 days respectively for second, third, fourth and fifth instar larvae. The larvae were found to pupate on the lower surface of leaves and form a characteristic rhesus monkey faced chrysalis. The pupal period was about 5.43 days (Table 17).

4.10.1. Feeding Efficacy of *S. epius*

The results of the study on total consumption of different stages of mealybugs by the predator are presented in Table 18. The mealybug consumption increased gradually as the stages of predator advanced and maximum feeding were found in the fifth instar larvae. The fifth instar larva of *S. epius* consumed significantly higher number of total ovisacs, first instar second and third nymphs, 21.69, 118.88, 40.88 and 20.94 respectively. The second instar larva fed lowest number of ovisacs (2.19), first instar (17.69) second instar (7.19) and third instar (1.88) larvae of papaya mealybugs. The third instar larva of *S epius* consumed minimum number of first, second and third instars larvae, 25.93, 12.15 and 7.50 mealybugs respectively whereas,



Second instar larva

Third instar larva

Fourth instar larva

Fifth instar larva

Pupa

Adult

Plate 22. Life stages of *S.epius*, predator of papaya mealybug

the fourth instar larva fed maximum number of 50.25, 26.06 and 17.13 of first, second and third instar larvae of papaya mealybug respectively (Table 18).

4.11. SYMPTOMS OF INFESTATION

The nymphs and adults sucked sap from the tender portions of mulberry plant. Usually colonies appeared as clusters of cotton-like masses on the terminal tender portion of the plants with long waxy filaments. The continuous feeding of the nymphs and adults of mealybug resulted in crinkling, rosetting, and general leaf distortion. When the infestation proceeded, yellowing of leaves was followed by drying and shedding. Sooty mould also occured in the upper surface of leaves, which rendered them unfit for silkworm feeding (Plate 23).

4.12. PHENOL CONTENT IN MEALYBUG INFESTED MULBERRY LEAVES

The study was conducted to know the accumulation of phenolics in the mulberry leaves in both healthy and the mealybug infested samples. The phenol content was found to be more in the infested samples and found to be increasing with the increase in the per cent damage. The total phenol content was found to be the highest (1.72) at 100 per cent infestation level whereas in the lowest was observed in healthy (0.97) (Table 19).

4.13. ROLE OF PAPAYA MEALYBUG AS A VECTOR IN DISEASE TRANSMISSION

In order to detect the presence of virus in the suspected samples, DAC –ELISA was employed. The absorbance was measured at 405 nm in an ELISA reader (BIO-RAD Microplate reader 680). The average absorbance of diseased and healthy samples was 0.013 and 0.008 respectively against the

Mealybug colony on mulberry

Crinkling of mulberry leaves

Rosetting of mulberry leaves

Yellowing of mulberry leaves

Plate 23. Symptoms of papaya mealybug infestation on mulberry

Table 17. Duration of different life stages of papaya mealybug predator, *S. epius*

Sl no.	Instar/Stage	*Duration(Days) (Mean ± S.E)
1	First instar larva	2.60 ± 0.52
2	Second instar larva	1.80 ± 0.42
3	Third instar larva	1.40 ± 0.52
4	Fourth instar larva	2.00 ± 0.00
5	Fifth instar larva	2.20 ± 0.42
6	Pupa	5.43 ± 0.50
	Total larval duration	10.00 ± 0.67

* Mean of 10 observations

Table 18. Feeding potential of *S. epius* on different life stages of papaya mealybug

Different Instars of *Spalgis epius*	Number of different stages of mealybugs consumed* (Mean ± SE)			
	Ovisac	Ist Instar	IInd Instar	IIIrd Instar
2nd	2.19 ± 0.56	17.69 ± 2.06	7.19 ± 0.69	1.88± 0.38
3rd	4.31 ± 0.06	25.93 ± 0.20	12.15 ± 0.03	7.50± 0.25
4th	17.88 ± 0.25	50.25 ± 0.13	26.06 ± 0.06	17.13 ± 0.38
5th	21.69 ± 0.06	118.88 ± 1.13	40.88 ± 1.13	20.94 ± 0.69
CD (0.05)	1.22	4.63	2.59	1.77

* Mean of 10 observations

antibody of Sugarcane bacilliform mosaic virus (SCBMV) and 0.707 and 0.643 respectively against Banana streak virus (BSV) (Table 20). In both cases the absorbance of diseased sample was not more than two or three times than that of the healthy sample. These results indicated the absence of virus in the mealybug infested mulberry plants.

4.14. EFFICIENCY OF COMMERCIALLY AVAILABLE PREDATORS ON PAPAYA MEALYBUG

4.14.1. Feeding Potential of *C. carnea*

4.14.1.1. No Choice Condition

The data presented in Table 21 showed significant differences (P=0.05) in the mean consumption of *C. carnea* on different stages of papaya mealybug. The first instar larvae of *C. carnea* consumed minimum number of ovisacs (1.38) of papaya mealybug whereas maximum number of ovisacs (3.25) was consumed by third instar larva. The second instar larvae of *C. carnea* consumed 1.88 ovisacs.

The third instar larvae of *C. carnea* consumed higher number of first instar nymphs (330.75) of papaya mealybug whereas second instar larvae consumed 206.13 nymphs of mealybug. The first instar larvae of *C. carnea* consumed the lowest number of first instar mealybug nymphs (109.25).

The first instar of *C. carnea* consumed minimum number of second instar papaya mealybug nymphs (37.88) whereas maximum number (120.63) was consumed by third instar of *C. carnea*. The second instar *C. carnea* consumed 69.88 second instar mealybug nymphs (Table 20)

A similar feeding trend was observed with third instar larvae of *C. carnea*. The third instar of *C. carnea* consumed maximum number of 87.25 third instar mealybug nymphs whereas, the first instar of *C. carnea* consumed minimum number of 12.63 third instar mealybug nymphs. The second instar *C. carnea* consumed 37.75 third instar mealybugs. Third instar

Table 19. Total phenol content in the infested mulberry leaves

Sl. No	Per cent infestation	* Change in phenol content (mg g^{-1} on fresh weight basis)
1	0	0.97
2	25	1.13
3	50	1.42
4	75	1.60
5	100	1.72

*Mean of three replications

Table 20. Reaction of leaf extracts of mulberry for the detection virus using DAC-ELISA

Antiserum used	*Absorbance at 405 nm	
	Healthy	Diseased
SCBMV	0.008	0.013
BSV	0.643	0.707

*Mean of three replications

of *C. carnea* consumed higher number of first, second and third instars of mealybug per day compared with first and second instars of the predator.

4.14.1.2. Free Choice Test

It was observed that the average consumption of first instar papaya mealybug nymphs by third and second instar larvae of *C. carnea* were on par. The second and third instar *C. carnea* consumed 23.50 and 23.04 first instar mealybugs respectively. The minimum number of first instar mealybug nymphs (16.21) was consumed by the first instar *C. carnea* (Table 22).

The third instar *C. carnea* consumed higher number of second instar mealybug nymphs (11.58) which differed from the consumption by second (10.42) and first (7.00) instar star larvae of *C. carnea*.

Higher number of third instar mealybug nymphs (6.88) was consumed by third instar *C. carnea* followed by second instar (3.75). The minimum number of third instar mealybug nymphs (0.75) was consumed by first instar *C. carnea* (Table 22).

4.14.2. Feeding Potential of *C. montrouzieri*

4.14.2.1. No Choice Test

The first instar grub of *C. montrouzieri* consumed minimum number of ovisacs (4.38) of papaya mealybugs whereas the fourth instar grub consumed maximum of 13.13 ovisacs (Table 23). The number of ovisacs consumed by third and second instar grub was 9.63 and 7.13 respectively.

The fourth instar grub of *C. montrouzieri* consumed higher number of first instar mealybug nymphs (337.50) which differed significantly from 124.75, 174.25 and 218.00 nymphs consumed by first, second and third instar grub of *C. montrouzieri* respectively.

First instar grub of *C. montrouzieri* consumed minimum number of second instar mealybug nymphs (67.00) whereas the maximum number of second instar mealybug nymphs (209.25) consumed by fourth instar grub.

Table 21. Feeding potential of *C. carnea* on different life stages of papaya mealybug (No choice condition).

Different Instars of *C. carnea*	Total number of different stages of mealybugs consumed* (mean ± SE)			
	Ovisac	1st instar nymphs	2nd instar nymphs	3rd instar nymphs
1st	1.38 ± 0.18	109.25 ± 1.37	37.88 ± 0.76	12.63 ± 0.26
2nd	1.88 ± 0.13	206.13 ± 3.78	69.88 ± 1.04	37.75 ± 0.59
3rd	3.25 ± 0.16	330.75 ± 1.59	120.63± 0.98	87.25 ± 0.56
CD (0.05)	0.47	7.34	2.75	1.45

* Mean of four replications

Table 22. Feeding potential of *C. carnea* on different instars of papaya mealybug (Free choice condition)

Different Instars of *C. carnea*	Number of different instars of mealybugs consumed* (mean ± SE)		
	1st instar nymphs	2nd instar nymphs	3rd instar nymphs
1st	16.21 ± 0.40	7.00 ± 0.69	0.75 ± 0.12
2nd	23.04 ± 0.34	10.42 ± 0.75	3.75 ± 0.26
3rd	23.50 ± 0.48	11.58 ± 1.16	6.88 ± 0.22
CD (0.05)	1.21	0.93	0.61

* Mean of four replications

The consumption of second instar mealybug nymphs by third and second instar grub was 169.25 and 97.00 respectively (Table 23).

The fourth instar grub of *C. montrouzieri* consumed maximum number of 137. 38 third instar mealybug nymphs where as minimum consumption of 31.88 mealybugs by first instar grub. The third instar grub of *C. montrouzieri* consumed 83.25 third instar mealybug nymphs, whereas the second instar grub consumed only 54.13 third instar mealybug nymphs (Table 23).

4.14.2.2. Free Choice Test

The fourth instar grub of *C. montrouzieri* was a voracious feeder and it consumed 84.46, 52.58 and 31.46 papaya mealybug nymphs of first, second and third instar respectively (Table 24). The minimum of number of mealybug nymphs was consumed by first instar grub of *C. montrouzieri.* It consumed an average of 24.50 first, 14.88 second and 7.71 third instar mealybugs. Second and third instar grub consumed an average number of first instar (43.00 and 60.17), second instar (29.96 and 41.50) and third instar (14.17 and 23.13) mealybug nymphs respectively.

4.15. EFFICACY OF DIFFERENT INSECTICIDES ON PAPAYA MEALYBUG

4.15.1. Adult

After 24 hours, dimethoate 0.1% recorded maximum percentage mortality (93.33) followed by imidacloprid 0.01% (90.00) dimethoate 0.05% (86.67) and imidacloprid 0.005% (83.33). Percentage mortality in abamectin 0.006% and 0.003% treatments was 80.00 and 73.33 respectively followed by dichlorvos 0.05% (70.00). The per cent mortality recorded with neem seed kernel extract (NSKE) 5% was 66.67 whereas the least reduction percentage was recorded with NSKE 2.5% (56.67) (Table 25).

After 48 hours, 100% mortality of mealybugs was observed on the leaves treated with dimethoate (0.05%, 0.1%) and imidacloprid (0.005%,

Table 23. Feeding potential of *C. montrouzieri* on different life stages of papaya mealybug (No choice condition)

Different instars of *C. montrouzieri*	Total number of different instars of mealybugs consumed* (mean ± SE)			
	Ovisac	1st instar nymphs	2nd instar nymphs	3rd instar nymphs
1st	4.38 ± 0.18	124.75 ± 0.94	67.00 ± 0.85	31.88 ± 0.77
2nd	7.13 ± 0.30	174.25 ± 1.06	97.00 ± 0.88	54.13 ± 1.23
3rd	9.63 ± 0.26	218.00 ± 1.98	169.25 ± 0.86	83.25 ± 1.13
4th	13.13 ± 0.40	337.50 ± 2.16	209.25 ± 0.94	137.38 ± 1.38
CD (0.05)	1.04	4.72	2.59	3.32

* Mean of four replications

Table 24. Feeding potential of *C. montrouzieri* on different instars of papaya mealybug (Free choice condition)

Different Instars of *C. montrouzieri*	Number of different instars of mealybugs consumed* (mean ± SE)		
	1st Instar nymphs	2nd Instar nymphs	3rd Instar nymphs
1st	24.50 ± 0.47	14.88 ± 0.45	7.71 ± 0.32
2nd	43.00 ± 0.48	29.96 ± 0.63	14.17 ± 0.48
3rd	60.17 ± 1.12	41.50 ± 0.50	23.13 ± 0.40
4th	84.46 ± 0.48	52.58 ± 0.27	31.46 ± 0.66
CD (0.05)	2.00	1.39	1.39

* Mean of four replications

0.01%). This was followed by abamectin 0.006% (93.33%) and dichlorvos 0.05% (90.00%). The per cent mortality observed with NSKE 5% and abamectin 0.003% were on par (86.67). The lowest mortality per cent (80.00) was observed with NSKE.

4.15.2. First Instar (Crawlers)

Dimethoate 0.1% recorded maximum percentage mortality (96.67) followed by imidacloprid 0.01% (93.33), dimethoate 0.05% (86.67) and imidacloprid 0.005% (83.33). Per cent mortality of both abamectin 0.006% and abamectin 0.003% was recorded as 76.67 and 70 respectively. 73.33% mortality was given by dichlorvos 0.05%. The per cent mortality recorded with neem seed kernel extract (NSKE) 5% was 66.67 where as the least reduction percentage recorded with NSKE 2.5% (63.33) (Table 26)

After 48 hours, 100% mortality of mealybugs was observed on the leaves treated with dimethoate (0.05%, 0.1%) and imidacloprid (0.005%, 0.01%). The per cent mortality recorded with abamectin 0.006% was 96.67 followed by dichlorvos 0.05% (93.33), abamectin 0.003% (90.00) and NSKE 5% (86.37). The lowest per cent mortality was observed with NSKE 2.5% (83.33) (Table26).

4.16. EFFECT OF COMBINATIONS OF DIFFERENT INSECTICIDES ON PAPAYA MEALYBUG

4.16.1. Adult

The highest percentage mortality was observed the combination of dimethoate 0.05% + econeem plus 2 ml L^{-1} (93.33) followed by dimethoate 0.1% (90.00) and imidacloprid 0.01% (86.67). Combination of imidacloprid 0.005% + econeem plus 2 ml L^{-1} (83.33) were found to be effective when compared with the combination of dimethoate and imidacloprid with NSKE 5% and the percentage mortality was observed 80.00 and 76.67 respectively (Table 27).

Table 25. Efficacy of different insecticides against adult papaya mealybug by leaf dip method

Sl. No.	Insecticides	*Percentage mortality	
		24 HAT	48 HAT
1	T1 Dichlorvos 0.05 %	70	90
2	T2 Dimethoate 0.05 %	86.67	100
3	T3 Dimethoate 0.1 %	93.33	100
4	T4 Imidacloprid 0.005 %	83.33	100
5	T5 Imidacloprid 0.01 %	90	100
6	T6 Abamectin 0.003 %	73.33	86.67
7	T7 Abamectin 0.006 %	80	93.33
8	T8 Neem seed kernel extract (NSKE) 2.5 %	56.67	80
9	T9 NSKE 5 %	66.67	86.67
10	T10 Control (water spray)	0	0
	CD (0.05)	9.90	9.33

HAT- Hours after treatment
* Mean of three replications

Table 26. Efficacy of different insecticides against first instar papaya mealybug by leaf dip method

Sl. No.	Insecticides	*Percentage mortality	
		24 HAT	48 HAT
1	T1 Dichlorvos 0.05%	73.33	93.33
2	T2 Dimethoate 0.05%	86.67	100
3	T3 Dimethoate 0.1%	96.67	100
4	T4 Imidacloprid 0.005%	83.33	100
5	T5 Imidacloprid 0.01%	93.33	100
6	T6 Abamectin 0.003%	70	90
7	T7 Abamectin 0.006%	76.67	96.67
8	T8 Neem seed kernel extract (NSKE) 2.5%	63.33	83.33
9	T9 Neem seed kernel extract (NSKE) 5%	66.67	86.37
10	T10 Control (water spray)	0	0
	CD (0.05)	11.64	8.23

HAT- Hours after treatment
* Mean of three replications

After 48 hours, 100% mortality of mealybugs was observed on the leaves treated with dimethoate 0.1% and combination of dimethoate 0.05% + econeem plus 2 ml L^{-1}. The treatments imidacloprid 0.01%, combination of dimethoate 0.05% + NSKE 5% and combination of imidacloprid 0.005% + econeem plus 2 ml L^{-1} were on par with the per cent mortality of 96.67. Lowest per cent mortality (93.33) was observed with the combination of imidacloprid 0.005% + NSKE 5% (Table 27).

4.16.2. First Instar

Combination of dimethoate 0.05% + econeem plus ml L^{-1} was found to be effective (96.67%) followed by dimethoate 0.1% (93.33%) and imidacloprid 0.01% (90.00%).The lowest percentage mortality was recorded with the combination of imidacloprid and dimethoate with NSKE 5% and the percentage mortality was observed 80.00 and 83.33 respectively. The combination of imidacloprid 0.005% + econeem plus 2 ml L^{-1} gave 86.67 mortality (Table 28).

After 48 hours, 100% mortality of mealybugs was observed on the leaves treated with dimethoate 0.1%, imidacloprid 0.01% and in the combination of dimethoate 0.05% + Econeem plus 2 ml L^{-1}. The combination of dimethoate 0.05% + NSKE 5% and combination of imidacloprid 0.005% + econeem plus 2 ml L^{-1} were on par in effectiveness with 96.67 % mortality. Lowest per cent mortality of mealybugs (93.33) was recorded with the combination of imidacloprid 0.005% + NSKE 5% (Table 28).

4.17. IMPACT OF EFFECTIVE TREATMENTS ON SILKWORM REARING

Among the treatments, the maximum number of cocoons was harvested from control (T4) (94 cocoons/100 numbers of silkworms reared). The combination of dimethoate 0.05% + econeem plus 2 ml L^{-1} (T1) came next with 91/100 worms reared followed by imidacloprid 0.01% (T3) (85.17/100

Table 27. Efficacy of combinations of different insecticides against adult papaya mealybug by leaf dip method

Sl. No.	Insecticide treatments	*Percentage mortality	
		24 HAT	48 HAT
1	T1 Dimethoate 0.1% (Ist)	90	100
2	T2 Imidacloprid 0.01% (IInd)	86.67	96.67
3	T3 Half Ist + NSKE 5%	80	96.67
4	T4 Half IInd + NSKE 5%	76.67	93.33
5	T5 Half Ist + Econeem plus 2 ml L^{-1}	93.33	100
6	T6 Half IInd + Econeem plus 2 ml L^{-1}	83.33	96.67
7	T7 Control (water spray)	0.00	0.00
	CD (0.05)	12.09	7.64

HAT- Hours after treatment
* Mean of three replications

Table 28. Efficacy of combinations of different insecticides against first instar papaya mealybug by leaf dip method

Sl. No.	Insecticide treatments	*Percentage mortality	
		24 HAT	48 HAT
1	T1 Dimethoate 0.1% (Ist)	93.33	100.00
2	T2 Imidacloprid 0.01% (IInd)	90.00	100.00
3	T3 Half Ist + NSKE 5%	83.33	96.67
4	T4 Half IInd + NSKE 5%	80.00	93.33
5	T5 Half Ist + Econeem plus 2 ml L^{-1}	96.67	100.00
6	T6 Half IInd + Econeem plus 2 ml L^{-1}	86.67	96.67
7	T7 Control (water spray)	0.00	0.00
	CD (0.05)	7.64	6.62

HAT- Hours after treatment
* Mean of three replications

worms reared). The least number of cocoons were harvested from the treatment, dimethoate 0.1% (T2) (60.17/100 worms reared) (Table 29).

The highest total larval duration was observed in the treatment T2 (592.5 hrs). This was followed by T3 (590.33 hrs). The lowest total larval duration was found in T4 with 575 hrs, which was on par with T1 (576.33 hrs) (Table 29).

No significant difference was observed between the treatments on single cocoon weight. The maximum weight of cocoon was found to be in T4 (1.57g) followed by T1 (1.56g). Single cocoon weight of T3 (1.41g) was slightly higher than that of the treatment T2 (1.38g) (Table 29).

The highest shell ratio recorded in T4 (23.06) was on par with T1 (22.09). The shell ratio of the treatment with T2 and T3 was found to be 18.87 and 19.31 respectively and was on par (Table 29).

Among the four treatments, the effective rearing rate (ERR) by number was highest in T4 (9400.00). This was followed by T1 (9050.00). The treatment T3 (8516.68) was next in order. The very low ERR was recorded by T2 (7466.67) (Table 29).

The ERR by weight was highest in T4 (14152.77 g) followed by the treatment T1 (13744.69 g). The lowest ERR by weight was in T2 (12823.85 g), which was on par with T3 (13300.20 g) (Table 29).

4.17.1. Effect of Insecticides on Larval Weight of Mulberry Silkworm

The effect of different insecticides on the larval weight of silkworms is presented in the Table 30.

The highest weight of first instar larvae was recorded in T4 (control) (0.55 g) which was on par with T1 (dimethoate 0.05% + econeem Plus 2 ml L^{-1}) (0.54 g). The lowest larval weight in T2 (dimethoate 0.1%) (0.48 g) than the T3 (imidacloprid 0.01%) (0.50 g) treated ones.

The highest mean larval weight of second instar larvae was in T4 (1.39 g). This was followed T1 (1.16 g). The treatments T2 (1.09 g) and T3 (1.10 g) were statistically on par.

Table 29. Effect of different insecticides on the larval duration and important economic traits of mulberry silkworm

Sl. No.	Treatments	Total Larval duration (hrs)	Economic traits				
			Total number of cocoon harvested	Single cocoon weight (g)	Shell ratio	Effective rearing rate [number]	Effective rearing rate [weight (g)]
1	T1 (Dimethoate 0.05% + Econeem Plus 2 ml L^{-1})	576.33	91.00	1.56	22.09	9050.00	13744.69
2	T2 (Dimethoate 0.1%)	592.50	60.17	1.38	18.07	7466.67	12823.85
3	T3 (Imidacloprid 0.01%)	590.33	85.17	1.41	19.31	8516.68	13300.2
4	T4 Control (water spray)	575.00	94.00	1.57	23.06	9400.00	14152.77
	CD (0.05)	7.62	2.60	0.25	1.30	275.72	547.33

*Mean of six replications

The larval weight of the third instar larvae in different treatments varied from 0.84 g to 0.90 g. The highest mean larval weight was recorded in T4 (0.90 g) followed by T1 (0.87 g) and T3 (0.85 g) were statistically on par. The lowest larval weight was found to be in the treatment T2 (0.84 g).

The fourth instar larval weight varied from 8.45 g to 9.08 g in different treatments. The highest mean larval weight was in T4 (9.08 g). The other treatment T1 (8.80 g) was found to be superior while comparing with T3 (8.57 g) and T2 (8.45 g), which were on par.

The highest mean larval weight of fifth instar larvae was recorded in T4 (38.93 g) followed by T1 (36.61 g). The treatment T3 had a mean larval weight of 34.90 g whereas the lowest larval weight was recorded in T2 (27.55 g) (Table 30).

4.17.2 Effect of Insecticides on Growth Rate of Mulberry Silkworm

The results of the study on the growth rate of silkworm larvae in different treatments are presented in Table 31.

4.17.2.1. Second Instar

The larvae in T4 (control) (1.53) had highest growth rate followed by T1 (dimethoate 0.05% + econeem plus 2 ml L^{-1}) (1.25) and T3 (imidacloprid 0.01%) (1.21) which were on par. The lowest growth rate was recorded with T2 (dimethoate 0.1%) (1.17) (Table 31).

4.17.2.2. Third Instar

The lowest growth rate was recorded with T2 (2.89), whereas the highest growth rate was observed T4 (3.65) followed by T1 (3.64) and T3 (3.52) which were statistically on par (Table 31).

4.17.2.3. Fourth Instar

A non significant growth rate between the treatments was observed in fourth instar. The growth rate in T4, T1, T3 and T2 were in a decreasing order of 9.11, 9.07, 9.04 and 9.03 respectively (Table 31).

4.17.2.4. Fifth Instar

The highest growth rate was recorded in T4 (3.29). This was followed by Tl (3.16), which were statistically on par with T4 and T3 (3.07). The growth rate observed in T2 (2.26) was the lowest (Table 31).

4.18. FIELD EVALUATION OF EFFECTIVE TREATMENTS IN THE MANAGEMENT OF PAPAYA MEALYBUG IN MULBERRY

Field evaluation was carried out with the treatment found effective in the laboratory along with sutiable farmers' practice identified from the survey. For this field conditions in the farmers' fields at Agali, Sholayur and Puthur panchayats of Palakkad district were selected. Second round spraying with dichlorvos and econeem plus was done in the treatments T9, T10 and T11. The population of mealybug per 10 cm apical shoot in different treatments at different intervals after application is presented in Table 32, 33 and 34.

4.18.1. Agali

4.18.1.1. 7 DAT

Among the treatments (T7) dimethoate and econeem plus suppressed the maximum number of mealybugs (18.45) followed by (T3) dimethoate (20.48), (T8) imidacloprid and econeem plus (23.16) and (T6) dichlorvos + econeem plus (28.39) number of mealybugs.The mean number of mealybug in (T1) Pruning and weeding treatment (46.68) was found to be higher when compared to all the treatments. The mean number of mealybugs in the treatments observed with (T5) imidacloprid was 27.60 whereas (T2) dichlorvos and (T4) econeem plus reduced population of mealybugs of 29.13 and 41.16 respectively. (Table 32)

Table 30. Effect of insecticides on larval weight of mulberry silkworm

Sl. No.	Treatments	*Weight of larva (gram/10 larvae)				
		1st instar larva	2nd instar larva	3rd instar larva	4th instar larva	5th instar larva
1	T1 (Dimethoate 0.05% + Econeem Plus 2 ml L^{-1})	0.54	1.16	0.87	8.80	36.61
2	T2 (Dimethoate 0.1%)	0.48	1.09	0.84	8.45	27.55
3	T3 (Imidacloprid 0.01%)	0.50	1.10	0.85	8.57	34.90
4	T4 Control (water spray)	0.55	1.39	0.90	9.08	38.93
	CD (0.05)	0.01	0.01	0.02	0.18	1.43

* Mean of six replications

Table 31. Effect of insecticides on growth rate of mulberry silkworm

Sl No.	Treatments	2nd instar	3rd instar	4th instar	5th instar
1	T1 (Dimethoate 0.05% + Econeem Plus 2 ml L^{-1})	1.25	3.64	9.07	3.16
2	T2 (Dimethoate 0.01%)	1.17	2.89	9.03	2.26
3	T3 (Imidacloprid @ 0.01%)	1.21	3.52	9.04	3.07
4	T4 Control (water spray)	1.53	3.65	9.11	3.29
	CD (0.05)	0.07	0.14	N.S	0.18

* Mean of six replications

4.18.1.2. 14 DAT

The maximum reduction of mealybugs was observed in T7 (20.55) followed by T3 (22.72), T8 (26.85) and T6 (29.56). Among the remaining treatments with lowest population was recorded in T5 (30.29) followed by T2 (33.37) and T4 (47.88). The highest number of mealybugs was recorded in T1 (49.97) (Table 32).

4.18.1.3. 21 DAT

The maximum reduction of mealybug population was recorded in (T10) second spray with dichlorvos + econeem plus 15 days after the first spray of dimethoate + econeem plus (7.72) followed by (T11) imidacloprid + econeem plus (16.29) and (T9) dichlorvos + econeem plus (20.55). Among the remaining treatments, the lowest population was recorded with T7 (28.36) followed by T8 (29.12), T3 (30.72), T6 (35.27), T5 (36.47) and T2 (38.95). The treatments with higher number of mealybug population were in T1 (55.95) and T4 (50.49) (Table 32).

4.18.1.4. 28 DAT

The least effective treatments with maximum number of mealybugs were in T1 (70.31) and T4 (57.47). The most effective treatments with minimum number of mealybugs was T10 (11.64) followed by T11 (18.68) and T9 (25.13). Among the remaining treatments, the lowest number of mealybugs were T8 (31.10), T7 (32.47), T3 (36.24), T6 (38.21) and T2 (42.68). The treatments T4 (57.47) and T5 (43.65) also had higher number of mealybugs (Table 32).

4.18.2. Sholayur

4.18.2.1. 7 DAT

The mean number of mealybugs observed was the lowest in T7 (19.84) followed by T8 (20.31) and T3 (22.76). The remaining treatments with minimum number of mealybugs were T6 (25.40), T5 (26.83),

Table 32. Population of papaya mealybug at different intervals after application of different treatments in Agali panchayat

Sl. No.	Treatments	*Papaya mealybug population (No. of mealybugs /10 cm apical shoot)			
		7 DAT	14 DAT	21 DAT	28 DAT
1	T1 Pruning + weeding	46.68 (6.83)	49.97 (7.07)	55.95 (7.48)	70.31 (8.38)
2	T2 T1 + Dichlorvos (2 ml L^{-1})	29.13 (5.40)	33.37 (5.78)	38.95 (6.24)	42.68 (6.53)
3	T3 T1+ Dimethoate (1.7 ml L^{-1})	20.48 (4.53)	22.72 (4.77)	30.72 (5.54)	36.24 (6.02)
4	T4 T1+ Econeem plus(2 ml L^{-1})	41.16 (6.42)	47.88 (6.92)	50.49 (7.10)	57.47 (7.58)
5	T5 T1 + Imidacloprid (0.6 ml L^{-1})	27.60 (5.25)	30.29 (5.50)	36.47 (6.04)	43.65 (6.61)
6	T6 T1+ Dichlorvos + Econeem plus	28.39 (5.33)	29.56 (5.44)	35.27 (5.94)	38.21 (6.18)
7	T7 T1+ Dimethoate + Econeem plus	18.45 (4.30)	20.55 (4.53)	28.36 (5.33)	32.47 (5.70)
8	T8 T1+ Imidacloprid + Econeem plus	23.16 (4.81)	26.85 (5.18)	29.12 (5.40)	31.10 (5.58)
9	T9 T6 + T6**			20.55 (4.53)	25.13 (5.01)
10	T10 T7 + T6**			7.72 (2.78)	11.64 (3.41)
11	T11 T8 + T6 **			16.29 (4.04)	18.68 (4.32)
12	T12 Control	70.09 (8.37)	70.90 (8.42)	86.65 (9.31)	102.07 (10.10)
	CD (0.05)	0.02	0.04	0.06	0.04

DAT- Days After Treatment

*Mean of five replications

**2nd spray was taken up with dichlorvos 2 ml + econeem 2 ml L^{-1} on 15 days after first spray.

Figures in the parentheses are square root transformed values.

T2 (28.45) and T4 (32.48). The highest number of mealybugs (46.45) was recorded in T1 (Table 33).

4.18.2.2. 14 DAT

The lowest number of mealybugs was recoded in T7 (20.80) followed by T3 (23.47), T8 (25.55) and T6 (28.48). The treatments observed with more number of mealybugs were T5 (32.45) T2 (34.05) and T4 (38.97). The higher number of mealybugs was observed in T1 (50.60) (Table 33).

4.18.2.3. 21 DAT

The most effective treatments with minimum number of mealybugs were T10 (7.93) T11 (15.89) and T9 (21.80). The remaining treatments with lower number of mealybugs were T7 (24.29) T8 (27.42) T3 (28.63), T6 (35.09) and T5 (37.12). The higher number of mealybugs was recored with the treatments T2 (42.95) and T4 (44.32). The least effective treatment was T1 (56.07) (Table 33).

4.18.2.4. 28 DAT

The number of mealybugs was found to be the highest in T1 (70.43). The treatments with maximum control were recorded with T10 (12.03), T11 (19.49) and T9 (22.67). The remaining treatments with lower number of mealybugs were T7 (25.08), T8 (30.32), T3 (32.42) and T6 (38.60). The population was higher in treatments T5 (44.23), T2 (45.55) and T4 (47.33) (Table 33).

4.18.3. Puthur

The mean number of mealybugs per 10 cm apical shoot were observed in different treatments are represented in Table 34.

Table 33. Population of papaya mealybug at different intervals after application of different treatments in Sholayur panchayat

Sl No.	Treatments	*Papaya mealybug population (No. of mealybugs /10 cm apical shoot)			
		7 DAT	14 DAT	21 DAT	28 DAT
1	T1 Pruning + weeding	46.45 (6.82)	50.60 (7.11)	56.07 (7.49)	70.43 (8.39)
2	T2 T1 + Dichlorvos (2 ml L^{-1})	28.45 (5.33)	34.05 (5.84)	42.95 (6.55)	45.55 (6.75)
3	T3 T1 + Dimethoate (1.7 ml L^{-1})	22.76 (4.77)	23.47 (4.84)	28.63 (5.35)	32.42 (5.69)
4	T4 T1 + Econeem Plus (2 ml L^{-1})	32.48 (5.70)	38.97 (6.24)	44.32 (6.66)	47.33 (6.88)
5	T5 T1 + Imidacloprid (0.6 ml L^{-1})	26.83 (5.18)	32.45 (5.70)	37.12 (6.09)	44.23 (6.64)
6	T6 T1 + Dichlorvos + Econeem plus	25.40 (5.03)	28.48 (5.34)	35.09 (5.92)	38.60 (6.21)
7	T7 T1 + Dimethoate + Econeem plus	19.84 (4.45)	20.80 (4.56)	24.29 (4.93)	25.08 (5.01)
8	T8 T1 + Imidacloprid + Econeem plus	20.31 (4.51)	25.55 (5.05)	27.42 (5.24)	30.32 (5.51)
9	T9 T6 + T6**			21.80 (4.67)	22.67 (4.76)
10	T10 T7 + T6**			7.93 (2.82)	12.03 (3.46)
11	T11 T8 + T6 **			15.89 (3.99)	19.49 (4.41)
12	T12 Control	71.96 (8.48)	73.13 (8.55)	89.19 (9.44)	104.68 (10.23)
	CD (0.05)	0.05	0.04	0.05	0.06

DAT- Days After Treatment
*Mean of five replications
**2nd spray was taken up with dichlorvos 2 ml + econeem 2 ml L^{-1} on 15 days after first spray.
Figures in the parentheses are square root transformed values.

4.18.3.1. 7 DAT

The mean number of mealybugs in T7 (20.44) was found to be the lowest followed by T8 (22.96) and T3 (24.02). The population was found to be higher in treatments T6 (25.20), T2 (27.03) and T5 (28.27). Higher number of mealybugs was recorded in T4 (40.65) and T1 (44.92) (Table 34).

4.18.3.2. 14 DAT

The most effective treatment with lowest number of mealybugs (22.81) was in T7. The other effective treatments were T8 (24.77), T3 (28.00) and T6 (29.05). The treatments with higher number of mealybugs were T5 (30.04) and T2 (32.99). The treatments T1 and T4 were the least effective with 48.39 and 46.24 mealybugs respectively (Table 34).

4.18.3.3. 21 DAT

The mean number of mealybugs was the lowest in T10 (8.47). The other effective treatments followed were T11 (18.24), T9 (22.34) T7 (25.95) and T8 (27.37). The remaining treatments with higher number of mealybugs were T3 (30.63), T5 (33.91), T6 (36.67) and T2 (43.95). The treatments T1 (54.21) and T4 (50.00) were found to be least effective (Table 34).

4.18.3.4. 28 DAT

The treatments observed with minmum number of mealybugs were T10 (13.04), T11 (20.87) and T9 (25.37) were found to be superior when compared with other. The other effective treatments were T7 (24.77), T8 (32.37), T3 (33.27) and T5 (36.54). The treatments T6 (40.29) and T2 (48.05) were came next in order. The least effective treatments were T1 (67.74) and T4 (56.50) (Table 34).

Table 34. Population of papaya mealybug at different intervals after application of different treatments in Puthur panchayat

Sl. No.	Treatments	*Papaya mealybug population (No. of mealybugs /10 cm apical shoot)			
		7 DAT	14 DAT	21 DAT	28 DAT
1	T1 Pruning + weeding	44.92 (6.70)	48.39 (6.96)	54.21 (7.36)	67.74 (8.23)
2	T2 T1 + Dichlorvos (2 ml L^{-1})	27.03 (5.20)	32.99 (5.74)	43.95 (6.63)	48.05 (6.93)
3	T3 T1+ Dimethoate (1.7 ml L^{-1})	24.02 (4.90)	28.00 (5.29)	30.63 (5.53)	33.27 (5.77)
4	T4 T1+ Econeem plus (2 ml L^{-1})	40.65 (6.38)	46.24 (6.80)	50.00 (7.07)	56.50 (7.04)
5	T5 T1 + Imidacloprid (0.6 ml L^{-1})	28.27 (5.32)	30.04 (5.48)	33.91 (5.82)	36.54 (6.04)
6	T6 T1 + Dichlorvos + Econeem plus	25.20 (5.01)	29.05 (5.39)	36.67 (6.06)	40.29 (6.35)
7	T7 T1 + Dimethoate + Econeem plus	20.44 (4.52)	22.81 (4.78)	25.95 (5.09)	24.77 (4.98)
8	T8 T1 + Imidacloprid + Econeem plus	22.96 (4.79)	24.77 (4.98)	27.37 (5.23)	32.37 (5.69)
9	T9 T6 + T6**			22.34 (4.72)	25.37 (5.04)
10	T10 T7 + T6**			8.47 (2.91)	13.04 (3.61)
11	T11 T8 + T6 **			18.24 (4.27)	20.87 (4.57)
12	T12 Control	80.28 (8.96)	81.21 (9.01)	98.76 (9.94)	113.99 (10.63)
	CD (0.05)	0.08	0.06	0.04	0.10

DAT- Days After Treatment
*Mean of five replications
**2nd spray was taken up with dichlorvos 2 ml + econeem 2 ml L^{-1} on 15 days after first spray.
Figures in the parentheses are square root transformed values.

4.19 POPULATION OF MEALYBUGS PER PLANT AT DIFFERENT INTERVALS AFTER APPLICATION OF DIFFERENT TREATMENTS.

The mealybug observed per plant after each treatment is presented in Table 35, 36 and 37. The promising treatment was the combination of dimethoate and econeem plus along with second spray of dichlorvos + econeem plus. In general, all the insecticides were found to be quite effective upto 10 days after application. It was observed that in treatments without second round spraying, infestation of mealybugs was found to be increased later.

4.19.1. Agali

4.19.1.1. 7 DAT

The most effective treatments T7 (35.69) and T8 (37.58) were statistically on par. The remaining effective treatments with minimum number of mealybugs per plant were T3 (46.19), T6 (50.60) and T5 (54.94). The higher number mealybugs were observed in treatments T1 (85.63), T4 (75.50) and T2 (73.62) (Table 35).

4.19.1.2. 14 DAT

The most effective treatments with minimum number of mealybugs were T7 (39.48) and T8 (41.69), which were statistically on par. Among the remaining treatments, T6 (52.81) and T5 (58.50) were statistically on par. The higher number of mealybugs was recorded with T4 (81.55) and T2 (75.84). The least effective treatment with highest number of mealybugs was observed in T1 (102.63) (Table 35).

4.19.1.3. 21 DAT

The treatments T3 (50.62), T8 (46.05), T9 (49.99), were on par in effectivness followed by T6 (55.75), T5 (65.93) which were also statistically on par. The most effective treatment with minimum number of mealybugs was observed in T10 (14.16) followed by T11 (30.34) and T7 (40.05) which were statistically on par. The treatment T1 (128.91) was the least effective (Table 35).

4.19.1.4. 28 DAT

Among the treatments, T5 (70.41) and T2 (82.54) were statistically on par followed by T7 (43.97) and T8 (47.74) and T9 (54.33), T3 (55.44) and T6 (58.15) which were statistically on par followed by T4 (85.03). The maximum reduction in the number of mealybugs was recorded in T10 (23.59) followed by T11 (32.26). The maximum number of mealybugs was recorded in T1 (160.09) (Table 35).

4.19.2. Sholayur

4.19.2.1. 7 DAT

The least effective treatment was T1 (100.68). The treatments that suppressed the mealybug population were T3 (55.35) followed by T5 (62.44) whereas T6 and T4 reduced the population upto 67.60 and 89.92 mealybugs respectively. The most effective treatments with minimum number of mealybugs were T7 (39.54), T8 (43.98) (Table 36).

4.19.2.2. 14 DAT

Among the treatments, the mean number of mealybug was low in T7 (45.07) followed by T8 (49.32). The number of mealybugs in other effective treatments were in the following order of T3 (59.50), T6 (61.40), T5 (63.91), T2 (78.86) and T4 (90.93). Severe infestation of mealybugs was observed in T1 (109.68 mealybugs) (Table 36).

4.19.2.3. 21 DAT

The mean number of mealybugs in T1 was 121.55 and this was found to be the least effective treatment. The lowest population of mealybugs was

Table 35. Population of papaya mealybug at different intervals after application of different treatments in Agali panchayat

Sl. No.	Treatments	*Papaya mealybug population (No. of mealybugs/ plant)			
		7 DAT	14 DAT	21 DAT	28 DAT
1	T1 Pruning + weeding	85.63 (9.25)	102.63 (10.13)	128.91 (11.35)	160.09 (12.65)
2	T2 T1 + Dichlorvos (2 ml L^{-1})	73.62 (8.58)	75.84 (8.71)	79.92 (8.94)	82.54 (9.09)
3	T3 T1 + Dimethoate (1.7 ml L^{-1})	46.19 (6.80)	48.17 (6.94)	50.62 (7.11)	55.44 (7.45)
4	T4 T1 + Econeem (2 ml L^{-1})	75.50 (8.69)	81.55 (9.03)	83.51 (9.14)	85.03 (9.22)
5	T5 T1 + Imidacloprid (0.6 ml L^{-1})	54.94 (7.41)	58.50 (7.65)	65.93 (8.11)	70.41 (8.39)
6	T6 T1 + Dichlorvos + Econeem plus	50.60 (7.11)	52.81 (7.27)	55.75 (7.47)	58.15 (7.63)
7	T7 T1 + Dimethoate + Econeem plus	35.69 (5.97)	39.48 (6.28)	40.05 (6.33)	43.97 (6.63)
8	T8 T1 + Imidacloprid + Econeem plus	37.58 (6.13)	41.69 (6.46)	46.05 (6.79)	47.74 (6.91)
9	T9 T6 + T6**			49.99 (7.07)	54.33 (7.37)
10	T10 T7 + T6**			14.16 (3.76)	23.59 (4.86)
11	T11 T8 + T6 **			30.34 (5.51)	32.26 (5.68)
12	T12 Control	128.34 (11.33)	129.80 (11.39)	208.94 (14.46)	228.35 (15.11)
	CD (0.05)	0.18	0.44	0.82	0.72

DAT- Days After Treatment
*Mean of five replications
**2nd spray was taken up with dichlorvos 2 ml + econeem 2 ml L^{-1} on 15 days after first spray.
Figures in the parentheses are square root transformed values.

recorded with T10 (17.22) followed by T11 (36.59). The treatments that suppressed mealybugs were T9 (45.14) T7 (47.25) and T8 (52.63). The higher number of mealybugs were observed in T3 (60.63), T5 (67.43), T6 (76.91), T2 (83.10) and T4 (93.86) (Table 36).

4.19.2.4. 28 DAT

The most effective treatment was T10 (26.05) followed by T11 (42.17). The other effective treatments with lesser number of mealybugs were T7 (49.10), T9 (52.01) and T8 (54.34). Among the remaining treatments, higher number of mealybugs were recorded in T3 (65.70), T5 (69.71), T6 (82.98), T2 (87.63) and T4 (98.48). The highest population of mealybugs was observed in T1 (152.59) (Table 36).

4.19.3. Puthur

4.19.3.1. 7 DAT

The treatments with lower mean number of mealybugs were in T1 (98.42) and T4 (95.97), which were statistically on par. The most effective treatment was T7 (37.72). The treatments also effectively controlled the mealybugs were in T8 (48.84), T6 (53.81), T3 (59.79) and T5 (66.13) (Table 37).

4.19.3.2. 14 DAT

The lowest population of mealybugs were recorded in treatments T7 (45.42) followed by T8 (52.84.), T6 (59.96), T3 (63.99.) and T5 (68.37). Comparatively higher number mealybugs were observed in T4 (97.38). The least effective treatment was in T1 (103.35) (Table 37).

4.19.3.3. 21 DAT

The most effective treatment was T10 (18.05) followed by T11 (38.90). The treatments T7 (51.55), T9 (56.34) and T8 (58.39) were on par in effectiveness followed by T3 (65.32), T5 (72.22) and T6 (67.14)

Table 36. Population of papaya mealybug at different intervals after application of different treatments in Sholayur panchayat

Sl No.	Treatments	*Papaya mealybug population (No. of mealybugs/ plant)			
		7 DAT	14 DAT	21 DAT	28 DAT
1	T1 Pruning + weeding	100.68 (10.03)	109.68 (10.47)	121.55 (11.03)	152.59 (12.35)
2	T2 T1 + Dichlorvos (2 ml L^{-1})	67.60 (8.22)	78.86 (8.88)	83.10 (9.11)	87.63 (9.36)
3	T3 T1 + Dimethoate (1.7 ml L^{-1})	55.35 (7.44)	59.50 (7.71)	60.63 (7.79)	65.70 (8.10)
4	T4 T1 + Econeem plus (2 ml L^{-1})	89.92 (9.48)	90.93 (9.54)	93.86 (9.69)	98.48 (9.92)
5	T5 T1 + Imidacloprid (0.6 ml L^{-1})	62.44 (7.90)	63.91 (7.99)	67.43 (8.21)	69.71 (8.35)
6	T6 T1 + Dichlorvos + Econeem plus	56.85 (7.54)	61.40 (7.84)	76.91 (8.77)	82.98 (9.11)
7	T7 T1 + Dimethoate + Econeem plus	39.54 (6.29)	45.07 (6.71)	47.25 (6.87)	49.10 (7.01)
8	T8 T1 + Imidacloprid + Econeem plus	43.98 (6.63)	49.32 (7.03)	52.63 (7.25)	54.34 (7.37)
9	T9 T6 + T6**			45.14 (6.72)	52.01 (7.21)
10	T10 T7 + T6**			17.22 (4.15)	26.05 (5.10)
11	T11 T8 + T6 **			36.59 (6.05)	42.17 (6.49)
12	T12 Control	155.92 (12.45)	158.46 (12.59)	193.24 (13.90)	226.87 (15.06)
	CD (0.05)	0.09	0.08	0.10	0.11

DAT-Days After Treatment
*Mean of five replications
**2nd spray was taken up with dichlorvos 2 ml + econeem 2 ml L^{-1} on 15 days after first spray.
Figures in the parentheses are square root transformed values.

which were also statistically on par with each other. The number of mealybugs were more in treatments T2 (87.56), and T4 (101.47) which were statistically on par in effectiveness. The least effective treatment was in T1 (170.31) (Table 37).

4.19.3.4. 28 DAT

The superior treatment was T10 (27.81) followed by T11 (44.51). The treatments T7 (56.96), T8 (58.39) and T9 (66.72) were on par in effectiveness. The mean number of mealybugs in treatment T3 (70.96), T5 (76.32), and T6 (72.33) were on par followed by T2 (93.14), and T4 (105.43) which wwere also statistically on par. T1 (197.84) alone recorded as the least effective treatment (Table 37).

4.20. EFFECT OF VARIOUS TREATMENTS ON LEAF DAMAGE OF MULBERRY

4.20.1. Agali

The most effective treatment with minimum number of leaves damage was in T10 (4.41) and T7 (5.10) which were on par in effectiveness followed by and T11 (9.07). The treatments T8, T9 and T5 were statistically on par with each other with 31.27 damaged leaves. Among the remaining treatments T3 (32.20) and T6 (33.59) were statistically on par followed by T4 (38.73). The treatments with maximum number of leaf damage were recorded in T2 (43.87) and T1 (46.19) (Table 38).

4.20.2. Sholayur

The superior treatments with minimum number of leaves damaged per plant were T10 (4.13), T7 (5.56) and T11 (9.72). Among the remaining treatments, moderate leaf damage were recorded in T8 (29.12), T5 (31.58), T3 (31.85), T6 (32.19) and T4 (36.13). More number of leaves damaged were recorded in T1 (45.98) and T2 (40.39) (Table 38).

Table 37. Population of papaya mealybug at different intervals after application of different treatments in Puthur panchayat

Sl. No.	Treatments	*Papaya mealybug population (No. of mealybugs/ plant)			
		7 DAT	14 DAT	21 DAT	28 DAT
1	T1 Pruning + weeding	98.42 (9.92)	103.35 (10.17)	170.31 (13.05)	197.84 (14.07)
2	T2 T1 + Dichlorvos (2 ml L^{-1})	75.73 (8.70)	82.41 (9.08)	87.56 (9.36)	93.14 (9.65)
3	T3 T1 + Dimethoate (1.7 ml L^{-1})	59.79 (7.73)	63.99 (7.10)	65.32 (8.08)	70.96 (8.42)
4	T4 T1 + Econeem plus (2 ml L^{-1})	95.97 (9.80)	97.38 (9.87)	101.47 (10.07)	105.43 (10.27)
5	T5 T1 + Imidacloprid (0.6 ml L^{-1})	66.13 (8.13)	68.37 (8.27)	72.22 (8.50)	76.32 (8.74)
6	T6 T1 + Dichlorvos + Econeem plus	53.81 (7.33)	59.96 (7.74)	67.14 (8.19)	72.33 (8.50)
7	T7 T1 + Dimethoate + Econeem plus	37.72 (6.14)	45.42 (6.74)	51.55 (7.18)	56.96 (7.55)
8	T8 T1 + Imidacloprid + Econeem plus	48.84 (6.99)	52.84 (7.27)	58.39 (7.64)	58.39 (7.64)
9	T9 T6 + T6**			56.34 (7.51)	66.72 (8.17)
10	T10 T7 + T6**			18.05 (4.25)	27.81 (5.27)
11	T11 T8 + T6**			38.90 (6.24)	44.51 (6.67)
12	T12 Control	170.97 (13.06)	173.17 (13.16)	210.34 (14.50)	240.26 (15.50)
	CD (0.05)	0.25	0.23	0.83	0.77

DAT -Days After Treatment
*Mean of five replications
**2nd spray was taken up with dichlorvos 2 ml + econeem 2 ml L^{-1} on 15 days after first spray.
Figures in the parentheses are square root transformed values.

4.20.3. Puthur

The similar trend was observed in Puthur. The most effective treatment was identified in T10 with 4.88 number of leaves damaged followed by T7 (6.09) and T11 (10.59). The treatments with moderate leaf damage were in the order T3 (30.75), T5 (31.03), T9 (31.46), T8 (32.99), T6 (35.06) and T4 (36.42). The treatments with more number of leaves were damaged in T1 (46.54) and T2 (41.71) (Table 38).

4.21. EFFECTS OF VARIOUS TREATMENTS ON SHOOT DAMAGE

The effect of various treatments on shoot damage in different locations is presented here in Table 39. The average number of shoots maintained per plant was 10 after pruning.

4.21.1. Agali

The number of shoots damaged per plant was maximum in the treatments T1 (6.36) followed by T2 (5.55) and T4 (5.36) which were found statistically on par. The treatments recorded with minimum shoot damage T6 (4.26) and T9 (4.06) followed by T8 (4.54) and T3 (4.72) which were statistically on par. The lowest shoot damage per plant was recorded in T10 (1.16) followed by T7 (1.35) and T11 (2.52) (Table 39).

4.21.2. Sholayur

The shoots with lowest damage was observed in T10 (1.25) which was on par with T7 (1.29) followed by T11 (2.21). The number of shoots damaged moderately were in T9 (4.21), T8 (4.25), T6 (4.34) which were statistically on par. The treatments T5 (4.54) and T3 (4.69) were on par in effectiveness. The damage level was found more in treatments T2 (5.39) and T4 (5.40) which were also on par with each other (Table 39).

Table 38. Effect of various treatments on leaf damage of mulberry

Sl. No.	Treatments	*No. of leaves infested/plant		
		Agali	Sholayur	Puthur
1	T1 Pruning + Weeding	46.19 (6.80)	45.98 (6.78)	46.54 (6.82)
2	T2 T1 + Dichlorvos (2 ml L^{-1})	43.87 (6.62)	40.39 (6.36)	41.71 (6.46)
3	T3 T1 + Dimethoate (1.7 ml L^{-1})	32.20 (5.67)	31.85 (5.64)	30.75 (5.55)
4	T4 T1 + Econeem plus (2 ml L^{-1})	38.73 (6.22)	36.13 (6.01)	36.42 (6.03)
5	T5 T1 + Imidacloprid (0.6 ml L^{-1})	31.27 (5.59)	31.58 (5.62)	31.03 (5.57)
6	T6 T1 + Dichlorvos + Econeem plus	33.59 (5.80)	32.19 (5.67)	35.06 (5.92)
7	T7 T1+ Dimethoate + Econeem plus	5.10 (2.26)	5.56 (2.36)	6.09 (2.47)
8	T8 T1+ Imidacloprid + Econeem plus	31.27 (5.59)	29.12 (5.40)	32.99 (5.74)
9	T9 T6 + T6**	31.27 (5.59)	31.64 (5.62)	31.46 (5.61)
10	T10 T7 + T6**	4.41 (2.10)	4.13 (2.03)	4.88 (2.21)
11	T11 T8 + T6 **	9.07 (3.01)	9.72 (3.12)	10.59 (3.25)
12	T12 Control	50.86 (7.13)	50.29 (7.09)	51.42 (7.17)
	CD (0.05)	0.20	0.12	0.10

DAT -Days After Treatment
*Mean of five replications
**2nd spray was taken up with dichlorvos 2 ml + econeem 2 ml L^{-1} on 15 days after first spray.
Figures in the parentheses are square root transformed values.

4.21.3. Puthur

The treatments with more number of shoots damaged were T8 (4.67), T9 (4.72), T6 (4.79), T3 (4.89) and T5 (5.07) which were on par in effectiveness.The treatments T10 (1.38) and T7 (1.52) were statistically on par followed by T 11 (2.45). The highest shoot damage were recorded in treatments T1 (6.53) followed by T4 (5.71) and T2 (5.91) which were on par in effectiveness (Table 39).

4.22. EFFECT OF VARIOUS TREATMENTS ON LEAF YIELD

The weight of harvested leaves per plant was taken separately for different treatments are presented in Table 40.

4.22.1. Agali

The highest leaf yield of was recorded in T10 (1.64 kg/plant) followed by T7 (1.35 kg) and T11 (1.23 kg). The lowest leaf yield was recorded in treatments T1 (0.58 kg) and T4 (0.57 kg) which were on par in effectiveness followed by T6 (0.77 kg), T2 and T5 (0.79) which were also statistically on par. The treatments T9 (0.82 kg) and T8 (0.84 kg) were statistically on par with each other. The treatment T3 gave the yield 0.92 kg per plant (Table 40).

4.22.2. Sholayur

Among the treatments, the highest leaf yield was obtained in T10 (1.62 kg) followed by T7 (1.30 kg) and T11 (1.22 kg). The treatments T1 (0.57 kg) and T4 (0.57 kg); T5 (0.78 kg) and T6 (0.76 kg) which were on par with each other. The treatment T2 (0.79 kg) was on par with T5. The yield of remaining treatments were T3 (0.95 kg), T8 (0.86 kg) and T9 (0.82 kg) (Table 40).

Table 39. Effect of various treatments on shoot damage of mulberry

Sl. No.	Treatments	*No. of shoots infested/plant		
		Agali	Sholayur	Puthur
1	T1 Pruning + weeding	6.36 (2.52)	6.38 (2.53)	6.53 (2.56)
2	T2 T1 + Dichlorvos (2 ml L^{-1})	5.55 (2.36)	5.39 (2.32)	5.91 (2.43)
3	T3 T1 + Dimethoate (1.7 ml L^{-1})	4.72 (2.17)	4.69 (2.17)	4.89 (2.21)
4	T4 T1 + Econeem plus (2 ml L^{-1})	5.36 (2.32)	5.40 (2.32)	5.71 (2.39)
5	T5 T1 + Imidacloprid (0.6 ml L^{-1})	5.03 (2.24)	4.54 (2.13)	5.07 (2.25)
6	T6 T1 + Dichlorvos + Econeem plus	4.26 (2.06)	4.34 (2.08)	4.79 (2.19)
7	T7 T1 + Dimethoate + Econeem plus	1.35 (1.16)	1.29 (1.14)	1.52 (1.23)
8	T8 T1 + Imidacloprid + Econeem plus	4.54 (2.13)	4.25 (2.06)	4.67 (2.16)
9	T9 T6 + T6**	4.06 (2.01)	4.21 (2.05)	4.72 (2.17)
10	T10 T7 + T6**	1.16 (1.08)	1.25 (1.12)	1.38 (1.18)
11	T11 T8 + T6 **	2.52 (1.59)	2.21 (1.49)	2.45 (1.57)
12	T12 Control	8.33 (2.89)	8.50 (2.92)	8.87 (2.98)
	CD (0.05)	0.05	0.08	0.09

*Mean of five replications

**2nd spray was taken up with dichlorvos 2 ml + econeem 2 ml L^{-1} on 15 days after first spray.

Figures in the parentheses are square root transformed values.

4.22.3. Puthur

The highest leaf yield was recorded in T10 (1.61 kg) followed by T7 (1.29 kg), T11 (1.22 kg) and T3 (0.95 kg) which were significantly superior to all other treatments. The yield of the remaining treatments T8 (0.86 kg) and T9 (0.81 kg), were on par followed by T6 (0.79 kg), T5 (0.78 kg) and T2 (0.75 kg) which were also statistically on par. The lowest yield observed in T4 (0.57 kg) and T1 (0.58 kg) which were on par in effectiveness (Table 40).

4.23 RETURNS AND BENEFIT: COST RATIO ON DIFFERENT TREATMENTS

While considering the total returns, the treatment T10 recorded the highest net return per hectare (Rs. 6, 12, 000) followed by T11 (Rs. 5, 97,600). Treatment T9 gave Rs. 5, 76, 000 followed by T7 Rs. 5, 54, 400 and T8 Rs.5, 47, 200. The lowest return was obtained in the treatment, T1 (Rs. 5, 11, 200) but was higher than that in control (Rs. 4, 68, 000) (Table 41).

The results on benefit: cost ratio revealed that the treatment T10 had the highest B: C ratio (2.07) and was followed by T11 (2.00). The treatment T9 showed a B: C ratio of 1.95 and the next highest value was recorded in the treatment T7 (1.93). The least B: C ratio was recorded in the control (1.77).

Table 40. Effect of various treatments on mulberry leaf yield

Sl. No.	Treatments	*Yield of leaf kg /plant		
		Agali	Sholayur	Puthur
1	T1 Pruning + Weeding	0.58 (0.76)	0.57 (0.75)	0.58 (0.76)
2	T2 T1 + Dichlorvos (2 ml L^{-1})	0.79 (0.89)	0.79 (0.89)	0.75 (0.87)
3	T3 T1 + Dimethoate (1.7 ml L^{-1})	0.92 (0.96)	0.95 (0.98)	0.95 (0.99)
4	T4 T1 + Econeem plus(2 ml L^{-1})	0.57 (0.75)	0.57 (0.75)	0.57 (0.75)
5	T5 T1 + Imidacloprid (0.6 ml L^{-1})	0.79 (0.89)	0.78 (0.88)	0.78 (0.88)
6	T6 T1 + Dichlorvos + Econeem plus	0.77 (0.88)	0.76 (0.87)	0.79 (0.89)
7	T7 T1 + Dimethoate + Econeem plus	1.35 (1.16)	1.30 (1.14)	1.29 (1.13)
8	T8 T1 + Imidacloprid + Econeem plus	0.84 (0.92)	0.86 (0.93)	0.86 (0.93)
9	T9 T6 + T6**	0.82 (0.90)	0.82 (0.91)	0.81 (0.91)
10	T10 T7 + T6**	1.64 (1.28)	1.62 (1.27)	1.61 (1.27)
11	T11 T8 + T6 **	1.23 (1.11)	1.22 (1.11)	1.22 (1.10)
12	T12 Control	0.49 (0.70)	0.5 (0.71)	0.5 (0.73)
	CD (0.05)	0.02	0.01	0.02

*Mean of five replications

**2nd spray was taken up with dichlorvos 2 ml + econeem 2 ml L^{-1} on 15 days after first spray.

Figures in the parentheses are square root transformed values.

Table 41. Returns and benefit: cost ratio on different treatments for the management of papaya mealybug on mulberry

Sl. No	Cocoon Weight Kg ha^{-1} year^{-1} (300 DFLs)	Return (Rs. ha^{-1} year^{-1})	Expenses (Rs ha^{-1} year^{-1})			Benefit Cost ratio
			Leaf production cost	Cocoon production cost	Total cost	
T1	1704	511200	160550	116090	276640	1.85
T2	1752	525600	165490	116090	281580	1.87
T3	1800	540000	165613.5	116090	281704	1.92
T4	1728	518400	166107.5	116090	282198	1.84
T5	1776	532800	169503.8	116090	285594	1.87
T6	1800	540000	171047.5	116090	287138	1.88
T7	1848	554400	171171	116090	287261	1.93
T8	1824	547200	175061.3	116090	291151	1.88
T9	1920	576000	179075	116090	295165	1.95
T10	2040	612000	179198.5	116090	295289	2.07
T11	1992	597600	183088.8	116090	299179	2.00
T12	1560	468000	148200	116090	264290	1.77

Discussion

5. DISCUSSION

Studies were carried out on the different basic aspects of papaya mealybug infesting mulberry, *viz.*, identification of the pest, its population distribution, biology, natural enemies, collateral hosts, role in disease transmission and effect of commercially available predators on the pest. Plant protection materials under different categories, *viz.*, botanicals, chemical insecticides and their combinations were screened and best combinations were selected. These were evaluated individually and in combinations against papaya mealybug under field conditions. The impact of these treatments on yield was also assessed. The results of the investigations carried out at College of Agriculture, Vellayani and farmers fields at Agali, Sholayur and Puthur panchayats of Palakkad district are discussed in this chapter.

5.1. SURVEY OF PESTS AND NATURAL ENEMIES

5.1.1. Distribution of Egg Masses in Different Seasons

The highest mean number of egg masses was recorded in all the three locations were in July 2010, *viz.*, 3.67, 3.80, 3.82 egg masses per 10 cm apical shoot in Agali, Sholayur and Puthur respectively. This was followed by mean egg mass count in June 2010 (Agali (3.61), Sholayur (3.57) and Puthur (3.59)). The mean number of egg masses was found to be the lowest in December 2009 for all locations i.e. Agali, Sholayur (1.05) and Puthur (1.04). From March 2010, the population was found to be gradually increasing and reached its peak in the month of July and then it was found slowly declining. This trend was continuously observed in all the three locations (Fig. 1)

The egg masses were found along with the adult mealybugs in the terminal shoots and under the young leaves. Due to the low temperature during the months of December to January and February, mean number of egg masses was found to be low in all locations. However, large number of egg masses was observed in Parthenium weeds during winter season.

5.1.2. Distribution of Mealybug in Different Locations

Assessment of the intensity of papaya mealybug infestation in three selected panchayats in Palakkad district during the period from October 2009 to September 2010 at monthly intervals revealed that the number of mealybugs per 10 cm apical shoot was high in the month of July 2010 (57.79, 59.46 and 55.15) followed by June 2010 (53.59, 57.07 and 51.16) and May 2010 (47.82, 49.10 and 44.94) in Agali, Sholayur and Puthur panchayats respectively (Fig. 2). A gradual reduction in the number of mealybugs was observed in August 2010 and September 2010. The results were in accordance with the report of Shekhar and Qadri (2009). They reported that the mealybugs attain an epiphytotic status during the months of June/July. According to Thangamalar *et al.* (2010), the population of mealybugs was on the rise during June to September with peak incidence of the pest observed during second fortnight of July.

The population was also high in plants in August. From October 2009 to December 2009, the population was found to be declining with gradual increase in the succeeding months and reached its peak in July. Shreedharan *et al.* (1989) reported that the pest, *P. citri* was severe in summer season (March-July) and no incidence was observed in winter season (October-November) in Mandarin orange (*Citrus reticulata* Blanw.). The present findings are in accordance with the report of Rao (1926) about the incidence of *F. virgata,* it was more severe during dry season or prolonged period of drought. Das *et al.* (1948) also observed heavy build-up of the *F. virgata* during July-August on jute.

The survey was conducted in panchayats in Palakkad district close to Coimbatore. The climatic conditions prevailing in these surveyed areas and Coimbatore were almost similar. The rainy season was mainly in October, November months followed by the winter season in December to January.

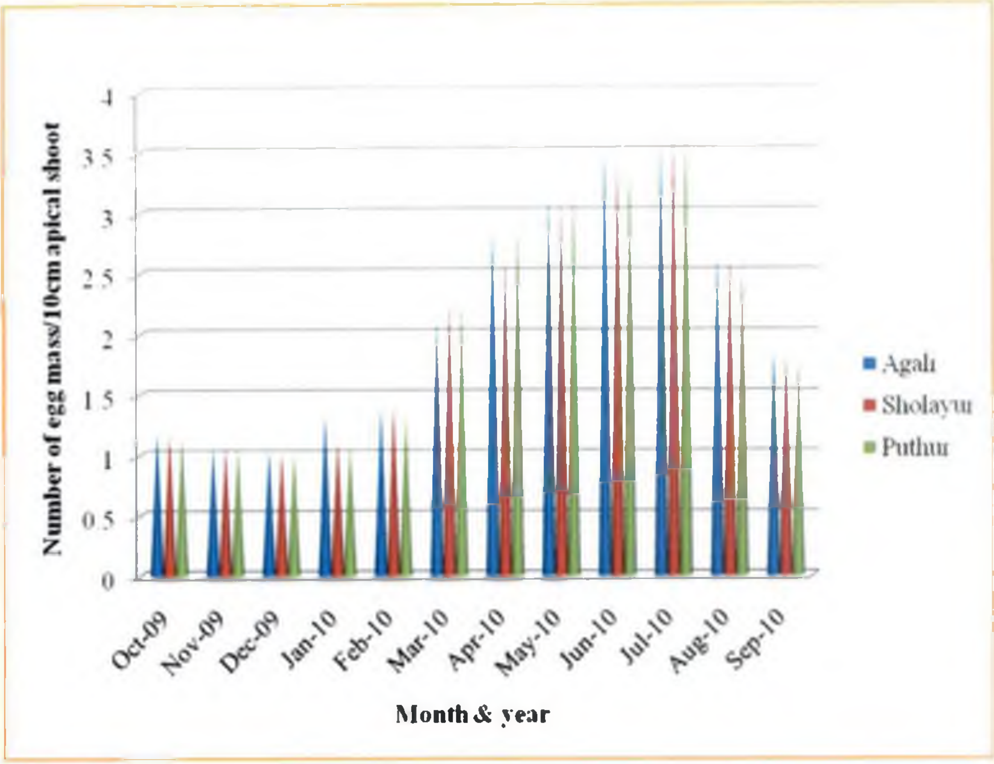


Fig. 1 Occurrence of papaya mealybug egg mass at different locations in Attappadi block

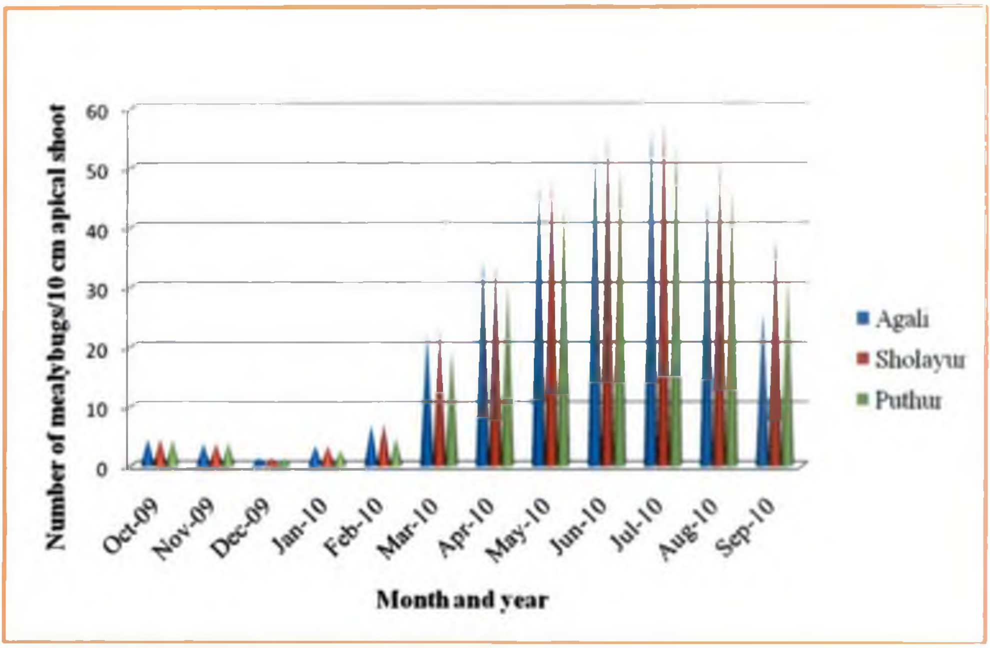


Fig. 2 Occurrence of papaya mealybug at different locations in

During this period, temperature was low in these areas. The reduction in the population of mealybugs in December to January was found to be coinciding with the climatic conditions with the surveyed areas.

5.2. POPULATION OF *S. EPIUS*

When the population of mealybug increased, predator of papaya mealybug *Spalgis* larvae population also increased i.e., in July 2010, the predatory larvae were found in the shoots along with mealybugs. The number of *Spalgis* larvae was maximum in Sholayur (2.88), Agali (2.84) and Puthur (2.81) whereas its population was lowest in December (0.23), (0.21) and (0.15) in Sholayur, Puthur and Agali respectively (Fig. 3). The predator population also increased from April 2010 to August 2010 and gradually declined during September 2010. The mean number of *Spalgis* larvae were found to be declining from October 2009 and reached lowest level in December 2009 and gradually increased in succeeding months and the highest number was observed in July.

According to Thangamalar *et al.* (2010) the mealybug, *P. marginatus* and *S. epius* population was high in mulberry garden especially in the variety (V-1) during June to November 2009. During June to October *S. epius* was the prominent predator, it fed on ovisacs, nymphs and adults of papaya mealybug.

5.3. ASSOCIATION AMONG DIFFERENT MEALYBUGS

In Agali, the papaya mealybug population was high in December, 2009 (1.23) and reached its peak in July, 2010 (59.89) (Fig.4). During these months, papaya mealybug population might be suppressing the population of both pink hibiscus and breadfruit mealybugs. Similar trend was also observed in Puthur panchayat (Fig.6). Eventhough, pink hibiscus mealybug (9.47) population was high during February 2010 and might be suppressing the population of the other two mealybugs. In all observations, the

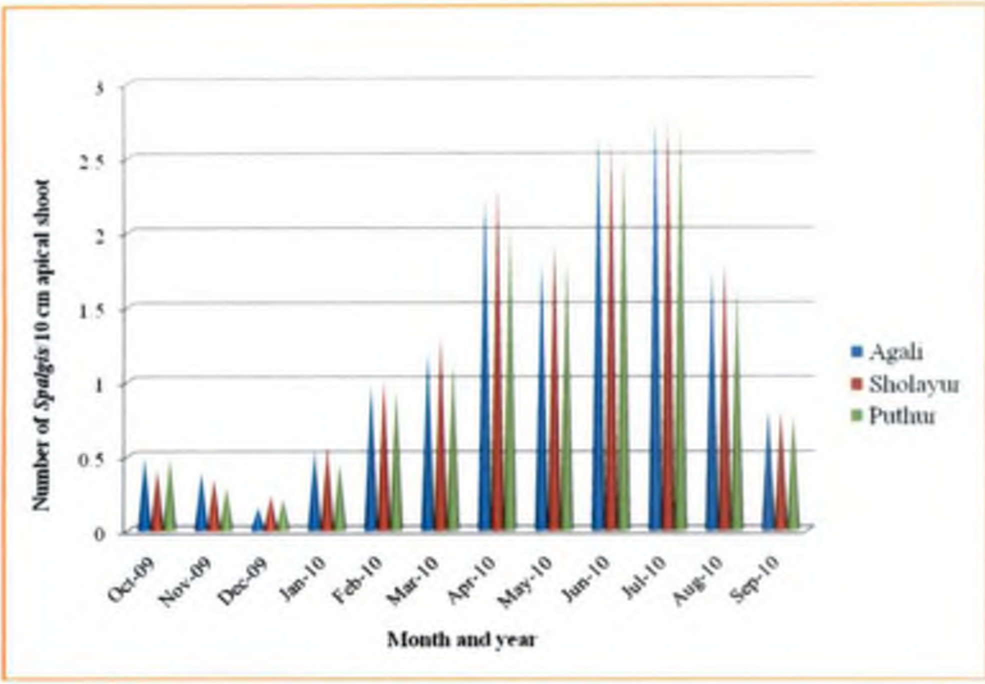


Fig. 3 Occurrence of *S. epius* at different locations in Attappadi block

population of breadfruit mealybug was lower than the other mealybugs. The population of pink hibiscus mealybug (8.57) was found to be high in Sholayur in December 2009 (Fig.5). The population of papaya mealybug was the maximum in July 2010 (58.57) and they suppress the population of pink hibiscus mealybugs. The breadfruit mealybug was not found in Sholayur panchayat during the period of study. Similar studies were done by Tanwar *et al.* (2010) in Peramblur district of Tamil Nadu. They found that the leaves and fruits of guava were found infested with a complex of mealybugs in which, *F. virgata* population was high and might be suppressing the population of the other two mealybugs *viz.*, *P. marginatus* and *M. hirsutus*.

The fluctuation in the population of different species of mealybugs may be due to the changes in climatic condition of this mulberry growing areas. The papaya mealybug population was found to be high in summer months especially from May to August and its population showed positive correlation with maximum temperature.

5.4. ALTERNATE AND COLLATERAL HOSTS OF PAPAYA MEALYBUG

The examination of all crops and weeds in and around the mulberry gardens showed the occurrence of papaya mealybug colonies on 60 plant species belonging to 27 families including pulses, oilseeds, fibre crops, green manures, vegetables, fruit trees, flower plants, tuber crops, medicinal plants, biodiesel plants, tree species and weeds. Plants from the family Asteraceae, Euphorbiaceae, Malvaceae and Solanaceae were generally found as preferred hosts of this mealybug species. Among the hosts, *P. hysterophorus* (Asteraceae), *H. rosa sinensis*, *S. acuta* (Malvaceae), *J. curcas*, *M. esculenta* (Euphorbiaceae) and *P. alba* (Apocynaceae) harboured this pest round the year and acted as a persistent source for the spread of *P. marginatus*. According to Ben-Dov (1994), *P. marginatus* is highly polyphagous and the hosts listed were *C. papaya* (Caricaceae), *A. curmanensis* and *P. hysterophorus* (Compositae), *Acalypha* sp., *M. chloristica* and

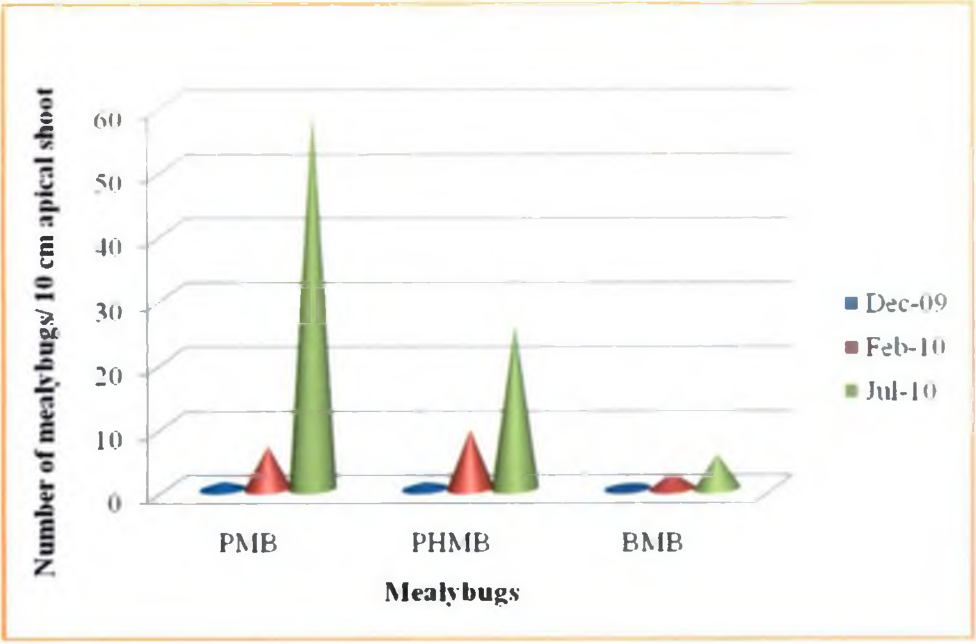


Fig. 4 Population buildup of different mealybugs in Agali panchayat of Attappadi block

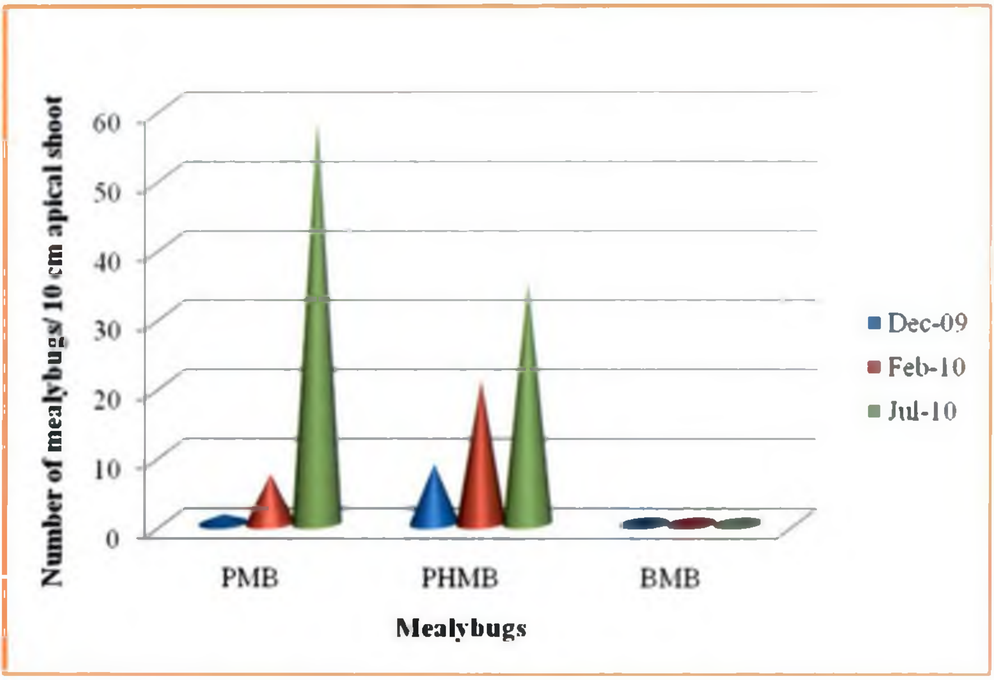


Fig. 5 Population buildup of different mealybugs in Sholayur panchayat of Attappadi block

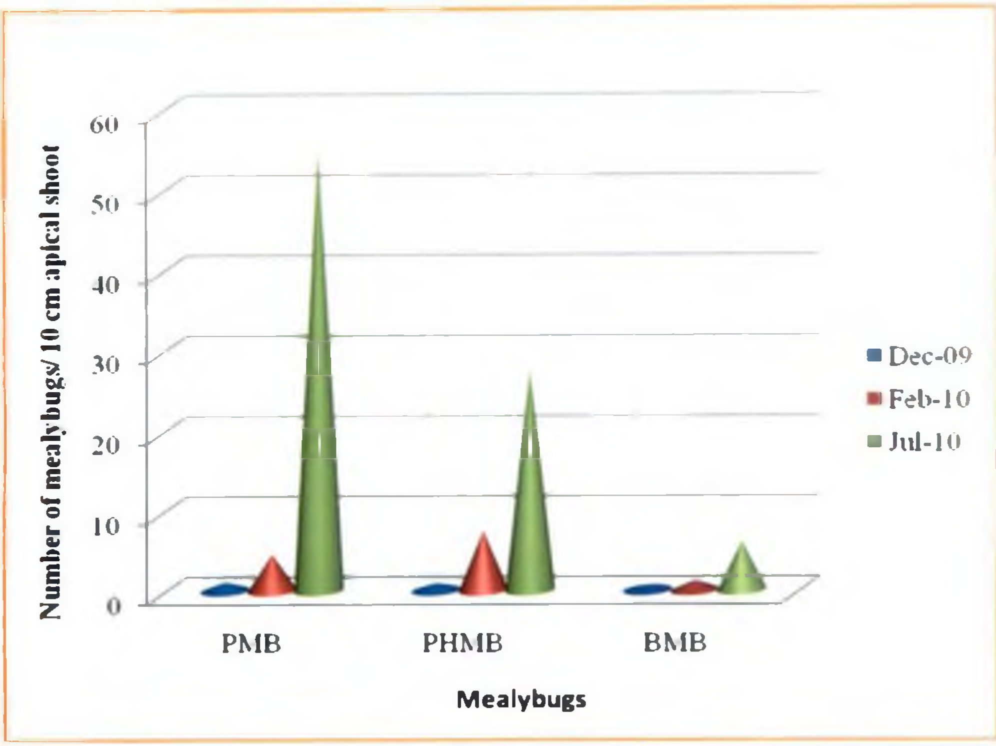


Fig. 6 Population buildup of different mealybugs in Puthur panchayat of Attappadi block

M. esculenta (Euphorbiaceae), *M. pigra* (Mimosaceae), *Hibiscus* sp. and *Sida* sp. (Malvaceae). Meyerdirk *et al.* (2004) also studied the wide host range of papaya mealybug and reported 60 species including economically important plants and weeds. Heu *et al.* (2007) reported that in Hawaii, heavy infestation of papaya mealybug was observed on papaya, *Plumeria*, *Hibiscus* and *Jatropha*. Ben-Dov (2008) identified the presence of papaya mealybug in 22 plant families. According to Regupathy and Ayyasamy (2010) the weed species like Parthenium, Abutilon, Sida etc., also provided a green bridge for the successful perpetuation of this mealybug throughout the year. An extensive survey conducted during 2009-2011 by Sakthivel *et al.* (2010) revealed the presence of *P. marginatus* on 133 plant species belonging to 48 families and high host preference was noticed in 33 plants.

5.4.1. Preference to Weed Hosts

Observation of papaya mealybug on five selected weed hosts, *viz*., *P. hysterophorus, T. procumbens, S. acuta, P. niruri* and *U. lobata* revealed that the maximum number of egg masses was observed on *P. hysterophorus* (11.64) followed by *S. acuta* (7.50) and the lowest in *P. niruri* (2.87). Similarly higher number of mealybugs was recorded in *P. hysterophorus* (147.01) followed by *S. acuta* (117.19) and the lowest number of mealybug were observed in *P. niruri* (36.43). The number of *S. epius* was high in *P. hysterophorus* (7.45).

5.5. MULBERRY CULTIVATION IN ATTAPPADI BLOCK

Weeding was not carried out properly in mulberry gardens maintained by the farmers and the gardens were heavily infested mainly by *Partheinum*. Crop residues infested with mealybugs were also heaped near the field without burning or burying. This might be the major reason for the continuous infestation of mealybugs throughout the year in the field. These observations were also corroborating with the observations made by

Regupathy and Ayyasamy (2010). The biofuel crop *Jatropha* planted as fence in the garden also acted as a host in unfavourable condition.

5.6. CORRELATION OF PAPAYA MEALYBUG POPULATION WITH PREDATOR POPULATION AND WEATHER PARAMETERS

Correlation analysis between papaya mealybug, *P. marginatus* and weather parameters showed that a positive correlation existed between papaya mealybug and maximum temperature (+0.468) wind speed (+0.690) and sunshine hours (+0.257). The correlation with minimum temperature, rainfall and relative humidity was negative (-0.340, -0.463 and -0.108 respectively). The correlation between mealybug population and maximum temperature in the present finding was in agreement with the report of Suresh *et al.* (2010). They reported a positive correlation between the population of *P. marginatus* infesting *P. alba* and temperature in Tamil Nadu by observing high population of both nymphs and adults of papaya mealybug on *Plumeria.* According to Dhawan *et al.* (2009), all the weather parameters influenced the population of cotton mealybug, *P. solenopsis* in all districts in Punjab. There was a positive correlation existed among the per cent field infestation, number of infested rows by mealybug and temperature whereas, negative correlation was observed with relative humidity and rainfall.

There was a positive correlation between predator, *S. epius* population with maximum temperature (+0.177), wind speed (+0.553) and sunshine hours (+0.427) whereas it was negatively correlated with minimum temperature (-0.165), rainfall (-0.485) and relative humidity (0.113). A significant positive correlation (+0.886) was existed between the population of mealybug and its predator.

5.7. IDENTIFICATION OF MEALYBUGS OF MULBERRY

The mealybug species identified from mulberry gardens of Palakkad district were *P. marginatus, M. hirsutus* and *I. aegyptiaca.* Among these three species identified *P. marginatus* was heavily infested in the mulberry gardens.

Papaya mealybug, *P. marginatus*, was first described in 1992 (Williams and Granara de Willink, 1992) and redescribed by Miller and Miller (2002). In India, the incidence of papaya mealybug was first recognized by Muniappan, who visited in the campus orchards of Tamil Nadu Agricultural University in July 2008. Later, Shekhar and Qadri (2009) reported that papaya mealybug *P. marginatus* was found infesting severely the mulberry gardens of Coimbatore and Erode districts of Tamil Nadu. During July 2009, papaya mealybug was found infesting the mulberry gardens in Agali, Sholayur and Puthur, the three panchayats in Palakkad district of Kerala (Krishnakumar and Rajan, 2009).

5.8. BIOLOGY OF MEALYBUGS

5.8.1. Papaya Mealybug

An attempt had been made to mass rear the mealybug on whole pumkin fruit papaya fruits, sprouted *Amorphophallus* as well as sprouts and plants of potatoes. The mealybugs did not feed on pumpkin fruits and *Amorphophallus* sprouts and could not be established. Although they were found feeding on papaya fruits, these mealybugs did not survive long under laboratory conditions due to rotting of the fruits by its continuous feeding. However these could be reared successfully in mass on sprouts and plants of potato.

5.8.1.1. Eggs

Eggs were greenish yellow, elongate-oval in shape and were found in an egg sac, entirely covered with white wax. An egg measured an average of 0.36 mm in length and 0.26 mm in width.

The incubation period ranged from 5 to 7 days during March - April and 6 to 9 days in November - December period. This in conformity with the findings of Mishra (2011), who reported eggs hatched in 5-6 days. According to Amarasekare *et al.* (2008b), eggs hatched on different hosts like *Acalypha, Hibiscus, Parthenium* and *Plumeria* were an average of 8.6,8.4,8.8 and 8.5 days respectively. In the present study, the incubation period was found shorter during March - April compared to November - December. This difference in incubation might be due to the influence of lower or higher temperature that prevailed during these months.

On an average, 92.26 ± 2.55 per cent eggs hatched to crawlers during March to April period.

5.8.1.2. Nymphal Instar

The rearing of papaya mealybug on potato sprouts could be continued successfully upto 30-35 days. Hence all the nymphal instars could be studied while rearing. Nymphal instars were identified and separated based on the morphological dimensions. It revealed that males and females had four and three nymphal instars respectively. This observation is in conformity with Mishra (2011), who reported that female crawlers had three instars and males, four instars. The fourth instar of male is produced in a cocoon referred to as pupa.

5.8.1.2.1. First Instar Nymphs (crawlers)

The newly emerged nymphs (crawlers) were entirely different from other developmental stages in that they lacked the white waxy covering on their body and were light greenish yellow in colour compared to the usual yellow colour. The crawlers were found congregated beneath the white waxy material secreted by the adult female, before laying eggs. Three to four days after hatching, the crawlers started dispersing and were found feeding on tender sprouts provided for feeding.

The first instar nymphs measured an average of 0.36 mm in length and 0.27 mm in width. Miller and Miller (2002) observed that the mealybug had an average length of 0.4 mm and width of 0.2 mm.

The first instar took an average of 6.1 days to moult to the second instar. According to Amarasekare *et al.* (2008b), papaya mealybug took an average of 6.20 and 6.60 days in *Hibiscus* and *Plumeria* respectively for the completion of first instar.

5.8.1.2.2. Second Instar Nymph

The female nymphs appeared as yellow with slight mealy coating with an average of 0.63 mm length and 0.44 mm width. The male nymphs were light pink in colour and measured an average length of 0.71 mm and width of 0.33 mm. According to Miller and Miller (2002), male and female nymphs measured an average of 0.7, 0.6 mm in length and 0.4, 0.3 mm width respectively.

The female and male instars took an average of 5.2 days and 6.4 days to moult to the third instar. Amarasekare *et al.* (2008b) reported the second instar female took an average of 3.8, 3.5, 5.2 and 5.3 days for the completion of this stage on *Acalypha, Hibiscus, Parthenium* and *Plumeria* respectively.

5.8.1.2.3. Third Instar Nymph

The female nymphs were yellow in colour with an average of 1.29 in length and 0.78 mm in width. The third instar female took an average of 5.4 days to become an adult female. Miller and Miller (2002) reported that the body length and width of third instar female was1.1 mm and 0.7 mm. Amarasekare *et al* (2008b) concluded that third instar female required 6.3 days in *Acalypha,* 5.0 days in *Hibiscus*, 4.7 days in *Parthenium* and 5.1days in *Plumeria* for its development. According to Mishra (2011), the developmental period of third instar female was 5.5 days.

The third instar male nymph (prepupa) measured an average of 0.89 mm length and 0.36 mm width. The third instar took an average of 3.5 days to moult to the fourth instar. The study conducted on life history of papaya mealybug on four selected hosts by Amarasekare *et al* (2008b) revealed that the third instar male took an average of 2.8, 2.3, 3.4 and 2.7 days for the development if this stage on *Acalypha*, *Hibiscus*, *Parthenium* and *Plumeria* respectively. Miller and Miller (2002) reported that the third instar male measured an average of 0.9 mm length and 0.4 mm width.

5.8.1.2.4. Fourth Instar Male.

The fourth instar of the male (pupa) was found in a cocoon, which could be easily distinguished from all other instars of mealybug. They measured an average of 0.93 mm length and 0.36 mm width. According to Miller and Miller (2002), the body of pupa measured an average of 1mm long and 0.3 mm wide.

5.8.1.3. Adult Female

The adult females were yellow coloured, oval in shape and measured an average of 2.38 mm length and 1.49 mm. The body was dusted with mealy wax not thick enough to hide body colour. Many short waxy filaments were seen around the body margin and the antennal segments were eight in number. Miller and Miller (2002) observed that the adult female with a body length of 2.2 mm and 1.4 mm width.

5.8.1.3.1. Adult Male

Adult males measured an average of 1.06 mm length and 0.34 mm width, with an elongate oval body that was widest at the thorax. They have ten segmented antennae, a distinct aedeagus, heavily sclerotized thorax and well developed wings. The observations were also similar to the descriptions made by Miller and Miller (2002).

5.8.1.3.2. Adult Behavior

Adult female mealybugs secreted loose white waxy filaments around the body before starting egg lying. The eggs were laid in an ovisac which was surrounded with the wax material. This wax might have been produced for the protection from enemies as well as from desiccation. This finding is in agreement with Macleod (2005) who observed *R. hibisci* infesting potted ornamental plants. The eggs were laid in a continuous chain. However the chain was not visible on eggs within the egg mass. The egg chain broke and the eggs were distributed within the egg mass. The adult was found shrunken after laying eggs.

5.8.1.4. Oviposition Period

Adult female stopped feeding and settled down before egg laying. The egg laying period ranged from 8 to 13 days with an average of 10.50 days. According to Tanwar *et al.* (2010), egg laying usually continued over a period of one to two weeks.

5.8.1.5. Fecundity

An adult female mealybug laid an average of 361.50 ± 117.37 eggs in its life period when reared on potato sprouts and the number of eggs within an egg mass ranged from 102 to 482. The eggs were laid in a folded chain fashion and later, the chain was broken distributing the eggs within the egg mass. However Walker *et al.* (2003) reported that an adult female laid 100 to 600 eggs in an ovisac.

5.8.2. Pink Hibiscus Mealybug

Freshly laid eggs were translucent and yellowish or light orange in colour. They were elongated and oval in shape. As incubation period advanced, the translucent eggs became pinkish in colour towards hatching. Theses results are in agreement with the reports of Misra (1919), Ghose (1972), Mani (1986) and Jadhav (1993).

The incubation period was an average of 4.1 ± 0.88 days. According to Misra (1919), the incubation period of mealybug was 5-8 days on mulberry, 6-7 days on mesta (Singh and Ghosh, 1970) and 3-8 days on rosselle (Ghose, 1972). Serrano and Laponite (2002) reported that, the incubation period of *M. hirsutus* was 5.3 ± 0.7 and 4.6 ± 0.6 days on sprouted potato and pumpkin, respectively. The above reports support the findings of the present investigation.

The per cent hatching of eggs varied from 78.60 to 86.20 with an average of 82.26 per cent. Serrano and Laponite (2002) reported that hatching percentage of *M. hirsutus* was 91.2 ± 8.0 on sprouted potato. These slight deviations from the present investigations may be due to differences in the temperatures and relative humidity that prevailed at different locations.

Nymphs were usually yellow to orange in colour with reddish compound eyes. The neonate larvae were oval in shape and they were highly mobile. During that stage, male and female were indistinguishable. The duration of first instar nymph lasted for 6 to 8 days with a mean of 7.2 ± 0.92 days. As the stage advanced, colour changed from orange to pink and entered second instar. According to Mani (1986), the duration of first nymphal instar occupied by female was 6.71 ± 0.47. Jadhav (1993) reported that the duration of first nymphal instar of female was 8-13, 7-11 and 6-9 days with a mean of 9.76, 8.72 and 7.50 at 21.5, 25.0 and 30.0°C respectively. The results of the present study are also more or less in line with the above reports.

The second instar nymphs were pink in colour with an appearance of white thin waxy secretions on the body. The duration of second instar nymph lasted for 6 to 7 days with a mean of 6.5 ± 0.53 days. According to Mani (1986), the duration of second nymphal instar occupied by female was 6.55 ± 0.52 days. Jadhav (1993) reported that the duration of second nymphal instar of female was 7-11, 8-9 and 7-9 days with a mean of 8.95, 8.35 and 8.17 days at 21.5, 25.0 and 30.0°C respectively. The results of the present study are also in agreement with inferences of the above workers.

The duration of third instar nymph lasted for 7 to 8 days with a mean of 7.5 ± 0.53 days. According to Mani (1986), the duration of third nymphal instar occupied by female was 7.90 ± 0.79 days. Jadhav (1993) reported that the duration of third nymphal instar of female was 9-15, 9-11 and 8-10 days with a mean of 10.21, 10.08 and 9.18 days at 21.5, 25.0 and 30.0°C respectively. The above observations of various authors are almost in line with the present findings.

Total nymphal period was an average of 21.2 ± 1.35 days. According to Mani (1986), the duration of total nymphal period occupied by female was 19-24 days with an average of 21.16 ± 1.07 days. Jadhav (1993) reported that the total duration of nymphal period was 26-31, 25-27 and 23-26 days with a mean of 28.10, 26.20 days at 21.5, 25.0 and 30.0°C respectively.

Adult females were soft, oval and distinctly segmented. The longevity of adult for female ranged between 10 to 13 days with a mean of 12.1 ± 1.20 days. Jadhav (1993) reported that longevity of female was 17-20, 13-16 and 11-12 dayswith a mean of 18.70, 14.00 and 11.50 days at 21.5, 25.0 and 30.0°C respectively on potato. The results of the present study are almost in agreement with the above reports.

The ovipositional period ranged from 6 to 8 days with a mean of 6.9 ± 0.74 days. According to Singh and Ghosh (1970) and Mani (1986), the ovipositional period ranged from 4-5 and 6-8 days respectively. Jadhav (1993) reported that ovipositional period was 11-13, 9-11 and 6-9 days with a mean of 11.80, 9.70 and 6.10 days at 21.5, 25.0 and 30.0°C respectively on potato.

The number of eggs laid by an adult female ranged from 202 to 351 with an average of 281.3 ± 49.89 eggs in its life period. The fecundity was 84-654, 232, 500 and 317 eggs per female according to Ghose (1972), Misra (1919), Reddy and Narayana (1986) and Babu and Azam (1987b) respectively.

5.8.3. Breadfruit Mealybug

The eggs were oval in shape and yellowish-orange in colour. The incubation period ranged from 8 to 10 days with an average of 9.0 days. Azab *et al.* (1969) reported an average incubation period of 8.6 days for breadfruit mealybug.

The first instar nymphs were bright orange in colour and were very active. The crawlers settled within a day and the body was covered by a waxy covering within two days. A long, thread like waxy filament developed near the anus, which receives droplets of honeydew as they are discharged. The duration of first instar nymph ranged from18 to 20 days with an average of 17.8 days.The second instar larvae were oval in shape and yellow to orange in colour. Immediately after moulting, the bugs were covered with a white mealy secretion. They are fringed with 21 snow-white waxy processes. The duration of second instar larvae ranged from 9 to 10 days with an average of 9.4 days. The third instar nymph was yellow to orange colour and the body was coated with a white mealy secretion. The duration of third instar larvae varied from 18 to 20 days with an average of 18.8 days. According to Azab *et al.* (1969), the average nymphal period for first, second and third were 19, 9.8 and 20.7 days respectively.

The deep orange coloured adults were broadly oval in shape with 11 segmented antennae. The abdomen was slightly convex dorsally and flattened ventrally. The legs were black in colour. The dorsal surface is covered with cushions of white mealy secretion, mingled with granular wax. Waxy process on thorax was stouter than those present in abdominal region. The female laid an average of 141.3 eggs in its life period.

5.9. MASS MULTIPLICATION OF PAPAYA MEALYBUG

Papaya mealybug did not feed on pumpkin fruits and amorphophallus sprouts. Although they were found feeding on papaya fruits, these mealybugs did not survive long under laboratory conditions due to rotting of the fruits by its continuous feeding. However these could be reared successfully on sprouts and plants of potato. Similar results were also reported Tsugawa (1972); Sagarra and Vincent (1999) and Serrano and Laponite (2002).

5.10. PREDATOR

In the present study, one lycaenid predator was observed feeding on the life stages of papaya mealybug. The predator was identified as *S. epius.* Ayyar (1929) reported that the lycaenid predator was commonly associated with the natural control of *P. iceryoides, P. glomeratus, P. lilacinus, P. citri infesting* cotton, *P. saman*, Chinese rose, *D. lablab* and sesbania. Pushpaveni *et al.* (1973) recorded natural control of *M. hirsutus* on mesta while Mani and Krishnamoorthy (1998) recorded *S. epius* as a natural enemy of mango green shield scale.

5.10.1. Biology of the Predator

The first instar larvae were pink in colour and remained inside ovisac of papaya mealybug. It took 2.6 days to moult to the next stage. The second instar larva was creamy white coloured and found outside the ovisac. The larvae were coated with white wax and difficult to distinguish from the mealybug. Total larval duration was observed as 10.0 days. The corresponding duration for second, third, fourth and fifth instars were 1.8, 1.4, 2.0 and 2.2 days respectively. The larvae were found to pupate on the lower surface of leaves and form a characteristic rhesus monkey faced chrysalis. The pupal period was about 5.43 days. According to Thangamalar *et al.* (2010), the total life cycle lasted for 14.83 days with the larval life span of 9.83 days (I instar: 2.5 days; II instar: 1.75 days; III instar: 1.41 days; IV instar: 2 days; V instar: 2.1 days) and the pupal period was about 5.45 days.

5.10.2. Feeding Potential of the Predator

The fifth instar larvae of *S.epius* were found to be a voracious feeder of mealybugs. It consumed higher number of ovisacs (21.69), 1st instar (118.88), 2nd instar (46.88) and adults (20.94) of papaya mealybug. The larvae were slug like and coated with wax coating. As *S. epius* camouflaged with mealybug population, it was very difficult to distinguish the predator from the prey. Feeding potential was gradually increased with the growth of the predator. Minimum number of adult mealybugs was fed by second instar larva (1.88) whereas the third and fourth instar fed 7.50, 17.13 adult mealybugs respectively. According to Thangamalar *et al.* (2010) in ex situ confinement studies, the fifth instar Spalgis larva consumed as much as 18 to 26 ovisacs, 112 to 132 nymphs and adult mealybugs. They also found that during the whole larval period the predatory larvae devoured about 42 to 53 ovisacs and 196 to 222 nymphs and adults of *P. marginatus*.

5.11. SYMPTOMS OF INFESTATION

Infestation of mealybug appeared as clusters of cotton-like masses on the above ground portion of the plants with long waxy filaments. Sap sucking by the nymphs and adults of mealybug resulted in crinkling, rosetting, and general leaf distortion. Sooty mould also occured on the upper surface of mulberry leaves. According to Shekhar and Qadri (2009), the pink mealybug, *Maconellicoccus hirsutus* infested only the apical young leaves of plants whereas the papaya mealybug infested all parts of mulberry plants such as leaves, stems, bottom shoots and stocks. The attacked leaves became wrinkled, plants stunted and leaves fell off after yellowing.

5.12. PHENOL CONTENT IN MEALYBUG INFESTED MULBERRY LEAVES

Plant tissues respond to leaf damage by mealybugs with the production of chemical substances like phenolics and the products of their oxidation. The phenol content was found to be more in the infested samples and found to be increasing with the increase in the extent of damage. The total phenol content in papaya mealybug infested mulberry leaves was found to be the highest (1.72) at 100 per cent infestation level whereas in the lowest observed in healthy (0.97) leaves. Similar trend was also observed by Janaki and Suresh (2012) in *S. viarum* and susceptible variety CO 2.

The estimation of phenol in the damaged leaves showed that the leaf damage was exclusively due to the attack of mealybugs and it was not due to any infection by microorganisms.

5.13. ROLE OF PAPAYA MEALYBUG AS A VECTOR IN DISEASE TRANSMISSION

In the present study, detection of virus in the plant samples was found to be successful using ELISA. DAC -ELISA was performed with infected mulberry plants using antibodies for SCBMV and BSV. The average absorbance of diseased and healthy samples was 0.013 and 0.008 respectively against the antibody of SCBMV and 0.707 and 0.643 respectively against BSV. The absorbance of diseased sample was not more than two or three times than that of the healthy sample. Infected samples on DAC-ELISA showed the absence of virus in the samples collected from infested mulberry gardens. This test also conclusively proved that the virus infected like symptoms observed in mulberry is only due to the heavy infestation of papaya mealybugs in the growing part of the plant and not by the action of virus.

5.14. EFFICIENCY OF COMMERCIALLY AVAILABLE PREDATORS ON PAPAYA MEALYBUG

5.14.1. *C. carnea*

5.14.1.1. No Choice Condition

Feeding efficacy of different larval stages of the predator was studied. The third instar larvae of *C. carnea* consumed significantly higher number of 3.25 ovisacs, 330.75 first instar, 120.63 second instar and 87.25 third instar nymphs of *P. marginatus* which differed significantly from 1.38 ovisacs, 109.25 first instar, 37.88 second instar and 12.63 third instar consumed by first instar *C. carnea*. The second instar *C. carnea* consumed 1.88 ovisacs, 206.13 first instars, 69.88 second instars and 37.75 third instar nymphs of

P. marginatus. Third instar of *C. carnea* consumed higher number of first, second and third instars of mealybug per day compared to first and second instars of the predator. Third instar predator proved to be the most voracious feeder of all the nymphal instars of *P. marginatus* compared to first and second instars. The reason for higher feeding potential of third instar might be due to its large size than other developmental stages of the predator. The increase in feeding potential of *C. carnea* with the advancement in development stage was in line with the findings of Canard and Principi (1984); Silva *et al.* (2002). Atlihan *et al.* (2004) reported that older larval instars of *C. carnea* displayed a higher rate of predation of *Hyalopterus pruni* than younger ones. Scopes (1969) and Yuksel and Gocmen (1992) also observed the third instar larvae of *C. carnea* consumed more number of aphids than second and first instar. According to Rashid *et al.* (2011), more cotton mealybugs, *P. solenopsis* were consumed by third instar larvae than by second and first instars of *C. carnea.*

5.14.1.2. Free Choice Condition

The different prey stages of mealybug were offered together to different larval instars of *C. carnea.* The third and second instar larvae of *C. carnea* consumed 23.50 and 23.04 of first instar mealybugs respectively and were on par whereas, the first instar consumed minimum number of 16.21 first instar nymphs of *P. marginatus*. Higher number of second instar mealybug nymphs were consumed by third instar larvae of *C. carnea* (11.58) followed by second instar (10.42) and first instar *C. carnea* (7.00) The third instar of *C. carnea* consumed significantly higher number of 6.88 third instar nymphs of mealybug whereas the second instar of predator consumed 3.75 third instar nymphs of *P. marginatus*. The first instar *C. carnea* consumed lowest number of 0.75 ± 0.69 third instar nymphs of mealybug. The higher response of the predator towards the first instar prey could be attributed to the absence of thin white waxy layer on the bodies of the first instar compared to second and third instar prey. Similar trend was also reported by

Liu and Chen (2001) for *C. carnea* reared on *Lipaphis erysmi*. In the present study, the observed preference of *C. carnea* for first instar prey may also be associated with the greater mobility of first instar prey compared to older instars. Similar results were also reported Sattar *et al.* (2007). They observed that first instar nymph of mealybug was the most preferred food of *C. carnea*.

5.14.2. *C. montrouzieri*

5.14.2.1. No Choice Condition

The fourth instar grub of *C. montrouzieri* consumed significantly higher numbers of 13.13 ovisacs, 337.50 first instar nymphs of *P. marginatus* followed by 218.00, 174.25 and 124.75 nymphs consumed by third, second and first instar grubs of *C. montrouzieri* respectively. First instar grub of *C. montrouzieri* consumed minimum number of 67.00 second instar nymphs of *P. marginatus* whereas the fourth instar grub consumed maximum number of 209.25 nymphs. This was followed by the consumption of 169.25 and 97.00 second instar mealybug nymphs by third and second instar grub of *C. montrouzieri* respectively The fourth instar grub of *C. montrouzieri* consumed maximum number of 137.38 of third instar mealybug nymphs whereas minimum consumption of 31.88 third instar mealybugs was by first instar grub. The third instar grub of *C. montrouzieri* consumed maximum number of 83.25 third instar mealybug nymphs followed by minimum consumption of 54.13 third instar mealybug nymphs by second instar grub of *C. montrouzieri*. The highest feeding rate was observed in the fourth larval instar than other instars which is in concurrence with the findings of Murthy (1982).

5.14.2.2. Free Choice Condition

Significantly higher number of 84.46 first instar nymphs of mealybug was consumed by fourth instar grub of *C. montrouzieri* whereas first instar grub of *C. montrouzieri* consumed minimum of 24.50 first instar mealybug nymphs. The third instar grub of *C. montrouzieri* consumed 60.17 first instar mealybug nymphs followed by second instar grub with 43.00 numbers of first instar mealybug nymphs. Maximum consumption of fourth instar *C. montrouzieri* was 52.58 second instar mealybug nymphs followed by third instar grub consuming on an average of 41.50 mealybug nymphs. Minimum number (14.88) of second instar mealybug nymphs were consumed by first instar grub of *C. montrouzieri* whereas the second instar grub of *C. montrouzieri* consumed maximum of 29.96 second instar mealybug nymphs. The maximum third instar mealybug nymphs (31.46) consumed by fourth instar grub of *C. montrouzieri* whereas the minimum number of 7.71 was consumed by first instar *C. montrouzieri* grub. The second and third instar grubs of C. *montrouzieri* consumed 14.17 and 23.13 third instar mealybug nymphs respectively. Khan *et al.* (2012) reported that in free choice condition, the first second and third instar grub consumed 109, 213 and 410 of first instar; 71.88, 149.50 and 205.13 of second instar and 47, 49.75 and 58.00 of third instar cotton mealybug, *P. solenopsis*. While comparing the consumption rate of *C. montrouzieri* grubs on both the mealybugs, higher number of mealybug consumption was observed in the case of *P. solenopsis*. Though *C. montrouzieri* was known to feed on *P. marginatus*, it could not provide satisfactory control (Mahalingam *et al.*, 2010).

5.15. EFFICACY OF CHEMICALS ON PAPAYA MEALYBUG

Among the insecticides evaluated, dimethoate 0.1% was superior followed by imidacloprid 0.01% in the case of both first instar and adult mealybugs. The least mortality percentage of adult as well as the first instar mealybugs was recorded with NSKE 2.5%. The effectiveness of other insecticides against adult as well as first instar mealybug were in the order of dimethoate 0.05% > imidacloprid 0.005% > abamectin 0.006 % > abamectin 0.003% > dichlorvos 0.05 > NSKE 5%. The most effective insecticides selected for further study were dimethoate 0.1 % (ranked first) and imidacloprid 0.01 (ranked second).

5.16. EFFICACY OF COMBINATIONS OF CHEMICALS AND BOTANICALS ON PAPAYA MEALYBUG

Combination of dimethoate 0.05% + econeem plus 2 ml L^{-1} was found to be superior with the highest per cent mortality of 93.33% and 96.67% for adult and first instar mealybugs respectively. Other effective treatments were in the order of dimethoate 0.1%, imidacloprid 0.01%, combination of imidacloprid 0.005% + econeem plus 2 ml L^{-1} and combinations of dimethoate and imidacloprid with NSKE 5%.

5.17. EFFECT OF CHEMICALS ON SILKWORM REARING

The residual effect of leaves was reduced maximum when the leaves fed at 15 days after the treatment. The most effective treatment in this study was the combination of dimethoate 0.05% + econeem plus 2 ml L^{-1} with effective rearing parameters. The silkworm larve fed the leaves sprayed with the combination of dimethoate 0.05% + econeem plus 2 ml L^{-1} gave a highest yield of 91 total cocoons with a total larval duration of 576 hours followed by imidacloprid 0.01% (85.17) with duration of 590.33 hours. The least number of cocoons were obtained by the treatment with dimethoate 0.1% (60.17) with higer larval duration of 592.5 hours. The single cocoon weight was found to be high in the combination of dimethoate 0.05% + econeem plus 2 ml L^{-1} (1.56 g) with highest shell ratio (22.09). The Effective Rearing Rate (ERR) was the highest in combination of dimethoate 0.05% + econeem plus 2 ml L^{-1} treated worms. In this treatment ERR by number and weight was 9050.00 and 13744.69 g respectively. Among the four treatments, the least effective treatment was dimethoate 0.1% with lowest ERR by number as well as weight.

5.17.1. Effect of Chemicals on Larval Weight of Silkworm

Among the different treatments, the combination of dimethoate and econeem plus gave highest mean larval weight. The mean larval weight of different instars were 0.54 gram, 1.16 gram, 0.87 gram, 8.80 gram and 36.61 gram respectively in first, second, third, fourth and fifth. The lowest larval weight was observed with dimethoate 0.1% (Fig.7)

5.17.2. Effect of Chemicals on the Growth Rate of Silkworm

While analyzing the growth rate of silkworm larvae, the treatment with the combination of dimethoate and econeem plus were found to be superior. The growth rate of second, third, fourth and fifth instar larva with the combination of dimethoate and econeem plus were 1.25, 3.64, 9.07 and 3.16 respectively. Poor growth rate was found to be in the treatment with dimethoate 0.1% (Fig.8).

5.18. FIELD EVALUATION OF SELECTED TREATMENTS IN THE MANAGEMENT OF PAPAYA MEALYBUG IN MULBERRY

Field evaluation against the papaya mealybug was done based on the effective treatments envisaged in the laboratory and the suitable farmers' practices identified from the survey. Each selected treatment was evaluated singly and in possible combinations and the results are discussed here.

Seven days after the first application, the plants treated with the combination of insecticides, dimethoate 0.05% + econeem plus 2 ml L^{-1} was found to be superior with the lowest number of mealybugs (18.45 (Agali); 19.84 (Sholayur) and 20.44 (Puthur) followed by imidacloprid + econeem plus (Figs 9, 10 and 11). Among the treatments with the use of single insecticide, dimethoate suppressed the population with 20.48, 22.76 and 24.02 mealybugs/10 cm apical shoot in Agali, Sholayur and Puthur respectively followed by imidacloprid whereas the performance with dichlorvos, econeem plus and their combination was least effective. Cultural

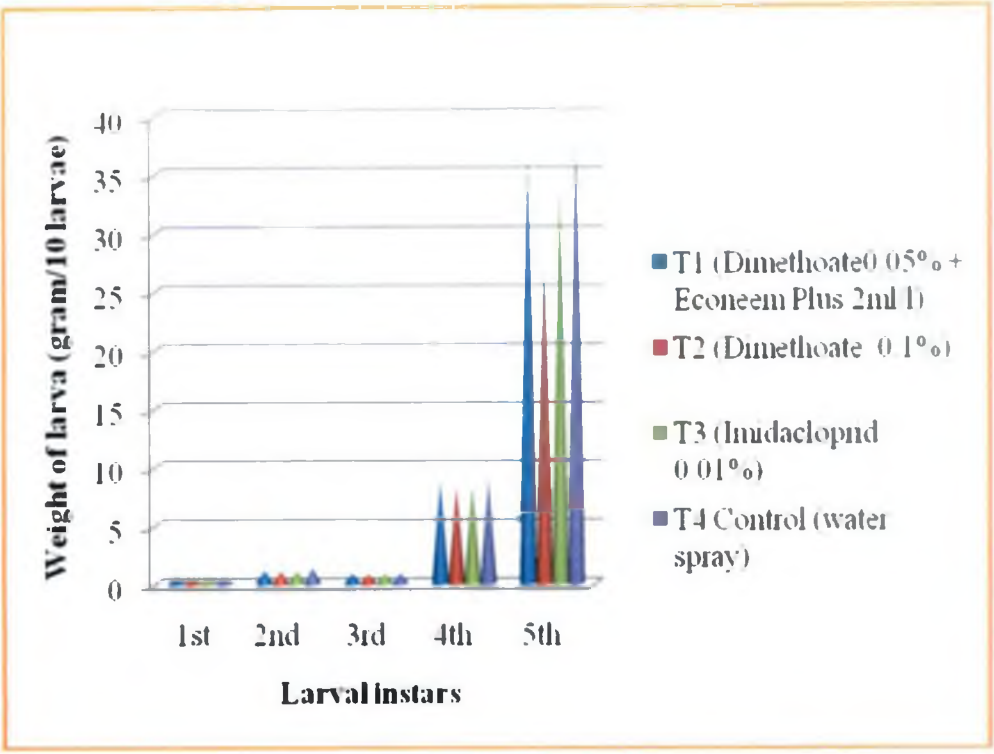


Fig. 7 Effect of insecticides on larval weight of mulberry silkworm

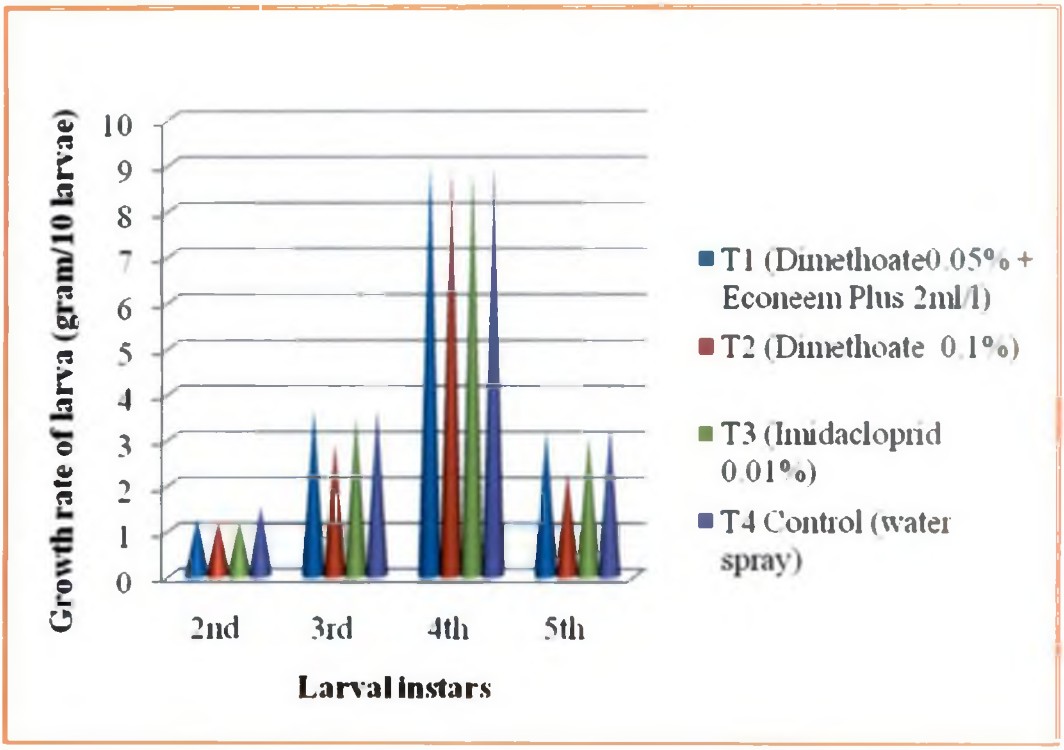


Fig. 8 Effect of insecticides on growth rate of mulberry silkworm

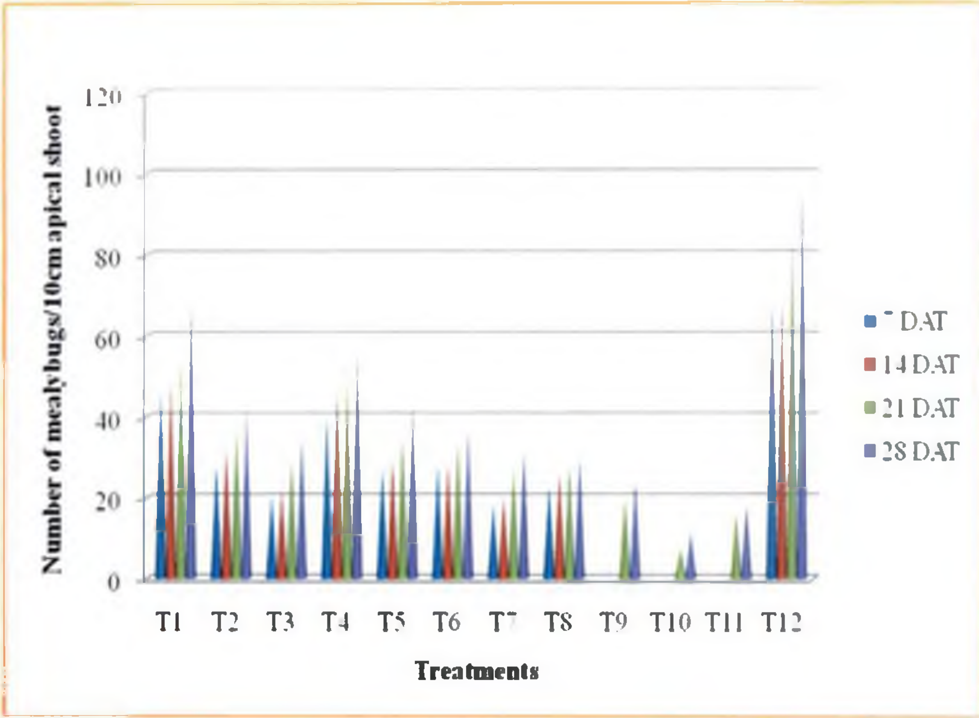


Fig. 9 Population of papaya mealybug at different intervals after application of different treatments in Agali panchayat

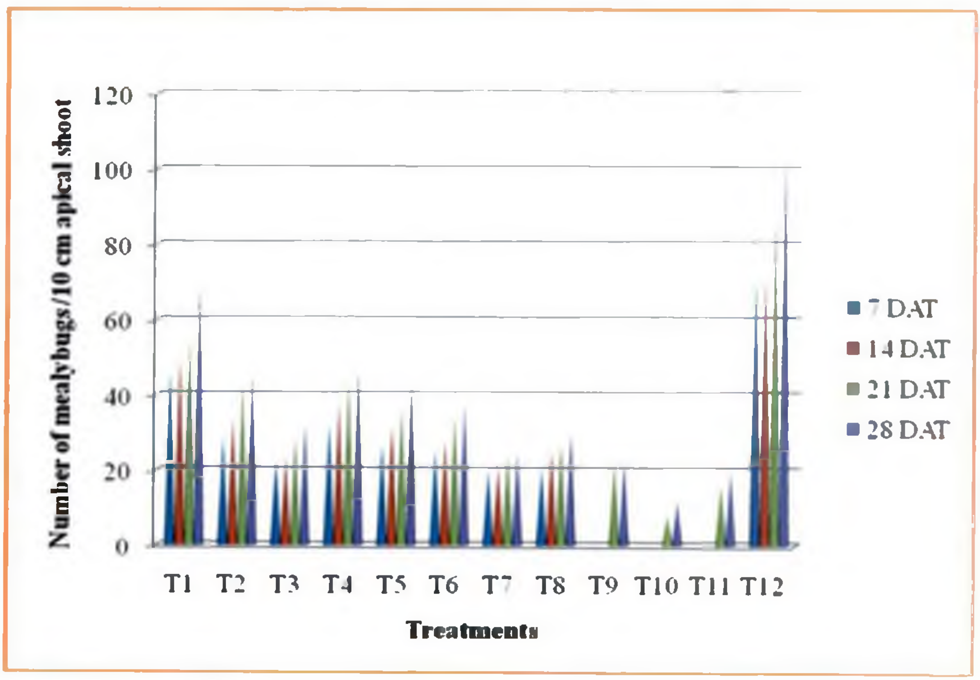


Fig. 10 Population of papaya mealybug at different intervals after application of different treatments in Sholayur panchayat

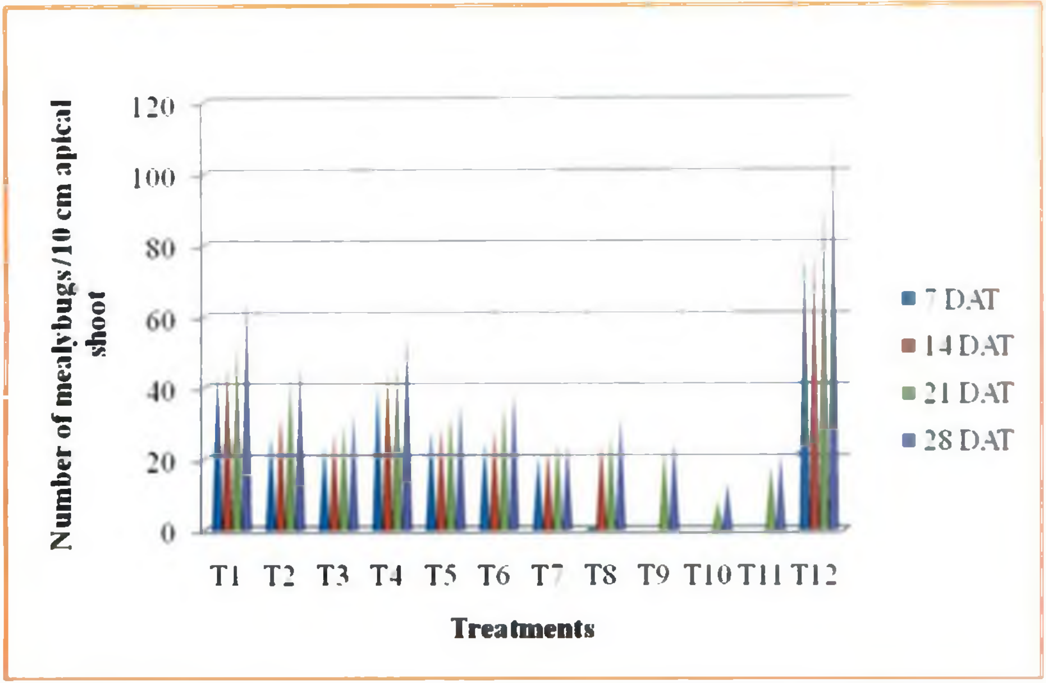


Fig. 11 Population of papaya mealybug at different intervals after application of different treatments in Puthur panchayat

practice (pruning + weeding) alone was not an effective control measure. The number of mealybugs was found to be gradually increasing at 14 DAT. However the number of mealybugs was low in the superior treatments. The second round spraying with dichlorvos 2 ml + econeem plus 2 ml L^{-1} was practiced along with plots treated with the combinations of dichlorvos, dimethoate and imidacloprid with econeem plus showed a better result upto the harvest of leaves. One week after (21 days) the second spray, the lowest number of mealybugs (7.72, 7.93 and 8.47 in Agali, Sholayur and Puthur respectively) was observed in the plants treated with the combination of dimethoate and econeem plus followed by imidacloprid. At 28 DAT, the population was still lower in the combination of dimethoate + econeem plus 11.64 (Agali); 12.03 (Sholayur) and 13.04 (Puthur). The effectiveness of dimethoate on mealybugs was in agreement with the findings of Mahalingam *et al.* (2010). According to Kumar and Prakasan (1992), dimethoate at 0.1 per cent was the most effective treatment against *P. lilacinus* in coffee cv. Catimor in Kerala.

The experiments conducted in the three panchayats Agali, Sholayur and Puthur revealed that all the treatments were found to be effective and superior to control. The crop required 30-45 days for the production of new flushes after pruning, for rearing a new batch of silkworm. Single round spraying was not effective upto the harvest. The effectiveness of the treatments was increased by second round spraying. Application of insecticides was restricted when the population of the predators was high in the field to enhance the natural control.

4.19 POPULATION OF MEALYBUGS PER PLANT AT DIFFERENT INTERVALS AFTER APPLICATION OF DIFFERENT TREATMENTS

Seven days after the first application, the plants treated with the combination of insecticides, dimethoate 0.05% + econeem plus 2 ml L^{-1} was found to be superior with the lowest number of mealybugs 35.69 (Agali);

39.54 (Sholayur) and 37.72 (Puthur) followed by imidacloprid + econeem plus. Among the treatments with the use of single insecticide, dimethoate suppressed the population with 49.19, 55.35 and 59.79 mealybugs/10 cm apical shoot in Agali, Sholayur and Puthur respectively followed by imidacloprid whereas the performance with dichlorvos, econeem plus and their combination was least effective. The number of mealybugs was found to be gradually increasing at 14 DAT. The second round spraying with dichlorvos 2 ml + econeem plus 2 ml L^{-1} was practiced along with plots treated with the combinations of dichlorvos, dimethoate and imidacloprid with econeem plus showed a better result upto the harvest of leaves. One week after the second spray, the lowest number of mealybugs (14.16, 17.22 and 18.05 in Agali, Sholayur and Puthur respectively) was observed in the plants treated with the combination of dimethoate and econeem plus followed by imidacloprid. At 28 DAT, the population was still lower in the combination of dimethoate + econeem plus 23.59 (Agali); 26.05 (Sholayur) and 27.81 (Puthur). The effectiveness of dimethoate on mealybugs was in agreement with the findings of Mahalingam *et al.* (2010). The promising treatment was the combination of dimethoate and econeem plus along with second spray of dichlorvos + econeem plus. It was observed that in treatments without second round spraying, infestation of mealybugs was found to be increased later.

5.20. EFFECT OF VARIOUS TREATMENTS ON LEAF DAMAGE OF MULBERRY

The leaves of selected plants with symptoms of crinkling, curling and twisting were counted as damaged leaves. The combination of dimethoate 1.7 ml + econeem plus 2 ml L^{-1} along with the second spraying with dichlorvos 2 ml + econeem plus 2 ml L^{-1} was observed as superior among all the treatments with minimum leaf damage (4.13, 4.41 and 4.88 in Sholayur, Agali and Puthur respectively) (Fig.12). The highest leaf damage was observed in the treatment with cultural control.

5.21. EFFECT OF VARIOUS TREATMENTS ON SHOOT DAMAGE

The shoots with stunted and distorted in appearance were counted for shoot damage. The number of shoots per plant was limited with ten to obtain high quality leaves. Severe damage (6.36, 6.38 and 6.53 numbers per plant in Agali, Sholayur and Puthur respectively) was observed in the plots where only pruning and weeding were practiced. The minimum number of shoots damaged was found in Agali (1.16), Sholayur (1.25) and Puthur (1.38) with the treatment combination of dimethoate 1.7 ml + econeem plus 2 ml L^{-1} along with the second spraying with dichlorvos 2 ml + econeem plus 2 ml L^{-1} (Fig.13).

5.22. EFFECT OF VARIOUS TREATMENTS ON LEAF YIELD

Similarly the highest leaf yield per plant was recorded in the treatment combination of dimethoate 1.7 ml + econeem plus 2 ml L^{-1} along with the second spraying with dichlorvos 2 ml + econeem plus 2 ml L^{-1} in Agali (1.64 kg/plant) Sholayur (1.62 kg) and Puthur (1.61 Kg). The poor leaf yield obtained with the leaves treated with econeem plus (0.57 kg each in Agali, Sholayur and Puthur) and cultural control (0.58 kg both in Agali and Puthur and 0.57 kg in Sholayur) were on par in all locations (Fig.14).

5.23. RETURNS AND BENEFIT: COST RATIO

The treatment combination of dimethoate 1.7 ml + econeem plus 2 ml L^{-1} along with the second spraying with dichlorvos 2 ml + econeem plus 2 ml L^{-1} recorded the highest total benefit (Rs.6, 12, 000 $ha^{-1}year^{-1}$) and the high benefit: cost ratio (2.07) followed by the treatment combination of imidacloprid 0.3 ml + econeem plus 2 ml L^{-1} along with the second spraying with dichlorvos 2 ml + econeem plus 2 ml L^{-1} (2.00)

Papaya mealybug infestation was observed in the mulberry gardens of Agali, Sholayur and Puthur panchayats of Attappadi block in Palakkad district. The infestation was severe in hot months of March to August.

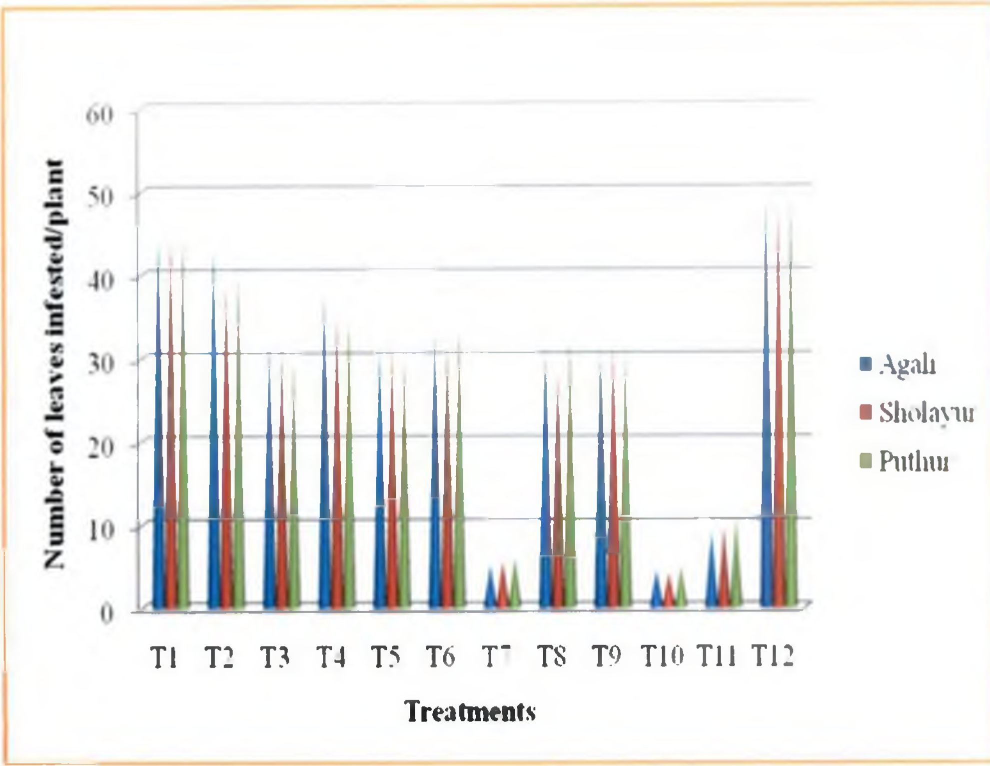


Fig.12 Effect of various treatments on leaf damage of mulberry

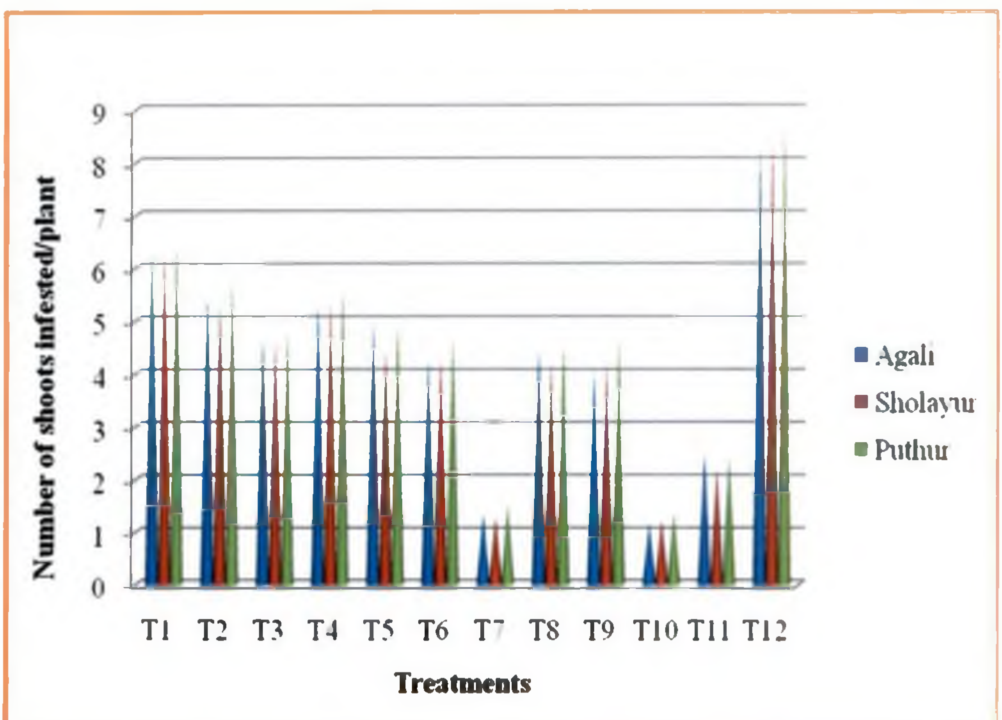


Fig. 13 Effect of various treatments on shoot damage of mulberry

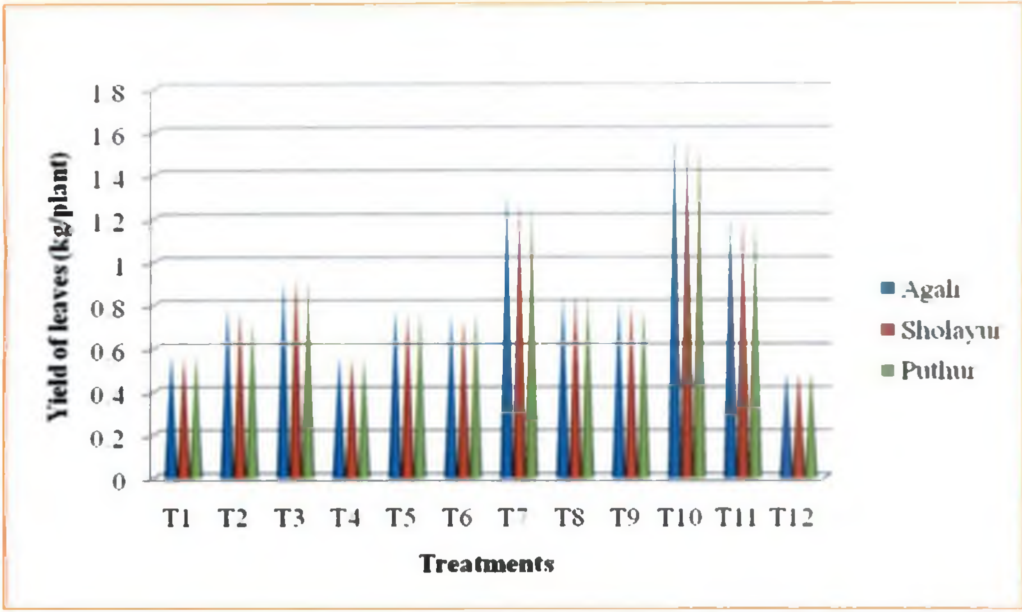


Fig. 14 Effect of various treatments on mulberry leaf yield

Among the three mealybugs identified from mulberry, papaya mealybug was the major one, found to be adversely affecting the sericulture industry. The larvae of canivorous butterfly *S. epius* was the major natural predator. The sericulturists in the Attappadi block were found to use insecticides with high residual toxicity leading to the death of silkworm larvae and thereby reducing cocoon yield.

In this context, present investigations revealed that cultural control measures like pruning, weeding and destruction of infested crop residues and the application of the combination of dimethoate 1.7 ml + econeem plus 2 ml L^{-1} along with the second spraying with dichlorvos 2 ml + econeem plus 2 ml L^{-1} was observed as superior among all the treatments to contain the pest. This treatment was proved to be yielding better B: Ç ratio also. Hence this can be incorporated in the integrated pest management strategies to be recommended against papaya mealybug in mulberry crop.

Summary

6. SUMMARY

The study entitled "Bio-ecology and management of papaya mealybug on mulberry" was conducted in College of Agriculture, Vellayani and farmers' fields at selected panchayats of Palakkad district during the period from October 2009 to December 2011.

Preliminary surveys conducted in the mulberry growing districts in Kerala revealed that papaya mealybug, *P. marginatus* was severely infested in the three panchayats of Attappadi block of Palakkad district *viz.*, Agali Sholayur and Puthur. The mean number of papaya mealybug and its egg masses in Attappadi block were high in July 2010. The population of mealybug and the number of egg mass were declined gradually from October to December 2009. Similarly highest mean number of predator, *S. epius* was observed in July 2010 and the lowest in December 2009.

In Agali, the papaya mealybug population was high in December 2009 (1.23) and reached its peak in July 2010 (59.89). Similar trend was followed in Puthur panchayat. The pink hibiscus mealybug (9.47) was found to increase during February 2010 and reduce the population of the other two mealybugs. In all observation periods, the population of breadfruit mealybug was still lower than the other mealybugs. The completion of pink hibiscus mealybug (8.57) was found to be high in Sholayur in December 2009. The population of papaya mealybug was the highest in July 2010 (58.57) and they suppressed the population of pink hibiscus mealybug. The breadfruit mealybug was not found in Sholayur panchayat during the study period.

Papaya mealybug incidence was observed on 60 plant species belonging to 27 families and the plants from the family Asteraceae, Euphorbiaceae, Malvaceae and Solanaceae were generally found as preferred hosts. Among the hosts, *P. hysterophorus* (Asteraceae), *H. rosa sinensis, S. acuta* (Malvaceae), *J. curcas, M. esculenta* (Euphorbiaceae) and *P. alba* (Apocynaceae) observed presence the papaya mealybug round the year and acted as a persistent source for the spread of papaya mealybug. The fast spreading nature of the weed, parthenium also acted as a factor for maximum coverage of this mealybug. Among the five selected weed hosts, maximum number of mealybugs and its egg masses were observed on *P. hysterophorus* and the lowest on *P. niruri.* It was observed that the farmers' fields and its nearby areas of Attappadi block were heavily infested by partheinum.

The population of papaya mealybug as well as its predator, *S. epius* was positively correlated with maximum temperature, wind speed and sunshine hours while negatively correlated with minimum temperature, rainfall and relative humidity. A significant positive correlation (+0.886) was existed between the population of mealybug and its predator.

The three mealybug species identified from mulberry gardens of Attappadi block were papaya mealybug, *P. marginatus,* pink hibiscus mealybug, *M. hirsutus* and breadfruit mealybug, *I. aegyptiaca.* Among them, papaya mealybug heavily infested the mulberry gardens.

Among the different host materials attempted sprouted potatoes were found to be good for rearing mealybugs in laboratory condition.

Biology of these three mealybugs was studied in detail on sprouted potatoes. Eggs of papaya mealybug were greenish yellow, elongate-oval in shape having an average length of 0.36 mm and 0.26 mm in width. Average incubation period ranged from 5.2 days during March-April 2010 and 7.3 days in November-December 2009. The egg laying period ranged from 8 to 13 days with an average of 10.50 days.

Males and females had four and three nymphal instars respectively. The first instar nymphs measured an average of 0.36 mm length and 0.27 mm width and took an average of 6.1 days to moult to the second instar.

The female nymphs appeared yellow with slight mealy coating with an average length of 0.63 mm and width of 0.44 mm. The male nymphs were light pink in colour and measured an average length of 0.71 mm and width of 0.33 mm. The female and male instars took an average of 5.2 days and 6.4 days respectively to moult to the third instar. The female nymphs were yellow in colour with an average of 1.29 mm in length and 0.78 mm in width. The third instar female took an average of 5.4 days repectively to become an adult female. The adult females were yellow coloured, oval in shape and measured an average of 2.38 mm length and 1.49 mm in width. An adult female mealybug laid an average of 361.50 eggs in its life period.

The third instar male nymph had an average of 0.89 mm length and 0.36 mm width. The third instar took an average of 3.5 days to moult to the fourth instar. The fourth instar of the male (pupa) was found in a cocoon that measured an average of 0.93 mm length and 0.36 mm width. Adult males measured an average of 1.06 mm length and 0.34 mm width, with an elongate oval body that was widest at the thorax.

Freshly laid eggs of pink hibiscus mealybug were elongated and oval in shape, translucent and yellowish or light orange in colour. The incubation period and per cent hatching averaged 4.1 days and 82.26 % respectively. Nymphs were usually yellow to orange in colour with reddish compound eyes. The duration of first instar nymph lasted 7.2 days. The second instar nymphs were pink in colour with white thin waxy secretions on the body with a mean duration of 6.5 days. The duration of third instar nymph lasted 7.5 days. Total nymphal period took an average of 21.2 days. Adult female was soft, oval distinctly segmented and laid an average of 281.3 eggs in its life period. The adult longevity and ovipositional period averaged 12.1 and 6.9 days respectively.

The eggs of breadfruit mealybug were oval in shape and yellowish-orange in colour. The mean incubation period was 9.0 days. The first instar nymphs were bright orange in colour with a mean duration of 18.9 days. The duration of second instar larvae ranged from 9 to 10 days with an average of 9.4 days. The third instar nymph was yellow to orange colour and the body was coated with a white mealy secretion with an average duration of 18.8 days. The deep orange coloured adults were broadly oval in shape with and laid an average of 141.3 eggs in its life period.

The phenol content was found to be more in the papaya mealybug infested leaf samples of mulberry and found to be increasing with the increase in the per cent damage. The total phenol content in papaya mealybug infested mulberry was found to be the highest (1.72) at 100 per cent infestation level whereas the lowest was observed in healthy (0.97).

DAC-ELISA was performed with infected mulberry plants using antibodies for SCBMV and BSV. Infected samples on DAC-ELISA showed the absence of virus in the leaf samples collected from infested mulberry gardens.

In the present study, one lycaenid predator, *S. epius* was observed feeding on the life stages of papaya mealybug. The first instar larvae of the predator were pink in colour and remained inside the ovisac of papaya mealybug. The larvae were coated with white wax and were difficult to distinguish from the mealybug. Total larval duration was observed as 10.0 days. The corresponding duration for first, second, third, fourth and fifth instars were 2.6, 1.8, 1.4, 2.0 and 2.2 days respectively. The pupal period was about 5.43 days. The fifth instar larvae of *S. epius* were found to be a voracious feeder of mealybugs. Feeding potential was gradually increased with the growth of the predator.

Papaya mealybug infestation appeared as clusters of cotton-like masses on the above ground portion of the plants with long waxy filaments. Sap sucking by the nymphs and adults of mealybug resulted in crinkling, rosetting, and general leaf distortion. Sooty mould also occurred on the upper surface of mulberry leaves.

Predatory potential of *C. carnea* and *C. montrouzieri* was investigated in the laboratory. Both the predators were found very active and successfully consumed all the nymphal instars of papaya mealybug. Third instar larvae of *C. carnea* were the most voracious feeder and consumed significantly higher number of ovisacs, first, second and third instar nymphs of mealybug as compared with first and second instar larvae of the predator. Similarly fourth instar grub of *C. montrouzieri* consumed higher number of ovisacs, first, second and third instar nymphs of mealybug.

Among the insecticides evaluated, dimethoate 0.1% was superior followed by imidacloprid 0.01% in the case of both first instar and adult mealybugs. The least mortality percentage of adult as well as the first instar mealybugs was recorded with NSKE 2.5%. The effectiveness of other insecticides against adult as well as first instar mealybug were in the order of dimethoate 0.05% > imidacloprid 0.005% > abamectin 0.006 % > abamectin 0.003% > dichlorvos 0.05 > NSKE 5%.

Combination of dimethoate 0.05% + econeem plus 2 ml L^{-1} was found to be superior with the highest per cent mortality of 93.33% and 96.67,% for adult and first instar papaya mealybug respectively.

The silkworm larvae fed with the leaves sprayed with the combination of dimethoate 0.05% + econeem plus 2 ml L^{-1} gave the highest yield of 91 total cocoons with a total larval duration of 576 hours. Single cocoon weight was found to be high (1.56 g) with highest shell ratio (22.09). The mean larval weight of different instars were 0.54, 0.87, 1.16, 8.80 and 36.61 gram respectively in first, second, third, fourth and fifth. In this treatment, ERR by number and weight was 9050.00 and 13744.69 g respectively. Among the four treatments, the least effective treatment was dimethoate 0.1% with lowest ERR by number as well as weight. While analyzing the growth rate of silkworm larvae, the treatment with the combination of dimethoate and econeem plus were found to be superior.

Field evaluation against the papaya mealybug was done based on the effective treatments in the laboratory and the suitable farmers' practices identified from the survey. The field experiments conducted in the three panchayats Agali, Sholayur and Puthur revealed that all the treatments were found to be effective and superior to control. The crop required 30-45 days for the production of new flushes after pruning for rearing a new batch of silkworm. Single round spraying was not effective upto the harvest. The effectiveness of the treatments was increased by second round spraying. Application of insecticides was controlled when the population of the predators was high in the field to enhance natural control.

The combination of dimethoate 1.7 ml + econeem plus 2 ml L^{-1} along with the second spraying with dichlorvos 2 ml + econeem plus 2 ml L^{-1} was observed as superior among all the treatments with minimum leaf and shoot damage and highest leaf yield per plant with the highest benefit cost ratio of 2.07

Salient Findings Emerged from the Studies

- Three mealybug species were found infesting the mulberry gardens of Kerala. They were papaya mealybug, *P. marginatus*, pink hibiscus mealybug, *M. hirsutus* and breadfruit mealybug, *I. aegyptiaca*. Among them, breadfruit mealybug infesting mulberry is the first report from Kerala.
- The population of papaya mealybug suppressed the population of pink hibiscus and breadfruit mealybugs in July whereas the pink hibiscus mealybug dominated over papaya and breadfruit mealybugs in December.
- The population of papaya mealybug was positively correlated with maximum temperature and the highest population was in June-July. It was negatively correlated with rainfall and relative humidity and the lowest population of the mealybug was observed in December-January.
- The heavy infestation of papaya mealybug was observed during July and it dominated both pink hibiscus mealybug and breadfruit mealybug in Agali, Sholayur and Puthur panchayats.
- The plants from the family Asteraceae, Euphorbiaceae, Malvaceae and Solanaceae were the most favoured hosts. Parthenium and jatropha acted as a persistent host for the successful perpetuation of papaya mealybug throughout the year.

- Sprouted potatoes were good host material for mass rearing all the three mealybugs. Mass multiplication of papaya mealybug was not possible with pumpkin but it was suitable for pink hibiscus mealybug.
- Potatoes with prominent eyes performed well in sprouting and 2-3 sprayings of 100 ppm gibberlic acid solution in alternate days under the dark condition enhacned the sprouting within four days.
- Estimation of total phenol in the damaged mulberry leaves showed that the leaf damage was exclusively due to the attack of mealybug.
- Infested samples tested with DAC-ELISA showed the absence of virus in the samples collected from infested mulberry gardens.
- The total larval duration was higher in breadfruit mealybug (47.1) followed by pink hibiscus mealybug (21.2) whereas the lowest was in papaya mealybug (14.8).
- The fifth instar larvae of predator *S. epius* was a voracious feeder of mealybugs which consumed 21.69 ovisacs, 118.88 Ist instar, 46.88 IInd instar and 20.94 adult mealybugs respectively. Adult rearing of spalgis for egg laying was not possible under laboratory condition.
- The effectiveness of insecticides against adult as well as first instar mealybug were in the order dimethoate 0.1 > imidacloprid 0.01 > dimethoate 0.05% > imidacloprid 0.005% > abamectin 0.006 % > abamectin 0.003% > dichlorvos 0.05 > NSKE 5% > NSKE 2.5%.
- The combination of dimethoate 1.7 ml and econeem plus 2 ml L^{-1} was found to be superior with the highest per cent mortality of and adult (93.33%) and first instar (96.67%)
- The leaves sprayed with the combination of dimethoate 1.7 ml and econeem plus 2 ml L^{-1} gave the highest yield of cocoons (91/100 larva reared), shell rario (22.09), ERR by number (9050.00) and ERR by weight (13744.69 g) with a total larval duration of 576 hrs.

- The integration of cultural practices and application of dimethoate 1.7 ml + econeem plus 2 ml L^{-1} along with the second spraying with dichlorvos 2 ml + econeem plus 2 ml L^{-1} were observed as superior among all the treatments with minimum leaf and shoot damage and the highest leaf yield per plant. This treatment gave total returns of Rs. 6, 12, 000 with the highest B: C ratio of (2.07). Hence this treatment can be recommended as an IPM strategy for the management of papaya mealybug on mulberry.

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BIO-ECOLOGY AND MANAGEMENT OF PAPAYA MEALYBUG ON MULBERRY

by

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ABSTRACT

The experiment entitled "Bio-ecology and management of papaya mealybug on mulberry" was carried out at College of Agriculture, Vellayani, Kerala Agricultural University and in farmers' fields at Agali, Sholayur and Puthur panchayats during October 2009 to July 2012. The main objectives of the study were to identify and assess the extent of infestation of papaya mealybug on mulberry, its role in disease transmission and population dynamics and to evolve an Integrated Pest Management (IPM) strategy to contain the pest.

Preliminary survey conducted in sericulture practising districts of Kerala revealed heavy infestation of the pest in three panchayats of Palakkad district in Kerala. The mealybugs identified in the survey were papaya mealybug, *Paracoccus marginatus* Williams and Granara de Willink, pink hibiscus mealybug, *Maconellicoccus hirsutus* (Green) and breadfruit mealybug, *Icerya aegyptiaca* (Douglas). The occurrence of papaya mealybug and its egg masses were found to be high during the period of May to August. The competition between these three mealybugs and also the influence of weather parameters on the population of the papaya mealybug was studied. The mealybug population showed positive correlation with maximum temperature, sunshine and wind speed and negative correlation with minimum temperature, rainfall and humidity. The different plants belonging to families Asteraceae, Euphorbiaceae, Malvaceae and Solanaceae were observed to be the most preferred hosts for papaya mealybug. The highest number of all life stages of papaya mealybug was observed on Parthenium, *Parthenium hysterophorus* L., which augmented the perpetuation of papaya mealybug in the absence of other crop hosts.

Sprouted potatoes were the host material used for studying the biology of the papaya mealybug, pink hibiscus mealybug and breadfruit mealybug. The average number of eggs laid by an adult papaya, pink

hibiscus and breadfruit mealybug were 361.50, 281.30 and 141.30 respectively. The mean larval period of papaya, pink hibiscus and bread fruit mealybugs were found to be 16.7, 21.2 and 47.1 days respectively.

DAC-ELISA was performed with infected mulberry plants using antibodies of SCBMV and BSV showed the absence of virus in the infected samples collected from the mealybug infested mulberry gardens. The phenol content was also assessed in the infested samples to get an indication of the level of resistance showed by the host plant against mealybug. The level of resistance of the plant found to be increasing with the increase in the per cent damage.

The fifth instar larvae of the predator, *Spalgis epius* was found as the most active feeder with a feeding potential of 21.69, 118.88, 40.88 and 20.49 of ovisacs and first, second and third instars of papaya mealybug respectively. Third instar larvae of green lacewing, *Chrysoperla carnea* (Stephens) and fourth instar grubs of ladybird predator, *Cryptolaemus montrouzieri* (Mulsant) were the most voracious feeders and they consumed significantly higher number of ovisacs, first, second and third instar nymphs of papaya mealybug as compared with first and second instar larvae of the predators.

Among the different insecticides evaluated in the laboratory against the first instar and adult papaya mealybugs, dimethoate 0.1% was superior followed by imidacloprid 0.01%. Among the combinations, dimethoate 0.05% + econeem plus 2 ml L^{-1} was found to be superior with the highest per cent mortality of 93.33% and 96.67% for adult and first instar papaya mealybugs respectively.

The silkworm larvae fed with the leaves after 15 days of treatment with the combination of dimethoate 0.05% + econeem plus 2 ml L^{-1} gave the highest yield of (91 /100 larva reared) cocoons with a total larval duration of 576 hours. Single cocoon weight was found to be high (1.56 g) with the highest shell ratio (22.09). The mean larval weight of different instars were

0.54, 0.87, 1.16, 8.80 and 36.61 gram respectively in first, second, third, fourth and fifth. In the above treatment, effective rearing rate (ERR) by number and weight were 9050.00 and 13744.69 g respectively.

Field evaluation with the combination of pruning and weeding along with application of dimethoate (0.05%) 1.7 ml + econeem plus 2 ml L^{-1} and also providing a second spraying with dichlorvos (0.05%) 2 ml + econeem plus 2 ml L^{-1} was observed to be superior among all the treatments with minimum leaf damage, shoot damage and highest leaf yield per plant. B: C ratio worked out also confirmed the superiority of this treatment. Hence this treatment can be recommended as an IPM strategy for the management of papaya mealybug on mulberry.

Appendices

APPENDIX- I

Proforma for collecting details about papaya mealybug infestation

1. Name of district

2. Name of the panchayat

3. Name and address of the farmer

4. Area under mulberry cultivation

5. Other mealybugs if any

6. Other crops cultivated

7. Other crops infested with mealybug

8. Weeds infested with mealybug

9. Existing natural enemies

10. Survey of pests and natural enemies and pathogens if any

Name of the month

Plant no.	No. of egg mass/10cm apical shoot	No.of mealybugs/10 cm apical shoot	No. of natural enemies/10 cm apical shoot
1 to 50			

11. Symptoms of infestation

12. Intensity of infestation (Incidental/low/medium/high)

12. Management measures followed
    (Insecticides, mode of application and no of times applied)

Date:

Place:

APPENDIX II

Monthly mean of weather parameters in the mealybug infested garden during the period from October 2009 to September 2010

Month & Year	Rainfall mm	Relative Humidity %	Temperature Maximum °C	Temperature Minimum °C	Wind speed ms^{-1}	Sunshine hr
October 2009	214.4	75.95	28.43	22.15	4	102.2
November 2009	307.9	80.09	27.73	21.05	1.35	26.5
December 2009	50.8	82.6	28.25	18.75	1.73	98.7
Jan uary 2010	0	72.18	29.64	16.16	2.06	149
February 2010	59.4	50.42	24.96	12.39	1.66	132.2
Mar ch 2010	22.2	39.51	24	13.17	2.1	166
April 2010	26.4	76.6	20.81	12.58	1.54	107.9
May 2010	·31	44.51	23.65	17.48	2.09	95.5
June 2010	29.8	72.7	21	16.61	5.2	100
July 2010	30.2	75.57	27.74	21.86	7.8	65.2
August 2010	25	70.35	27.94	22.38	5.04	33.2
September 2010	86	75.31	28.97	22.38	5.04	33.2

APPENDIX III

Buffers for DAC- ELISA

1. Phosphate buffered saline (PBS-pH 7.4)

Sodium chloride	- 8.0 g
Potassium dihydrogen phosphate	- 0.2 g
Disodium hydrogen phosphate	- 1.1 g
Potassium chloride	- 0.2 g
Sodium azide	- 0.2 g
Water	- 1000 ml

2. Wash Buffer (PBS- T)

Add 0.5ml/L of Tween-20 to PBS

3. Coating buffer (pH 9.6)

Sodium carbonate	- 1.59 g
Sodium bicarbonate	- 2.93 g
Sodium azide	- 0.2 g
Water	- 1000 ml

4. Antibody diluent buffer

Add 20 g PVP and 2 g ovalbumin to 1 1PBS-T

5. Enzyme conjugate diluent buffer (PBS-TPO)

Same as PBS-TPO

6. Substrate solution (pH 9.8)

Diethanolamine	- 97 ml
Sodium azide	- 0.2 g
Water	- 800 ml

Add HCl to give pH 9.8