BIONOMICS AND MANAGEMENT OF ROOT MEALYBUG ON BLACK PEPPER

by

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(2012-21-112)

THESIS

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DEPARTMENT OF AGRICULTURAL ENTOMOLOGY
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2016

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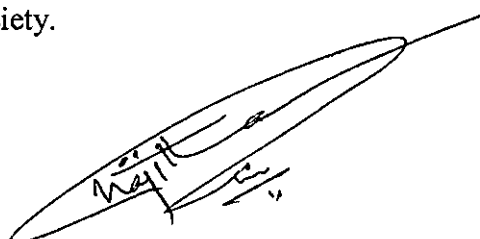
I, hereby declare that this thesis entitled **"BIONOMICS AND MANAGEMENT OF ROOT MEALYBUG ON BLACK PEPPER"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.



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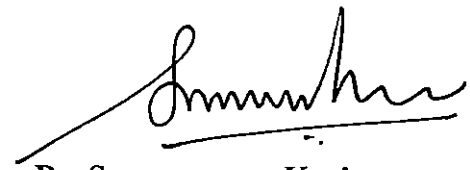

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Introduction

1. INTRODUCTION

Black pepper (*Piper nigrum* L.) is a flowering vine belonging to family Piperaceae, cultivated for its fruit which is usually dried and used as a spice. It is the third most added ingredient in food among the wide range of spices. It is popularly known as "the king of spices" which is native to India and mostly cultivated in tropical and sub-tropical regions (Ahmad *et al.*, 2010). This spice is also called as 'Black gold' due to its international trade factor.

The quality of black pepper is decided by its two attributes, aroma and pungency. The pepper oleoresin, containing the essential oil contributes to the aroma and the alkaloid, piperine contributes to the pungency (Srinivasan, 2007). Pepper is used in medicines also. Pepper extracts contain alkaloid (e.g. piperine), terpenes, flavones and volatile oils (e.g. piperyline) that contributes to the properties like sedating, detoxification, hypotensive, and anticancer activities (Butt *et al.* 2012; Meghwal and Goswami 2013; Yoon *et al.* 2015). Pepper is also used as a preservative and enhancer in meat and meat-based products (Thiel *et al.* 2014).

About 50 per cent of black pepper production is from India with an annual production of 53,000 tonnes from 1.25 lakh ha (GOI, Agriculture, Cooperation and Farmer's Welfare, 2016). Kerala is known as land of spices and accounts for 90 per cent of India's black pepper production followed by Karnataka and Tamil Nadu. It is grown in an area of 0.85 lakh ha with an annual production of 40,690 tonnes (Economics and Statistics Department, 2016) Calicut, Kannur, Kottayam and Idukki are the major pepper growing districts of Kerala.

India was the leading pepper producing and exporting country. But currently, Vietnam is the world's largest producer and exporter of pepper (Yogesh and Mokshapathy, 2013) with a production of 8.5 lakh tons. One of the reasons for this change in status is the low productivity of pepper in India i.e. 306 kg per hectare (Indian Stock Market, 2016). The presence of senile unproductive gardens, homestead system of cultivation and occurrence of pest and diseases contributes to low productivity of black pepper in India (Nybe and Sujatha, 2008).

Among the insect pests of black pepper, thirty four species of different insect pests have been reported to infest this crop in India. Major pests of black pepper are pollu beetle (*Lanka ramakrishnai* Prathapan and Viraktamath), marginal gall thrips (*Liothrips karnyi* (Bagnall)), top shoot borers *etc.* The leaf feeders and sap feeders including scales and mealybugs were grouped as minor pests (Devasahayam *et al.*, 1988).

Later Koya *et al.* (1996) identified mealybugs as important pests of black pepper by reporting seven species *viz.*, *Ferrisia virgata* Ckll., *Planococcus* sp., *P. citri* (Risso), *P. minor* (Mask.), *Pseudococcus* sp., *P. longispinus* (Tarigoni) and *P. orchidicola* Takahashi infesting different parts of black pepper vine. According to them, all the above species except *Planococcus* were reported to infest leaf, shoot and berry.

Recently, the infestation of root mealybugs on black pepper were reported to be severe in some districts of Kerala, especially higher altitude districts like Idukki and Wayanad. Five species of mealybugs *viz.*, *Planococcus* sp., *P. citri, P. lilacinus* Cockerell, *Dysmicoccus brevipes* (Cockerell) and *F. virgata* were reported to infest the roots and basal region of stem under the soil (Devasahayam *et al.*, 2010). The infestation of these root mealybugs mostly goes unnoticed as it is underground.

According to Devasahayam *et al.* (2010), nymphs and adult mealybugs suck sap from roots and basal stem region resulting in yellowing, defoliation and mortality of vines. They also reported that other plant parasitic organisms *viz.*, fungi, *Phytophthora capsici* (Leonian) and nematodes, *Meloidogyne incognita* (Kofoid and White) Chitwood and *Radopholus similis* (Cobb) Thorne were associated with root mealybugs. They also reported the presence of root mealybugs on some intercrops and weed plants in black pepper ecosystem.

The available literature shows that the roots of black pepper were infested by a complex of species of mealybugs instead of a single species, and research on its other aspects like, population dynamics of root mealybugs, biology of the pest and their management is meagre. Considering the above facts, it is essential to conduct a study on documentation of root mealybug species and associated fauna, collateral

hosts, population dynamics, biology and management of root mealybugs. Majority of farmers prefer chemical control for managing root mealybugs as it is very fast and immediately effective. But the indiscriminate use of chemicals causes serious hazards to the environment and human health. Hence, biocontrol has become an important strategy in pepper pest management programme. Keeping in view of the above situation the present project entitled "Bionomics and management of root mealybugs on black pepper" was carried out with the following objectives:

1. Documentation of root mealybugs and other associated fauna
2. Biology of root mealybugs in pepper
3. Susceptibility of popular pepper varieties to root mealybugs
4. Evaluation of entomopathogenic fungi against root mealybugs
5. Evaluation of chemical insecticides against root mealybugs
6. Compatibility of effective entomopathogenic fungus with insecticides
7. Management of root mealybug in pot culture experiment
8. Field evaluation of effective treatments

Review of literature

2. REVIEW OF LITERATURE

Root mealybugs are a group of pseudococcids which infest the underground parts of plants. They are known by different names such as hypogeic mealybugs, soil mealybugs or subterranean mealybugs. These are serious pests on many perennials and ornamental plants, and are known to infest the roots of potted plants and green house crops also. In most cases, the infestation goes unnoticed since they infest the underground portion and within that time plant may die. The available literature on root mealybug pests of black pepper and other crops, are reviewed here.

2.1 MEALYBUG PESTS OF BLACK PEPPER

The literature available on all mealybug species including root mealybugs reported from black pepper (*Piper nigrum* L.), root mealybugs of other members of family *Piperaceae* and other crops are reviewed here. Literature on their distribution, host range, associated fauna, biology and management are also critically reviewed in this chapter.

2.1.1 Aerial mealybugs of black pepper

A complex of mealybug species were reported to be infesting aerial parts of black pepper. Devasahayam *et al.* (1988) reported two mealybug species, *viz.*, *Ferrisia virgata* Cockerell and *Planococcus citri* (Risso) infesting tender shoots and berries of black pepper in India. Later Koya *et al.* (1996) reported seven species of mealybugs *viz.*, *F. virgata*, *Planococcus* sp., *P. citri, P. minor* (Mask.), *Pseudococcus* sp., *Pseudococcus longispinus* (Tarigoni) and *P. orchidicola* Takahashi. All these species, except *Planococcus* were reported to be infesting leaves, shoots and berries.

2.1.2 Root mealybugs of black pepper

Williams (2004) reported infestation of *Formicococcus polysperes* Williams on roots of *P. nigrum* from Kerala. Another five species of mealybugs *viz.*, *Planococcus* sp., *P. citri, P. lilacinus* Cockerell, *Dysmicoccus brevipes* Cockerell and *F. virgata* were found to be infesting the roots and basal region of stem under the soil (Devasahayam *et al.*, 2010).

2.1.3 Root mealybugs on other members of Piperaceae

Muthukrishnan *et al.,* 1958 as cited by Williams (1985a) listed *Geococcus citrinus* Kuwana on *Piper betle* L. from North Arcot District, Tamil Nadu State. *Formicococcus polysperes* also was found to infest roots of *P. betle* from Maharashtra, India (Williams, 2004).

2.1.4 Root mealybugs of other crops

Geococcus coffeae Green was reported on roots of many palnts in Hawaii such as *Acacia koa, Cladium,* coffee, croton, *Cyperus rotundus,* ferns, gerbera, *Indigofera anil,* mango, oleander, palms and pineapple (Beardsley, 1966 cited by Smitha, 2007). Rao *et al.* (1974) recorded green gram as a new food plant of coffee root mealybug *G. coffeae* in Tamil Nadu. *Planococcoides* sp. near to *P. robustus* Ezzat and Mc Connell was found infesting the roots of mango in the Kolar district of Karnataka, India (Puttarudriah and Eswaramurthy, 1976).

Root nodules of red gram (*Cajanus cajan* L.) and groundnut (*Arachis hypogea* L.) were found to be infested by *D. brevipes* and reported for the first time from South India (Rajagopal *et al.,* 1982). *Dysmicoccus brevipes* was found to infest underground plant parts and also foliage of groundnut. They feed on nodules and cut off the nutrient supply to plants (Singh *et al.,* 1986).

Williams (1985c) reported four species of root mealybugs *viz., Rhizoecus americanus* Hambleton, *R. cacticanus* Hambleton, *R. dianthi* Green and *R. saintpauliae* Williams infesting African violets (*Saintpaulia* spp.) fro Thailand.

Watson and Cox (1990) described two new species, *Planococcus fungicola* and *P. radicum* on coffee roots from Africa, among which, *P. fungicola* was recorded in Kenya and *P. radicum* in Nigeria and Tanzania. Godfrey and Pickel (1998) reported a subterranean pest, *R. kondonis* Kuwana on alfalfa (lucerne), prunes (plums, *Prunus domestica*) and other crops primarily in the Sacramento Valley of California.

Cassava root mealybug, *Stictococcus vayssieri* Richard was reported from Cameroon. Its nymphs and adults were found to attack young feeder roots of germinating cuttings causing leaf fall, wilting, die back and plant death (Ngeve, 2003).

Mathew *et al.* (2011) reported infestation of banana roots by *Geococcus citrinus* Kuwana and *G. coffeae.* Twenty eight collateral hosts were recorded for *G. citrinus.* Another mealybug species, buff coconut mealybug, *Nipaecoccus nipae* (Maskell) was reported from Kayamkulam, Kerala, India which was found to infest tender feeder roots of coconut seedlings (Josephrajkumar *et al.,* 2012).

Malumphy *et al.* (2014) reported another species, *Chryseococcus arecae* (Maskell) on members of 14 different plant families. Hosts included were several ornamental plant genera that were commonly grown in Britain, such as *Dendrobium, Dianthus, Erica, Gentiana, Meconopsis, Primula, Rhopalostylis* and grasses. This mealybug was observed to be feeding on tomato roots under quarantine laboratory conditions in U.K.

2.2 DISTRIBUTION AND HOST RANGE OF ROOT MEALYBUGS

2.2.1 Distribution and host range of *Formicococcus polysperes* Williams

Genus, *Formicococcus* was described by Takahashi in 1982 with the type species *F. cinnamomi* Takahashi from *Cinnamomum camphora* in Taiwan (Scalenet, 2013).

Later on 38 species of *Formicococcus* was described by different coccido-logists (Scalenet, 2013). Among which, Williams (2004) described *F. polysperes* from roots of *Macaranga triloba* (Thunburg) Muller Argoviensis in Malaysia, and provided details of host plants and distribution. It was found on roots of *Macaranga triloba, Macaranga conifer* (Zoll.) Mull.Arg. and *Sapium baccatum* Roxb. (Euphorbiaceae) from Malaysia, on roots of *Zingiber officinale* Rose. (Zingiberaceae), *Cocos nucifera* L. and *Rhapis excels* (Thunb.) (Aracaceae) from Philippines, on roots of *Z. officinale* from Thailand and on roots of *Lansium domesticum* Corr. from Vietnam.

In India, it was found on roots of *Piper nigrum* (Kerala), *P. betle* (Madhya Pradesh, Uttar Pradesh, and West Bengal), on pods of *Arachis hypogaea* (Orissa) and on *Areca catechu* (Uttar Pradesh) (Williams, 2004). It was also found on ginger in Malaysia by Watson (2007) and in Meghalaya, India by Firake *et al.* (2015).

2.2.2 Distribution and host range of *Dysmicoccus brevipes* (Cockerell)

The origin of *D. brevipes* is believed to be in the tropical areas of Central and South America (Carter, 1935). According to Beardsley (1963), genus *Dysmicoccus* was described by Ferris in 1950 and the type genus was *Dactylopius brevipes.*

According to Gupta and Norman (1975), two cultivars of tomato plants showing wilting and eventually dying within a month after transplanting revealed heavy root infestation of *D. brevipes*. Butani (1979) recorded *Musa* sp. as one of the host plants for *D. brevipes*. *Dysmicoccus brevipes* was commonly found to infest perennial grasses including sugarcane (Beardsley, 1982 as cited by Beardsley, 1993b). It is a serious pest of pineapple, and is commonly known as pink pineapple mealybug (Beardsley, 1993a). It was found infesting pineapple roots, leaves, fruits, blossom cups and crowns (Gonzalez – Hernandez *et al.,* 1999).

Hara *et al.* (2001) reported the infestation of *D. brevipes* on coffee, banana, caladium, sugarcane, canna, citrus, brinjal and palms in South America, Africa, Jamaica, Madagascar, The Dominician Republic, Florida, Louisiana, Massachusetts and Pakistan. It was first reported in Hawaii in 1910 (Hara *et al.,* 2001). *Dysmicoccus* sp. was observed to suck sap from the roots and rhizobium nodules of soybean grown in red sandy soil during the *kharif* and summer seasons in Karnataka, India (Thippaiah and Kumar, 1999). It was also known as an important pest of pineapple and banana in Taiwan and also reported to infest on the basal part and roots of groundnut growing near to a pineapple plantation (Huang *et al.,* 2002).

Watson (2007) reported *D. brevipes* attacking ginger along with other two species *viz., Formicococcus polysperes* and *Ferrisia virgata* in Malaysia, and below ground region of black pepper in Kerala (Devasahayam *et al.,* 2010). Basavaraju *et al.,* 2013 cited that Nair and Menon (1963) reported *D. brevipes* as a minor pest of arecanut and shown its possibility of becoming a major pest by infesting leaves and thereby inhibiting the growth.

2.2.3 Distribution and host range of *Pseudococcus* spp.

More than 150 species were described under the genus *Pseudococcus* including several major pests such as the citrophilus mealybug, *Pseudococcus calceolariae* (Maskell), the long-tailed mealybug, *P. longispinus* (Targioni - Tozzetti), the grape mealybug *P. maritimus* (Ehrhom) and the obscure mealybug *P. viburni* (Signoret) (Ben Dov, 1994).

Williams (1985b) described a new species namely, *P. mandio* from roots of cassava in Paraguay, Bolivia and Brazil. Forbes described another species, *P. sorghiellus* in 1985 and was recorded on sorghum, corn and various other grasses in Illinois (Ferris, 1953).

Pseudococcus longispinus is another species widespread throughout the world and occurring predominantly on a wide range of glasshouse crops in northern latitudes. It was recorded as an economic pest on citrus, pipfruit, grapevines, avocados, coffee, cocoa, palms and other horticultural and field crops in various parts of the world, especially the southern U.S.A., Australia, and New Zealand (DeBach 1949, Browning 1959, McKenzie, 1967 as cited by Charles, 1981). Swirski *et al.* (1980) reported serious infestation of *P. longispinus* in avacado plantations of Israel.

An unidentified species of *Pseudococcus* was reported to infest leaves, shoots and berries of black pepper along with other six species of mealybugs (Koya *et al.* 1996). Miller and Williams (1997) described *P. odermatti* and reported its infestation on *Aglaonema* and Citrus. A species of *Pseudococcus* was found in Israel in 1937 and was described by Green and hence commonly called as Green's mealybug. It was believed to have originated in East Asia and spread to Hawaii, Paraguay and Brazil (Kennett *et al.*, 1999). Another species of *Pseudococcus, P. cocotis* Maskell was reported to infest spadix, inflorescence and inner perianth of coconut by Rajan *et al.* (2010) as cited by Josephrajkumar *et al.* (2012). Correa *et al.* (2011) described *P. meridionalis* from Chile and displayed a wide host range including Japanese pear, persimmon, pomegranate, pear and grapes. *Pseudococcus comstocki* (Kuwana), a highly polyphagous species native to eastern Asia was first recorded in 1918 in

California and New York on ornamentals *viz.*, *Catalpa* sp. and *Morus* sp. (Pellizari *et al.*, 2012)

2.2.4 Distribution and host range of other root mealybugs

Rhizoecus is a genus of subterranean mealybugs which was added by Kunckel d'Herculais in 1878. Type species used for the description was *R. falcifer* Kunckel d'Herculais from France and later this species was reported from New Zealand by Cox (1978). Williams (1985a) documented three species of hypogeic mealybugs of genus *Rhizoecus* in India. Among the three species, *R. amorphophalli* was reported on roots of *Amorphophallus* sp. and *Zingiber officinale* from Kerala, on *Diascorea elephantipes* from Goa and on rhizomes of *Curcuma domestica* Valeton from Maharashtra. Other two species *viz.*, *R. cocois* Williams on coconut and *R. cynodontis* Green on *Cynodon dactylon* L. were recorded from Kerala and Andhra Pradesh, respectively. Another species of *Rhizoecus, R. hibisci* Kawai and Takagi, a polyphagous species is known to feed on both monocotyledonous and dicotyledonous plants. It was first described from the roots of tea (OEPP/EPPO, 2005). It had been found on palms, *Calathea* sp. and *Serrisa* sp. (Mathew and Mani, 2016).

A root mealybug of cassava, *Stictococcus vayssierei* was first reported in Cameroon in 1969 as a new species and at the same time it was observed on cassava in the Tobale Savanna in the Central African Republic (Richards, 1971 as cited by Ngeve, 2003).

Smitha *et al.* (2005) reported two species of root mealybugs *viz.*, *Geococcus citrinus* and *G. coffeae* infesting the roots of different banana cultivars in Kerala, India. The enset root mealybug, *Cataenococcus ensete* Williams and Matile-Ferrero was reported to be the most important insect pest of enset in Southern Ethiopia (Addis *et al.*, 2008a).

The mealybug, *Chryseococcus arecae* is another root meaybug species reported for the first time from Europe and was collected from the roots of *Meconopsis* sp. hybrid clones (Papaveraceae) in Sheriffmuir, Dunblane, Perthshire, Scotland (Malumphy *et al.*, 2014).

2.3 ECONOMIC IMPORTANCE OF ROOT MEALYBUGS

Koya *et al.* (1996) observed colonies of *Planococcus* sp on black pepper vine at the basal portion of stem near the root zone under the soil and severe infestation resulted in mortality of younger vines in the field and plants in the nursery. Root feeding by *Rhizoecus kondonis* Kuwana resulted in chlorotic and stunted lucerne plants. Injury caused by *R. kondonis* on prunes was suspected to be associated with limb dieback, reduced growth and decline of the orchard (Godfrey and Pickel, 1998).

According to Nair *et al.* (1980) as cited by Mathew and Mani (2016), *R. cocotis* was reported to be infesting young coconut palms which caused yellowing, loss of vigour and discolouration on the roots at the feeding points which eventually led to the drying up of such roots.

According to the report of OEPP/EPPO (2005), the adults and immature stages of *R. hibisci* was found to be feeding on plant roots, particularly new roots in the upper layer of soil reducing water and nutrient uptake by the host. Infestation reduced plant growth resulting in shrivelling and crinkling. Leaves of infested plants were wilted, became pale and turned yellow or grey and became soft, translucent and brown.

Hara *et al.* (2001) stated that the damage caused by root mealybugs is not specific, and the most common plant symptoms are slow growth, lack of vigour, and subsequent death. Adult female mealybugs will be noticeable as a form of white, waxy substance, especially in the spaces between the pot and the root ball. Potted palms and other slow growing plants were more susceptible to infestation by root mealybugs as they require lengthy bench time to attain marketable size.

The roots and basal stem region of black pepper vines were found to be infested by five species of mealybugs (*Planococcus* sp., *P. citri, P. lilacinus, D. brevipes* and *F. virgata*), and the infested vines showed slow or poor growth. Leaves were found to be wilted, became pale or turned yellow. Addis *et al.* (2010) reported that enset plants infested with mealybugs had retarded growth and dried lateral leaves. The insects attacked plants of all age groups but symptoms were more severe on two to four years old enset plants. The root mealybugs were found to

colonise on roots and corms. During periods of extreme drought, the mealybugs showed tendency to move towards the corm due to the drying up of roots.

Smitha and Mathew (2010c) reported adults and nymphs of *Geococcus* sp. sucking sap from the lateral roots of banana colonized at the junction of laterals with main root resulting in drying up of such roots. General weakening of the plant, yellowing and narrowing of leaves, reduction in bunch weight, *etc.* were the observed symptoms. *Geococcus citrinus* seriously damaged banana roots in reclaimed paddy fields whereas *G. coffeae* was associated with banana grown in uplands.

The grape root mealybug, *Xenococcus annandalei* Silvestri known to cause damage occasionally by sucking the sap from roots and the affected vines showed reduced vigour, shortening of fruit bearing canes, reduction in size of fruit bunches and yield. (Rajagopal *et al.*, 1997 cited by Mathew and Mani, 2016).

Some mealybugs are known to cause complex plant diseases. Sether *et al.* (1998) reported that closterovirus-like particles associated with mealybug wilt of pineapple were acquired and transmitted by the pink pineapple mealybug, *D. brevipes* and the grey pineapple mealybug, *D. neobrevipes* Beardsley. According to them, mealybugs acquired pineapple mealybug wilt-associated virus (PMWaV) from infected pineapple plants or detached leaves. Jahn *et al.* (2003) also reported that two species of mealybugs, *D. brevipes* and *D. neobrevipes* were associated with wilt disease of pineapple under field conditions.

Bhat *et al.* (2003) recorded association of badnavirus with *F. virgata.* It was established based on the symptomatology, vector transmission, electron microscopy and serology. The virus induced vein clearing, chlorotic flecks, chlorotic mottling along veins and characteristic curling of leaves leading to reduced vigour and yield. The virus was transmitted from diseased to healthy black pepper plants by grafting and through mealybug, *F. virgata.*

The fungal pathogen *Phytophthora capsici* and nematodes such as *Meloidogyne incognita* and *Radopholus similis*, were commonly associated with root mealybug infested vines. At Wayanad and Kozhikode districts of Kerala, all the root mealybug infested vines examined were also infested with *P. capsici* or nematodes or

both. The infested vines exhibited symptoms such as root rotting, absence of feeder roots *etc* (IISR, 2006).

Golino *et al.* (2002) as cited by Cid *et al.* (2010) stated that the main problem caused by the citrus mealybug is the transmission of important grapevine viruses (GVA, GVB, Grapevine leaf roll associated virus GLRaV-1, GLRaV-3, GLRaV-5, and GLRaV-9), even at low infestation levels.

Ferreira *et al.* (2015) reported that pineapple wilt is a complex disease involving the mealybug, *D. brevipes* and pineapple mealybug wilt associated virus -1, 2 and 3.

2.4 BIOLOGY OF ROOT MEALYBUGS

The knowledge on the biology of root mealybugs is limited due to its cryptic habit. Literature available on the biology of *F. polysperes* in India and abroad is meagre. Therefore, the biology of another species of *Formicococcus, F. njalensis* and other root mealybugs *viz., D. brevipes, Planococcus* sp., *Geococcus citrinus, Rhizoecus* sp. and *Cataenococcus* sp. *etc.* are reviewed here.

In general, the longevity of adult females of root mealybugs lasts from 27 to 57 days, which varies according to the species. White, cottony masses of egg-laying females or eggs are normally visible on the outside of the root mass when an infested plant is uprooted from its container. The newly hatched crawlers are highly mobile and are the dispersal stage. Crawlers settle down when they find a suitable site, they and begin to feed on roots. The complete life cycle of a root mealybug lasts for one to four months, depending on the species, climatic conditions, and availability of a food source (Hara *et al.*, 2001).

Ito (1938) studied the biology of pink and grey form of pineapple mealybug, *Pseudococcus brevipes* Ckll. (*D.* brevipes) on pineapple and recorded an average duration of 14, 9.8 and 10.3 days respectively, for the first, second and third instars of pink form. It was found to reproduce parthenogenetically without any males being produced and females lived up to 90 days. The average pre larviposition, larviposition and post larviposition periods of adult females were 27, 25 and 5 days respectively with an average of 234 crawlers produced per female. The duration of developmental

stages in grey form was 14.4, 8.9 and 11.3 days for first, second and third nympal instar, respectively. They reproduced sexually and total life cycle of paired and unpaired females was 95 and 148 days, respectively.

Strickland (1951) reported the biology of another species of *Formicococcus*, namely, *F. njalensis* (*Pseudococcus njalensis*) which reproduced ovoviviparously with low fecundity varying from 6 to 90 crawlers. Life cycle of female of *F. njalensis* included three nymphal instars with an average duration of 7, 5 and 7 days respectively, for first, second and third nymphal instar. The pre oviposition period recorded in *F. njalensis* was an average of 23 days.

Lim (1973) studied the biology of bisexual races of *D. brevipes* and found to have a relatively shorter life cycle than its parthenogenetic form. The female had three nymphal instars with duration of 10, 6.7 and 7.9 days, respectively while male had two nymphal instars, a pre pupal and pupal stage with 9.9, 5.8, 2.5 and 3.7 days, duration respectively. Adult longevity of males and females was 1 to 3 days and 17 to 49 days, respectively. Females reproduced ovoviviparously and produced 19 to 37 crawlers with sex ratio of 1:1. The pre larviposition, larviposition and post larviposition period was 14.6, 9.0 and 4.3 days, respectively.

Adult female of *Rhizoecus hibisci* laid eggs in a waxy ovisac and the number of eggs observed per ovisac were 11 to 84, varying between hosts. On an average the eggs hatched after 9 days. There were four instars in the female and five in the male including two pupal stages. Adult females lived for about a month, whereas the winged adult males were short-lived and rarely observed (OEPP/EPPO, 2005).

There were three instars in the life history of *Planococcus* sp. and males were not recorded. Females were viviparous with the fecundity ranged from 22 to 322 eggs. The pre oviposition and oviposition period ranged from 9 to 21 days and 10 to 40 days, respectively. The eggs were oval and yellowish orange whereas crawlers were light brown and generally took two days for settling. All the instars were flesh coloured immediately after moulting. The duration of first, second and third nymphal instars were ranged from 7 to 12, 4 to 6 and 5 to 9 days, respectively (IISR, 2006).

Three instars were noted in the females of *P. citri*, with duration of 5 to 11, 5 to 12 and 4 to 10 days, respectively for the first, second and third nymphal instars. The fecundity of females was 31 to 310 eggs with a pre oviposition period ranging from 3 to 15 days. The eggs were yellowish orange and laid in ovisac. Crawlers of this species also were light brown. In males there were two instars, prepupal or pupal stages with duration of 5 to 13, 5 to 12 and 4 to 10 days, respectively (IISR, 2006).

The biology of *Cataenococcus ensete* was studied by Addis *et al.* (2008b). They reported that the females were viviparous, and produced an average of 253 nymphs/female. The average duration of the first, second and third instar nymphs was 16.2, 18.15 and 19.75 days, respectively. The average life span of the adult female was 49.95 days.

Mathew *et al.* (2011) studied the biology of *G. citrinus* on sprouted green gram and found that *G. citrinus* is a bisexual species. The life cycle of females included three stages, namely, egg, nymph and adult while that of male consisted of four stages, egg, nymph, pupa and adult. The fecundity was 128. 2 eggs per female. There were three nymphal instars, and the average duration of different life stages was 10.8 days (eggs), 18 days (nymphs) and 5.0 days (pupa). The total life cycle took about 29-34 days. The longevity of adult female was 15.1 days and that of male was 5.0 days. The ratio of male: female was observed to be 1: 22.5.

Sreerag *et al.* (2014) studied the biology of *R. amorphophalli* on different tuber crops and their investigation revealed that the reproduction is sexual and on tubers of elephant foot yam, average fecundity and incubation period were 68.30 crawlers and 7.88 days, respectively. The total life cycle of mealybug including three nymphal instars took 27.10 days for female and 22.40 days for male with an additional pupal stage.

2.4.1. Growth phenology

The peak population of mediterranean vine mealybug, (*Planococcus vitis* (Nied.)) was found to be occur between mid-May and mid-June, followed by a sharp drop during July. A second, smaller peak occurred between October and December and during winter the mealybugs remained beneath the bark of the trunk at a very low

population level (Berlinger, 1977). According to Swirski *et al.* (1980), an annual peak population of *P. longispinus* was noticed in late spring and early summer which declined from autumn to winter and ended in April.

Liu and Chang (1984) observed that the population of *P. citri* on guava was highest during cool and dry months from November to April, and lowest in Warm and wet months from July to September.

Godfrey and Pickel (1998) reported that the root mealybug, *R. kondonis* had three generations per year with peaks of abundance in July-August, December-January and March-April. The root mealybug, *Stictococcus vayssieri* was also reported to be severe in the dry season than in the wet season (Ngeve, 2003). The peak infestation of root mealybugs was noted on black pepper in post monsoon season (IISR, 2006).

Cid *et al.* (2010) reported that the active period of citrus mealybug was from July to December with peak incidence at the end of July and August, and a lower peak in November. The population of *Geococcus* sp. was reported to increase with the commencement of South- West monsoon in June and reached a peak in July, followed by a decline in September, reaching the lower level in January and remained low up to May (Smitha and Mathew, 2010c). Biao (2012) reported that the natural population of pink pineapple mealybug, *D. brevipes* developed faster from October to December in the province of China.

Basavaraju *et al.* (2013) studied seasonal incidence of *D. brevipes* on arecanut and recorded the higher population during the period of December to July and the peak was noticed during March to May. They also observed that the maximum temperature was positively correlated with mealybug populations and the population remained low in the rainy and following winter season (July- December) due to adverse effect of low temperature.

Debojit *et al.* (2013) recorded the incidence of root mealybug, *Paraputo* sp. a pest of mulberry, at monthly intervals for three consecutive years. The mealybug population was low in December-January, increased with rise in temperature and

relative humidity up to rainy season (July-August) and then gradually declined. The peak mealybug population of 50.88 to 52.05 per plant was recorded in August.

Firake *et al.* (2015) reported the incidence of root mealybug, *Formicococcus polysperes* in ginger starting after early August and found increasing till harvesting period (January). Highest population was recorded from October to January, and no infestation was observed in, and before July.

2.5 INFLUENCE OF EDAPHIC FACTORS ON ROOT MEALYBUG INFESTATION

According to Godfrey and Pickel (1998), *R. kondonis* were found at 15.2 to 45.7 cm deep in the soil with an average of 8.3 colonies/1240 cm^3 soil core samples compared with depths of 0 to 15.2 cm with an average of 2.2/sample.

The population density of *C. ensete* was reported to be significantly higher on the roots than on the corms. The mealybugs were found up to a soil depth of 60 to 80 cm from the corm. The root density as well as mealybug population was found to decrease with increase in soil depth. About 99 per cent of the mealybugs and 96 per cent of the roots were collected within the upper 40 cm soil layer. In addition, about 90 per cent of the mealybugs were found within 60 cm radius from the plant (Addis *et al.*, 2008a).

Smitha and Mathew (2010c) recorded maximum population of *Geococcus* sp. within 20 to 40 cm radius followed by 40 to 60 cm, and in the case of vertical distribution, more mealybugs were collected within 20 cm depth. Devasahayam *et al.* (2010) observed root mealybug colonies at a depth of 2 m in severely affected black pepper vines.

2.6 ASSOCIATED ORGANISMS

The literature available on the association of root mealybugs with some microorganisms and ants are presented here.

2.6.1 Association with plant parasitic microbes

Baum (1968) reported that the coffee root mealybugs in Kenya were in association with a semi-parasitic fungus closely related to *Polyporus coffeae* Wakef.

The mealybug, *Planococcoides* sp. infesting roots of mango were found to be enclosed in a parchment like covering produced by a symbiotic fungus (Puttarudriah and Eswaramurthy, 1976). Devasahayam *et al.* (2010) also observed presence of *Phytophthora capsici* in root mealybug infested vines of black pepper.

2.6.2. Association with nematodes

Devasahayam *et al.* (2010) reported *Meloidogyne incognita* and *Radopholus similis* in black pepper vines infested with root mealybug. Two nematodes, *Rotylenchulus reniformis* and *M. javanica* were found to be associated with *D. brevipes* in mealybug wilt affected pineapple plants (Ferriera *et al.*, 2015).

2.6.3 Ant – Mealybug Association

Venkataramaiah and Rehman (1989) reported that nine species of ants were associated with mealybugs on coffee from the Coorg district of Karnataka and the Wayanad district of Kerala, India. The ant species were *Crematogaster* sp., *Tapinoma melanocephalum* (Fabricius), *Anoplolepis longipes* (Jerdon), *Oecophylla smaragdina* Fabricius, *Myrmicaria brunnea* Saunders, *Technomyrmex albipes* Smith, *Acropyga* sp., *Paratrechina longicornis* (Latreille), *Acropyga* sp. and *Plagiolepis* sp.

Eight species of ants, mostly in the three genera *viz., Pheidole, Camponotus,* and *Crematogaster* were found attending cassava mealybug, *Phenacoccus manihoti* Matile-Ferrero in coastal savannah and rainforest zones of Ghana. In most zones, ant densities were positively correlated with mealybug population densities. Ants of these three genera were found to be reducing the rate of parasitism by the exotic encyrtid parasitoid, *Epidinocarsis lopezi* (De Santis) (Cudjoe *et al.*, 1993). *Pheidole megacephala* (F.) was the most common ant species found to be associated with *Dysmicoccus* sp. in Hawaii (Gonzalez – Hernandez *et al.*, 1999). In soybean plants infested by *Dysmicoccus* sp., ants were found to be actively associated with the mealybugs during the summer (Thippaiah and Kumar, 1999).

Ant and mealybug interactions were studied by Jahn and Beardsley (2000) in a pineapple field near Honolua on the island of Maui and Hawaii. *Pheidole megacephala* were found to have a positive association with grey pineapple

mealybug, *D. neobrevipes* but there was no association with pink pineapple mealybug, *D. brevipes*.

Malsch *et al.* (2001) discovered intimate associations of *Pseudolasius* with five species of root mealybugs, *Planococcoides* sp., *Maconellicoccus multipori* (Takahashi) and three species of *Rhizoecus* in West and East Malaysian low land rainforest. All the three *Pseudolasius* species carried their pseudococcids when the pseudococcids are disturbed or during nest movement or during their movement to the feeding sites. Moreover, the *Pseudolasius* sp. permanently kept adults and immature instars of their mealybug partners within their nests.

In the southeast United States, Helms and Vinson (2003) stated that the invasive ant *Solenopsis invicta* Buren is known to derive carbohydrate (honeydew) resources from mealybugs utilizing grasses. Most important among the mealybugs was an invasive mealybug, *Antonina graminis* (Maskell). They found that mealybug occurrence increased significantly with increasing proximity to *S. invicta* mounds.

According to Jahn *et al.* (2003), at least 28 different species of ants were found to be attending mealybugs on pineapple. They reported that *Pheidole and Solenopsis* are the ant genera most commonly associated with pineapple mealybugs throughout the world. Five species of ants *viz., Anoplolepis* sp., *Crematogaster* sp., *Technomyrmex* sp. and two other unidentified species were reported to be associated with root mealybug colonies in black pepper (Devasahayam *et al.,* 2010). According to them, the infested black pepper vines were easily identifiable due to the activity of associated ant species.

Five species of ants *viz., O. smaragdina, Camponotus compressus* Fab., *C. sericius* Fab., *C. refuglaucus* Fab. and *S. geminata* Fab. were found to be associated with *D. brevipes* on arecanut. *O. smaragdina* was the predominant species in influencing the mealybug population in Arecanut (Basvaraju *et al.,* 2013). Feng *et al.* (2015) examined effects of tending by the native mutualistic ant *Tapinoma melanocephalum* on growth of *Phenacoccus solenopsis* Tinsley colonies on Chinese hibiscus, *Hibiscus rosa-sinensis* in field. Survival rate of mealybugs experiencing parasitoid attack was significantly higher on ant-tended plants than

on ant-excluded plants. In most cases, ants directly attacked the parasitoid, causing the parasitoid to take evasive action.

2.7 VARIETAL RESPONSE BY CROPS TO MEALYBUG INFESTATION

The susceptibility of some cocoa varieties to mealybugs, aphids and psyllids were assessed by recording the incidence of pods by these insects. None of the varieties showed significant difference in susceptibility to mealybugs, aphids or psyllids (Frimpong, 1980).

Gopalan *et al.* (1987) evaluated 17 rice varieties for resistance to mealybug, *Brevennia rehi* (Lindinger). According to their observations, infestation ranged from 19.1 per cent in IET 8616 to 58 per cent in AD 85001 and ACM 10 had the highest number of mealybugs per tiller (107.6). Godfrey and Pickel (1998) examined ten lucerne varieties for susceptibility to *R. kondonis* and all the ten varieties were found to be equally susceptible without any significant difference.

The response of six commonly cultivated varieties of banana *viz.*, palayankodan, njalipoovan, poovan, robusta, kodappanillakkunnan and nendran to the root mealybug *Geococcus* sp. were evaluated in field conditions. Out of these six varieties, palayankodan and njalipoovan was completely free from root mealybug infestation and nendran variety had significantly higher population of root mealybugs with an average of 4.38 colonies per sample (Smitha and Mathew, 2010b).

Tohamy *et al.* (2008) proved that the varieties Giza 21/95 and Giza 37/85 were highly susceptible to pink sugarcane mealybug infestation followed by the varieties G.T. 54/9 and Giza 47/88, while the other vatieties, Giza 96/74 and Ph 8013 were less susceptible based on per cent infested internodes and number of mealybug individuals per stalk.

2.8. MANAGEMENT OF ROOT MEALYBUGS

2.8.1 Prevention

The root mealybugs are very difficult to detect and control. Hence, every effort should be made to prevent their spread and establishment. The first resort for

mealybug control is the use or production of clean planting material. According to Addis *et al.* (2008a), proper inspection of roots of newly purchased and slow growing plants should be made to prevent the spread of root mealybugs. Irrigation water should not be allowed from infested area to the uninfested area as the water can act as an agent of dispersal. The alternate hosts which can harbour the mealybugs should be removed from the crop field (Hara *et al.,* 2001) and the infested plants should be properly disposed of, so that all the plant debris decays and no regrowth occurs (Addis *et al.,* 2008a).

2.8.2 Cultural Control

Hara *et al.* (2001) stated that hot-water dips of infested plants are as effective as insecticides against mealybugs. According to them, submerging potted Rhapis palms in water at 120°F (49°C) until the internal root ball temperature reached 115°F (46°C) was 100 percent effective in killing root mealybugs.

Tohamy *et al.* (2008) found that the number of mealybugs per sugar cane plant significantly decreased with the increase in space between the rows. Also burning of dry leaves left in the field integrated with flood irrigation after harvesting sugarcane stubble during March and April, significantly reduced the per cent of infested internodes by 73.5 and 70.2, respectively. While transplanting, planting pits should be left open for about a month so that any mealybug present in or in the vicinity of the planting hole will die of starvation. Repeated ploughing and removal of weeds and grasses in field are believed to eradicate the root mealybugs (Tadesse *et al.,* 2003 cited by Kefelegne *et al.*, 2014).

2.8.3 Biological control

There is poor natural enemy complex, particurlarly natural predators or parasites on root mealybugs (Mathew and Mani, 2016). Literature on occurence of natural enemies against root mealybug is limited. Hence, reports on the natural enemies for aerial mealybugs are also reviewed here.

2.8.3.1 Predators

Gonzalez – Hernandez *et al.* (1999) documented three predators *viz., Lobodiplosis pseudococci* (Felt), *Nephus bilucernarius* Mulsant and *Sticholotis ruficeps* Weise on pineapple mealybug from pineapple fields of Hawaii. Their mean densities ranged from 0.05 to 5.75, 0.1 to 1.8 and 0.05 to 0.2 individuals per plant, respectively.

A dipteran predator *Rhinoleucophenga capixabensis* (Drosophilidae) was described based on specimens collected from pineapple infested with *D. brevipes* in the state of Espírito Santo, Brazil. (Culik and Ventura, 2009).

Devasahayam *et al.* (2010) observed the larvae of *Spalgis* sp. predating on pepper root mealybug colonies. A predator namely *Scymnus* sp. (Coccinellidae: Coleoptera) was found to be feeding on *G. citrinus* (Smitha and Mathew, 2010c).

Tohamy *et al.* (2008) documented predators associated with sugarcane mealybug, *Saccharicoccus sacchari* Cockerell. They recorded the presence of *Scymnus syriacus* Mars. true spiders, *Rodolia cardinalis* (Mulsant), *Orius albidipenis* Reut, *Complomma iticoalsi* Puton, *Paederus alfieri* Koch, *Coccinella undecimpunctata* L., *Geocoris* sp. and *Cydonia vicina* Mulsant.

More than seven species of natural enemies of *D. brevipes* were reported from Leizhou Peninsula by Biao (2012), and the main netural enemies were *Chrysopa formosa* Brauer, *Horniolus hismatsui* Miyatake, *Scymnus (Pullus) tenius* Yang and *Aphidoletes* sp.

Poorani (2015) described *Horniolus sororius* collected from the coffee mealybugs. *Horniolus vietnamicus* Miyatake was found to be predating on the mealybug, *Planococcus lilacinus* infesting coffee (Irulandi *et al.*, 2001).

2.8.3.2 Parasitoids

Anagyrus ananatis Gahan was reported on pineapple, parasitising, *D. brevipes*, the dominant mealybug in the pineapple fields that were surveyed in Hawaii. The parasitization of *D. brevipes* by *A. ananatis* in the presence of ants ranged from

0.3 to 9.9 per cent. *Euryrhopalus propinquus* Kerrich was also found to be parasitising *D. brevipes* and *D. neobrevipes* and per cent parasitization per plant ranged from 0.05 to 2.2 (Gonzalez – Hernandez *et al.*, 1999).

Tohamy *et al.* (2008) identified an encyrtid parasitoid, *Anagyrus saccharicola* Timberlake as a primary endoparasitoid of pink sugarcane mealybug, *S. sacchari.* They recorded highest parasitism during September in plant cane and during August in first rattoon cane.

2.8.4 Microbial control

Murray (1978) observed that the third instar nymphs and adults of *P. citri* on passion fruit was attacked by a fungus similar to *Entomophthora fumosa* Speare and caused up to 58.1 per cent mortality during the period of high rainfall and humidity.

According to Ngeve (2003), successful biological control of root mealybug, *S. vaissieri* could be obtained with rhizosphere inhabiting biocontrol agents such as endomycorhizae.

Four isolates of microbial pathogens namely, *Nomuraea rileyi* (Farl.) Samson, *Verticillium lecanii* (Zimmerman) Viegas, *Metarhizium anisopliae* (Metschn.) Sorokin and *Aspergillus* sp. and four commercial products of microbial pathogens namely, *Paecilomyces* sp., *Beauveria bassiana* (Balsamo) Vuillemin, *V. lecanii*, and *M. anisopliae* were evaluated in laboratory bioassays for their efficacy against root mealybug. According to this report, natural isolates of microbial pathogens caused reduction in population ranging from 24.0 to 32.0 per cent in various treatments at 30 days after spray and commercial products of microbial pathogens caused reduction in population ranging from 9.6 to 13.3 per cent in various treatments at 30 days after spray (IISR, 2006).

The natural infection by fungal pathogen, *Paecilomyces lilacinus* (Thom) Samson on *Geococcus* sp. was reported by Mathew *et al.* (2010). It was pathogenic to both *G. coffeae* and *G. citrinus*. Smitha and Mathew (2010a) found *Cephalosporium lecanii* Zimmerman (*Lecanicillium lecanii*) as the best against *Geococcus* sp. among the three fungi screened, namely, *B. bassiana*, *Hirsutella sp.* and *C. lecanii*. At five

months after planting, treatment with *C. lecanii* recorded 1.95 colonies per sample followed by *Hirsutella* sp. (2.25 / 15 cm^3 soil sample). Smitha and Mathew (2011) isolated *Hirsutella* sp. which was found to cause infection to *G. citrinus* in banana ecosystem of Kerala.

The effectiveness of entomopathogenic fungus, *Isaria farinosa* (Holmsk.) Fries on citrus mealybug, *Planococcus citri* was investigated using four different inoculum densities and different relative humidities (RH). The entomopathogen caused 89.39 per cent mortality of ovisacs, 84.07 per cent mortality of second larval stage, 84.53 per cent mortality of adult females, and 78.71 per cent mortality of first larval stage at 95% RH and at 1 $x10^8$ conidia/ml inoculum concentration. Mortality per cent was found to be decreased with decrease in humidity level and inoculum densities (Demirci *et al.*, 2011).

Lemawork *et al.* (2011) evaluated the isolates of *B. bassiana* and *M. anisopliae* from Ethiopia for their efficacy against *C. ensete* under laboratory, pot and field conditions. Among the tested isolates, two strains (FF and PPRC 56) of *B. bassiana* was highly pathogenic to the adults causing 97 and 100 per cent mortality, respectively at 20 days after inoculation in laboratory condition. The isolates, PPRC 56, FF, PPRC 6 and Mm caused average mortality of 97, 95, 96 and 83 per cent respectively, in pot experiment and 51.33, 38.67, 29.33 and 19.33 per cent at first site and 54, 42.67, 32 and 25. 33 per cent at the second site in the field experiment.

2.8.4.1 Compatibility of microbial agents and chemicals

Cuthbertson *et al.* (2005) tested the compatibility of the entomopathogenic fungus, *Lecanicillium muscarium* (Petch) Zare & W. Gams and chemical insecticides to control the second instar stages of the sweet potato whitefly, *Bemisia tabaci* (Genn.). The effect on spore germination by direct exposure for 24 h to the insecticides imidacloprid, buprofezin, teflubenzuron and nicotine was determined. Acceptable spore germination was recorded only in case of buprofezin. However, all chemicals significantly reduced spore germination when compared to a water control.

Monocrotophos 35 EC, carbendazim 50 WP (0.1%), copper oxychloride (0.3%) and streptocyclin (200 ppm), were tested for its compatibility with *V. lecanii.* Out of these, streptocyclin was found most compatible with *V. lecanii* by recording maximum mycelial growth (61.60 mm) at 20 days after incubation and reduction in dry mycelial weight (9.51%), followed by methyl demeton, thiometon and dimethoate. Monocrotophos, mancozeb and TMTD were incompatible with the biological control agent. Dry mycelial weight reduction was at the extent of 100 per cent (Armarkar and Chikthe, 2008).

Amutha *et al.* (2010) studied the compatibility of *B. bassiana* with twelve insecticides commonly used for cotton pests management and were expressed as per cent growth inhibition. According to them, only chlorpyriphos 20 EC was rated as relatively less toxic, whereas spinosad 45 SC, Econeem 1 per cent, quinalphos 25 EC, acetamiprid 20 per cent, endosulfan 35 EC and thiodicarb 75 WP were slightly toxic. Imidacloprid 17.8 SL and triazophos 40 EC were moderately toxic and profenofos 50 EC, indoxacarb 14.5 EC and methyl demeton were highly toxic.

Mathew *et al.* (2011) studied the compatibility of *Paecilomyces lilacinus* with pesticides commonly used in banana ecosystem. They reported that copper hydroxy chloride (0.3%) and thimet were most compatible chemicals at seven days after inoculation. Among the insecticides, Furadan, neem cake and neem oil were reported to cause lesser per cent inhibition from 5.83 to 13.23 per cent.

Recommended doses of synthetic and botanical pesticides were tested for their compatibility with *Hirsutella* sp. infecting *G. citrinus.* The results showed that phorate and botanicals had lesser effect on fungal mycelial growth while carbendazim and quinalphos caused cent per cent inhibition even after 10 days of inoculation. Carbaryl and chlorpyriphos recorded 53.17 and 51.64 per cent inhibition, respectively followed by dimethoate with 34.17 per cent inhibition (Smitha and Mathew, 2011).

Compatibility of four formulated pesticides *viz.,* imidacloprid, abamectin, dicofol and methamidophos with the entomopathogenic fungus *L. lecanii* strain Y-57 was tested *in vitro* by Gonzalez *et al.* (2013). The concentrations of the pesticides tested were 10, 100, 200, 500, 1000 and 2000 mg/l. Growth inhibition, spore

production capacity and conidial germination of the fungus colony on solid media were evaluated and they classified dicofol as very toxic, methamidophos as lightly toxic and abamectin and imidacloprid as compatible with the entomopathogenic fungus. Dicofol inhibited the conidia germination totally, at all the concentrations studied and methamidophos at the field dose (1000 mg/l). No effect was observed with abamectin or imidacloprid.

XiaoMan *et al.* (2013) tested the compatibility of *V. lecanii* with ten insecticides by determining its sporulation, conidial germination and mycelial growth. According to them, all pesticides had significant influence on conidial germination, mycelial growth and sporulation of the fungus. Imidacloprid 25 WP had the lowest effect on conidial germination with 39.7 per cent of inhibition.

2.8.5 Botanicals in root mealybug management

Hussain *et al.* (1996) recommended neem oil and pongamia oil, both at 4 per cent for the control of *P. citri* on guava, based on a field trial conducted in Karnataka, India. According to them, they caused 93.23 and 89.39 per cent mortality of the pest, respectively at 10 days after second spray which was applied 10 days after the first spray.

Saminathan and Jayaraj (2001) tested the efficacy of botanicals against *F. virgata* by leaf dip method and neem recorded 50 per cent mortality at 72 hours, which was statistically on par with pungam (pongamia) and madhuca oils. Non-edible oils were observed to be more effective (36.67-50.00 per cent) than leaf extracts (26.67-33.33 per cent). At 72 hours, fortified neem oil recorded 63.6 per cent mortality, which was on par with that recorded by 3 per cent neem oil (54 per cent).

Using 1 per cent limonene with 0.75 per cent APSA-80 (all-purpose spray adjuant) and 0.1 per cent silwet L-77 (agricultural surfactant), a semitransparent mixture (primarily a micro emulsion) was found to be safe for most of the plants and provided good control of mealybugs when sprayed or used in one minute dips. When used at half strength, this mixture was reported to control ≥99 per cent of whiteflies, whereas the full strength mixture controlled 69 to 100 per cent of mealybugs and scales, including ≥ 93 per cent control of root mealybugs (Hollingsworth, 2005).

Various neem products *viz.,* Nimbicidine (1%), Neemgold (1%), neem oil (1%) and neem seed kernel extract (5%) caused per cent reduction of 52.6, 17.8, 21.8 and 40.3, respectively in root mealybug population (IISR, 2006).

Among the different botanicals tested against ensete root mealybug, *C. ensete* in the laboratory and pot experiments, 10 per cent seed water suspension of *Mellittia ferruginea* (Hochst.) Baker was toxic to the mealybugs (Tadesse *et al.*, 2010a). Smitha and Mathew (2010a) observed that drenching of neem seed kernel extract (NSKE) at 3 per cent at monthly intervals was superior to neem cake, neem oil and pongamia oil in reducing population of *Geococcus* sp. in banana.

Citronella oil at 5 per cent performed better towards controlling mulberry root mealybug *Paraputo* sp. followed by 5 per cent neem oil and 5 per cent neem leaf extract, without any adverse effect on silkworm rearing (Anonymous, 2011, cited by Mathew and Mani, 2016).

According to Kumar *et al.* (2012), 5 per cent NSKE caused 21.77 per cent reduction of cotton mealybug, *P. solenopsis* population after the third spray application. Basavaraju *et al.* (2013) reported that neem oil at 3 per cent significantly reduced the population of *D. brevipes* in arecanut and recorded 1.07 mealybugs per nut which was on par with pongamia oil at 3 per cent with an average of 1.13 mealybugs per nut.

2.8.6 Chemical control

According to Hamlen (1974), drench applications to infested *Aechmea fasciata* (Lindl.) with altosid, monocrotophos, dimethoate, diazinon, carbofuran and oxamyl were effective against *Rhizoecus floridanus* Hambleton at two weeks after treatment whereas, seventeen weeks after treatments with altosid, monocrotophos, dimethoate and oxamyl, the populations increased. The pineapple mealybug, *D. brevipes* feeding on roots of tomato in Ghana were treated with aldrin 40 D at 3 kg a.i/ha and resulted in the revival of infested plants (Gupta and Norman, 1975).

Murthy and Giridharan (1976) reported that soil application of thiodemeton at 0.5 g/plant and spraying with methyl demeton 0.05% were highly effective against a

severe attack of *Pseudococcus longispinus* on six month old coconut seedlings. Thiodemeton was applied to the soil at monthly intervals for a year against *Planococcoides* sp. in mango and the affected plants which had suffered dessication and leaf fall, showed signs of revival.

Eight insecticides were tested against root mealybugs, *G. coffeae* and *R. nemoralis* in coffee. Out of these, endosulfan and carbofuran both at 0.33 g/m^3, Mocap and Dacamox both at 0.26 g a.i/m^2, were reported as effective (Berrios and Hanania, 1979 as cited by Smitha, 2007). Hara *et al.*, (2001) stated that the chemical control of root mealybugs requires saturation of the root ball and potting medium to a level that allows the pesticide to penetrate the waxy secretion of mealybugs. Research has demonstrated that dipping or drenching with liquid insecticide is more effective than applying a granular formulation.

Enset plants infested with root mealybug (*Paraputo* sp.) in Ethiopia were treated with different insecticides and Phostoxin (aluminium phosphide) tablets and Phyrinex 48EC (chlorpyriphos) resulted in mean pseudostem circumference increase of 23.23 and 32.34 cm and in mean plant height increase of 71.09 and 58.11 cm, respectively, over the control (Bekele, 2001).

Eleven insecticides were evaluated in various concentrations in laboratory against root mealybug, *Planococcus* sp. in black pepper and indicated that imidacloprid 0.005%, acetamiprid 0.005% and carbosulfan 0.005% were more promising, resulting in over 90 per cent reduction in population of root mealybug at 30 days after treatment. Evaluation of promising insecticides in the field indicated that drenching the affected vines with imidacloprid 0.0125%, acetamiprid 0.0125% or carbosulfan 0.075% were effective in reducing the population of root mealybugs up to 60 days after treatment (IISR, 2006).

DeSouza *et al.* (2007) tested two neonicotinoid insecticides *viz.*, imidacloprid and thiamethoxam for their efficacy against coffee root mealybug, *Dysmicoccus taxensis* Tinsley and result showed that both insecticides in single application caused 100 per cent mortality independent of the age of plants. Among various synthetic chemicals, drenching of chlorpyriphos (0.05%) at monthly intervals @ 2.5 ml/l

effectively reduced the root mealybug population in banana and was found to be the best treatment (Smitha and Mathew, 2010b).

Tadesse *et al.* (2010b) evaluated six synthetic insecticides against ensete root mealybug. Among these, diazinon 60 EC and chlorpyriphos 48 EC caused at least 98 per cent mortality both under field and greenhouse conditions. Application of other insecticides *viz.,* endosulfan, dimethoate, fenitrothion and malathion caused 74.0, 65.0, 77.0 and 83.0 per cent mortality, respectively in green house and 51.0, 65.0, 51.0 and 50.0 per cent respectively, in the field trial.

In the field trials conducted in commercial vineyards against *Pseudococcus* sp., two neonicotinoid insecticides *viz.,* imidacloprid and SCAL 5085 were applied as soil drenching. Imidacloprid applied at 0.525 g a.i/vine reduced mealybug abundance by more than 99 per cent in the first trial whereas in the second trial, treatment applied in winter, SCAL 5085 applied at 0.263 g a.i/vine provided control equivalent to imidacloprid (Lo and Walker, 2011).

Drenching the affected vines with 0.075 % chlorpyriphos is effective in controlling the pepper root mealybug infestation in India and suggested a repeated drenching after 20 to30 days in case of persistent infestation (Mathew and Mani, 2016).

Materials and methods

3. MATERIALS AND METHODS

The present investigation on "Bionomics and management of root mealybug on black pepper" was carried out during the year 2013-16. The investigation included documentation of root mealybugs and associated fauna, study on the biology of the most common species, susceptibility of popular pepper varieties to the pest and its management. Materials used and methods employed for these studies are presented in this chapter.

3.1 DOCUMENTATION OF ROOT MEALYBUGS AND OTHER ASSOCIATED FAUNA

Purposive surveys were conducted during 2013-14 in Kannur, Wayanad and Idukki districts of Kerala where root mealybug infestation was reported previously, to document the species diversity of root mealybugs, the level of infestation on black pepper, to find out the collateral hosts and to identify the natural enemies associated with these mealybugs.

3.1.1 Preliminary survey for the identification and documentation of root mealybug species in black pepper

A preliminary survey was conducted in different panchayats of Kannur, Wayanad and Idukki districts from August to December 2013 to collect the root mealybugs infesting black pepper. The panchayats were selected based on the informations provided by the Officers of Department of Agriculture, Vegetable and Fruit Promotion Council of Kerala (VFPCK) and M. S. Swaminathan Research Foundation (MSSRF).

3.1.1.1 *Sample collection*

Infested vines were easily identified by the presence of ant colonies at the base of vines and yellowish discolouration of the foliage. The soil close to the roots was removed to a length of 15 cm to collect the mealybugs present on roots. Root mealybugs were collected separately from the infested vines of different locations in Wayanad and Idukki districts and preserved in 70 per cent ethyl alcohol for further investigation.

3.1.1.2 *Identification of root mealybug species*

Adult mealybugs were collected from infested black pepper vines at Wayanad and Idukki districts and preserved in 70 per cent ethyl alcohol in small vials of 5ml capacity. These were sent to Dr. Sunil Joshi, Principal scientist, National Bureau of Agricultural Insect Resources (NBAIR), Bengaluru, for identification.

3.1.2 Distribution of root mealybugs on black pepper vine

All the parts of black pepper vine, both below ground and above ground portions were thoroughly examined for root mealybug colonies so that their distribution along the vine could be studied. This was done throughout the study period.

3.1.3 Symptoms

The aerial and below ground symptoms of the root mealybug infested vines were observed throughout the study period.

3.1.4 Incidence of root mealybugs on black pepper with respect to varieties, standards used and age of the vine.

The variety, standards used for trailing and the age of infested black pepper vines were observed during the preliminary survey and per cent infestation of root mealybug was calculated with respect to these parameters.

3.1.5 Extent of root mealybug infestation in Wayanad and Idukki districts, Kerala

During the survey, the root mealybug infestation was not observed in Kannur district, hence, the present study was conducted only in Wayanad and Idukki districts of Kerala. Level of infestation of root mealybugs in black pepper was assessed for one year at monthly intervals from August 2013 to July 2014 in selected panchayats of Wayanad and Idukki districts, Kerala.

3.1.5.1 *Selection of panchayats*

Based on the preliminary survey, two pepper growing panchayats severely infested with root mealybugs were selected. The assessment of infestation level was done from August 2013 to July 2014 at monthly intervals in the selected panchayats.

3.1.5.2 *Assessment of level of root mealybug infestation*

From each panchayat, one pepper garden was selected and divided into three divisions and in each division 20 plants were selected at random for observations. Observations on 60 plants in each infested garden were recorded and per cent of infested vines in each location and in each district was calculated.

3.1.5.3 *Statistical analysis*

The data on per cent infestation in each district was subjected to ANOVA in Completely Randomised Design and the means were tested by the Duncan's Multiple Range Test (DMRT) to study the peak period of root mealybug infestation.

3.1.6 Identification of natural enemies

During survey, the root mealybug infested roots were examined thoroughly for the presence of natural enemies. Root samples were collected from different locations and brought to the laboratory for observing the presence of natural enemies. These observations were taken throughout the study period.

3.1.6.1 *Predator*

The predatory coccinellid grub obtained was reared to its adult stage and identified by Ms. Vidya C. V. and Dr. Haseena Bhasker, Dept. of Agricultural Entomology, College of Horticulture, Vellanikkara. The identification was confirmed by Dr. Poorani J., Principal Scientist, NRC Banana, Trichy, Tamil Nadu.

3.1.7 Collateral hosts

Root mealybug infestation was examined in weeds and other crops grown in and around the infested pepper garden to document their collateral hosts. Presence of mealybug colonies was observed after uprooting the plants. These observations were recorded throughout the investigation.

3.1.7.1 *Identification of collateral host*

Collateral hosts such as weeds and crop plants were identified by Dr. C. George Thomas, Dept. of Agronomy, College of Horticulture,Vellanikkara.

3.1.8 Associated organisms

During survey, the association of root mealybugs with other organisms like fungi, nematodes and ants were observed.

3.1.8.1 *Fungi*

Root samples of infested and healthy vines which were showing the symptoms of root rotting were collected and bought to the laboratory for observing the presence of fungi. Root bits were kept in cold water for 24 hours and incubated in low temperature to check the development of sporangia of *Phytophthora* sp. The isolation of microorganisms if any, associated with the root sample was carried out on Potato Dextrose Agar (PDA) medium by standard protocol.

3.1.8.2 *Nematodes*

Soil samples were collected from the root zone of infested pepper vines of the selected pepper garden and assessed the population of nematodes by using Cobb's decanting and sieving technique (Cobb, 1918). The nematode species was identified by Dr. Susannamma Kurien, Department of Agricultural Entomology, College of Horticulture, Vellanikkara. Nematode population was assessed by counting the number of nematodes.

3.1.8.3 *Ants*

Ants present in the rhizosphere of infested vines were collected separately in a polythene cover along with the soil. The ants were separated out in laboratory and preserved in 70 per cent ethyl alcohol in small glass vials of 5ml capacity. These preserved samples were sent to Dr. K. A. Karmaly, Taxonomist, Dept. of Zoology, St. Xavier's College for Women, Aluva, Ernakulam district and got identified.

3.1.9 Population dynamics of root mealybugs on black pepper

Population dynamics of root mealybugs was studied in an infested pepper garden in Mananthavady panchayat of Wayanad district, Kerala. The crop was kept free from insecticidal applications during the period of study. Observations were made from February 2015 to January 2016 at monthly interval.

Sixty vines were selected at random and tagged. Observations were made on these tagged vines at monthly intervals. The mealybugs present on 15 cm root length were recorded and expressed as number of mealybugs per 15 cm root length.

3.1.10 Correlation of root mealybug population with soil and weather parameters

Minimum and maximum soil temperature, soil moisture and rainfall data were recorded during the experiment period to study the relationship between the mealybug population and soil and weather parameters using correlation analysis.

3.1.10.1 *Soil temperature*

Minimum and maximum soil temperature was recorded daily by installing a soil thermometer in the garden and the monthly mean was calculated using the formula given below:

$$\text{Monthly mean temperature} = \frac{\text{Sum of temperature for a month}}{\text{Number of days in respective month}}$$

3.1.10.2 *Soil moisture*

Soil moisture was estimated by gravimetric method. Soil samples were collected in air tight plastic containers of size 500 ml. Fresh weight of soil was recorded and dried in hot air oven. Weight of the dried soil was recorded daily till it reached a constant weight. Soil moisture was expressed in per cent and was calculated using the following formula,

$$\text{Soil moisture (\%)} = \frac{\text{Weight of fresh soil} - \text{weight of dry soil}}{\text{Weight of dry soil}} \times 100$$

3.1.10.3 *Rainfall*

The monthly rainfall was collected from Coffee Research Station, Chundale, Wayanad.

3.2 BIOLOGY OF THE ROOT MEALYBUGS

Biology of the dominant species of root mealybug obtained during the survey was studied in the laboratory of Department of Agricultural Entomology, College of Horticulture, Vellanikkara. Two noded pepper cuttings were used as the substrate for the study. The temperature during the study period ranged from 29.46° C ± 0.4° C and relative humidity was 73.52 ± 6.97 per cent.

3.2.1 Laboratory rearing of mealybugs

Mature pumpkin fruits with abundant grooves were used as the substrate for mass rearing of mealybugs. Fresh pumpkin fruits were washed thoroughly using water, disinfected with 0.1% carbendazim and air dried. Such pumpkins were tied with twine along the grooves for providing grip to the released mealybugs and kept in aluminium netted insect rearing cages. Rearing cages were kept at temperature of 27-28°C. Ant pans were maintained to prevent the entry of ants into the cage. The adult mealybugs collected from pepper fields were released at the stalk region of pumpkin and covered with a steel bowl for seven days to provide darkness and to restrict the movement of mealybugs so that they will settle easily. The bowl was taken out after the settling down of mealybugs on the pumpkin fruit (Plate 1).

3.2.2 Biology of *Formicococcus polysperes*

Formicococcus polysperes was the dominant species of root meaybug obtained during the survey. Fecundity, reproductive period, developmental period, number of nymphal instars and adult longevity of *F. polysperes* were studied on pepper cuttings in the laboratory. Morphometrics of different life stages were also recorded.

a. Pumpkin fruit with bowl kept for easy settlement of mealybugs

b. Infested Pumpkin fruit after the removal of bowl

c. Mealybug colonies multiplied on pumpkin

d. Rearing cage

Plate 1: Laboratory rearing of root mealybug, *Formicococcus polysperes*

3.2.2.1 *Eggs*

Adult females were released on cut portions of pepper cuttings (runner shoots) with at least one node using camel hair brush. The pepper cuttings were kept in Petri plates lined with a layer of wet absorbent cotton and observed daily for egg laying.

3.2.2.2 *Nymphal instars*

One day old first instar nymphs (crawlers) were released on pepper cuttings. Nymphs used for the study were taken from single female. The pepper cuttings were kept in Petri plates lined with a layer of wet absorbent cotton and observed daily for recording the number and duration of nymphal instars. Moulting was confirmed by examining the presence of exuviae under stereoscopic microscope and removed after each moult. Twenty replications were observed.

3.2.2.3 *Adults*

The colour and shape of adult females and males were observed under Stereo Zoom microscope.

3.2.2.4 *Pre oviposition period*

Adult females after final molting were kept separately on pepper cuttings and observed regularly till the oviposition was started.

3.2.2.5 *Oviposition period*

Adult female mealybugs which started oviposition were kept separately and observed till the end of oviposition. Twenty replications were maintained.

3.2.2.6 *Post oviposition period*

Adult female mealybugs were observed regularly from the day it stopped ovipostion till death and post oviposition period was calculated. Twenty replications were maintained.

3.2.2.7 *Fecundity*

Adult females were observed daily to record the number of young ones produced. Nymphs delivered were removed daily to avoid repeated counting.

3.2.2.8 *Sex ratio*

Nymphs from each female were maintained separately and observed till the males and females can be distinguished so that sex ratio can be calculated. The nymphal instar forming cocoons were separated as males. Twenty relications were maintained.

3.2.2.9 *Adult longevity*

Females and males were observed separately from emergence to death of adults and longevity was calculated.

3.2.3 Morphometry of *Formicococcus polysperes*

Morphometric characters of all stages were measured using Stereo Zoom microscope (Lieca®) with image analyzer facility. Body length and width of twenty individuals of all the stages were measured to determine the average body size. Length was measured dorso-medially by taking the longest length of the insect from the head to the tip of the abdomen. Width was measured from middle region *i.e.* widest part of body.

3.3 SUSCEPTIBILITY OF POPULAR PEPPER VARIETIES

Four popular varieties of black pepper were evaluated to test their susceptibility to root mealybug, *F. polysperes.* The pepper varieties tested were Panniyur-1, Panniyur-2, Panniyur-8 and Karimunda. The experiment was conducted at College of Horticulture, Vellanikkara and laid out as pot experiment in Completely Randomized Block Design. The pepper varieties were collected from pepper unit, College of Horticulture, Kerala Agricultural University. One month old pepper seedlings were used for the experiment. Four replications were maintained for each variety and three plants were maintained per replication. Five gravid females were released at the collar region of pepper seedlings using a camel hair brush. Observations were recorded after 45 days of release and number of progenies were recorded by destructive sampling.

3.3.1 Statistical analysis

The data on number of progenies on different varieties was analysed statistically and the means were compared by Duncan's Multiple Range Test (DMRT).

3.4 EVALUATION OF ENTOMOPATHOGENIC FUNGI AGAINST ROOT MEALYBUG

Efficacy of four entomopathogenic fungi *viz., Beauveria bassiana* (Balsamo) Vuillemin, *Lecanicillium lecanii* (Zimm.) Zare & W.Gams, *Metarhizium anisopliae* (Metschnikoff) Sorokin and *Paecilomyces lilacinus* (Thom) Samson at three different doses of 2 $x10^6$, 2 $x10^7$ and 2 x 10^8 spores/ml were evaluated against root mealybug, *F. polysperes*. Both laboratory and pot culture experiments were conducted in Completely Randomized Design with 13 treatments and three replications. The treatment details are given in Table 1.

Broth culture of *B. bassiana* and *L. lecanii* was collected from AICRP on Biological Control of Crop Pests and Weeds, Vellanikkara and that of *M. anisopliae* and *P. lilacinus* was collected from Banana Research Station, Kannara. Broth culture with thick fungal mat were ground thoroughly in ordinary mixer to prepare spore suspension and filtered through double layered muslin cloth to remove the mycelial mat. The suspension was shaken thoroughly with a drop of teepol for the uniform dispersion of spores (Saranya *et al.*, 2010).

The spore count of the stock culture was determined using Haemocytometer (Lomer and Lomer, 1996) and the spore concentration was calculated using the formula,

$$\text{Number of spores/ml} = \frac{X \times 25 \times 10 \times 1000 \times D}{Y}$$

Where, X = Number of spores counted totally in big squares

Y = Number of big squares counted

D = Dilution factor

Table 1: Entomopathogenic fungi evaluated against root mealybug, *Formicococcus polysperes*

Treatments	Concentration (Spores/ml)
T_1: *Beauveria bassiana*	2×10^6
T_2: *B. bassiana*	2×10^7
T_3: *B. bassiana*	2×10^8
T_4: *Lecanicillium lecanii*	2×10^6
T_5: *L. lecanii*	2×10^7
T_6: *L. lecanii*	2×10^8
T_7: *Metarhizium anisopliae*	2×10^6
T_8: *M. anisopliae*	2×10^7
T_9: *M. anisopliae*	2×10^8
T_{10}: *Paecilomyces lilacinus*	2×10^6
T_{11}: *P. lilacinus*	2×10^7
T_{12}: *P. lilacinus*	2×10^8
T_{13}: Control (Teepol)	0.1%

The required concentrations of fungi were made from the stock culture by serial dilution technique (Waksmen and Fred, 1922).

3.4.1 *In vitro* evaluation of entomopathogenic fungi

Four species of entomopathogenic fungi at three different concentrations (2 $x10^6$, 2 $x10^7$ and 2 x 10^8 spores/ml) were tested in the laboratory. Three replications were maintained for each treatment. Single noded pepper cuttings surface sterilized with 1% sodium hypochlorite solution were kept in Petri dishes lined with moist tissue paper at the bottom. Ten third instar mealybug nymphs were released in each Petri dish and spore suspension of each entomopathogenic fungi at each concentrations were applied on pepper cuttings @ 1ml per Petri dish. Teepol solution (0.1 per cent) was used as control. All Petri dishes were covered in polythene bags and tied tightly to provide humidity. Mortality of *F. polysperes* was recorded at five and seven days after inoculation. The dead mealybugs were observed daily for the development of fungal growth and reisolation of pathogen associated with the dead mealybug was done to prove the pathogenicity.

3.4.2 Evaluation of entomopathogenic fungi against root mealybug, *Formicococcus polysperes* in pot experiment

One month old pepper seedlings of Panniyur-2 variety were used for the experiment. Pepper seedlings were planted in grow bags (20 x 15 cm) filled with potting mixture. These grow bags were kept under shade. The experiment was laid out in completely randomised design. Three replications were maintained for each treatment and six grow bags were maintained for each replication (Plate 2). Twenty five third instar mealybug nymphs were released at collar region of pepper seedlings using a camel hair brush. Treatments were applied as drenching. Drenching volume required for each grow bag was estimated prior to application and spore suspension was prepared for the estimated volume. Treatments were applied after one week of insect release and were given two times at one week interval. Observations on mortality were taken at one week after each application by destructive sampling. Three plants were sampled for each observation.

Plate 2: Layout of Pot culture experiment

3.4.3 Statistical analysis

Mortality per cent was calculated and analysed statistically by ANOVA. Treatment means were compared by Duncan's Multiple Range Test (DMRT).

3.5 EVALUATION OF CHEMICAL INSECTICIDES AGAINST ROOT MEALYBUG

Eight chemical insecticides were tested against the root mealybug, using the same procedure as mentioned in section 3.4.2. An untreated control was also maintained. The insecticides used and their doses are given in Table 2.

3.5.1 Statistical analysis

Per cent mortality was calculated and analysed statistically by ANOVA and treatment means were compared by Duncan's Multiple Range Test (DMRT).

3.6 COMPATIBILITY OF EFFECTIVE ENTOMOPATHOGENIC FUNGUS WITH INSECTICIDES

The most effective entomopathogenic fungus against the root mealybug, *F. polysperes* selected from the pot culture experiment was tested for its compatibility with all the insecticides used in screening experiment and two important fungicides which were commonly used for disease management in pepper. The test was carried out by poisoned food technique (Falck, 1907) and the treatment details of the experiment is given in Table 3.

Potato Dextrose Agar (PDA) medium was used for the study and 100 ml of PDA medium was sterilized separately in 250 ml conical flask. The chemicals used for testing were sterilized under UV light by placing it in laminar air flow. The required quantity of each chemical was added aseptically to the PDA medium separately to get the required concentration and transferred to sterile Petri plates. The entomopatogenic fungus (7mm disc) from an actively growing 10 days old culture was inoculated at the centre of the Petri plates using a sterile inoculation needle. PDA medium inoculated with fungus alone, served as control. The Petri plates were incubated under room temperature for fungal growth. Observations were taken at five, seven and ten days after inoculation. Three replications were maintained for each treatment.

Table 2: Insecticides tested against root mealybug, *Formicococcus polysperes*

Treatments	Insecticides	Dose
T_1	Bifenthrin 10 EC	60 g a.i/ha
T_2	Fipronil 5 EC	25 g a.i/ha
T_3	Imidacloprid 17.8 SL	25 g a.i/ha
T_4	Thiacloprid 21.7 SC	30 g a.i/ha
T_5	Thiamethoxam 25 WG	25 g a.i/ha
T_6	Emamectin benzoate 5 SG	6 g a.i/ha
T_7	Cartap hydrochloride 50 SP	500 g a.i/ha
T_8	Chlorpyriphos 20 EC	300 g a.i/ha
T_9	Control	

Table 3: Insecticides and fungicides used in testing of the compatibility of entomopathogenic fungus, *Lecanicillium lecanii*

Treatments	Insecticides/ fungicides	Dose
T_1	Bifenthrin 10 EC	60 g a.i/ha
T_2	Fipronil 5 EC	25 g a.i/ha
T_3	Imidacloprid 17.8 SL	25 g a.i/ha
T_4	Thiacloprid 21.7 SC	30 g a.i/ha
T_5	Thiamethoxam 25 WG	25 g a.i/ha
T_6	Emamectin benzoate 5 SG	6 g a.i/ha
T_7	Cartap hydrochloride 50 SP	500 g a.i/ha
T_8	Chlorpyriphos 20 EC	300 g a.i/ha
T_9	Copper hydroxide 77 WP	1%
T_{10}	Carbendazim 50 WP	0.1%
T_{11}	Control	

3.6.1 Radial growth of fungal colony in poisoned media

Observations on radial growth of fungus in each treatment and control were measured at five, seven and ten days after inoculation using a ruler.

3.6.2 Per cent inhibition of growth of *Lecanicillium lecanii* in poisoned media

Per cent inhibition of the fungal growth in the poisoned media was calculated using the following formula (Vincent, 1927).

$$\text{Per cent inhibition} = \frac{C - T}{C} \times 100$$

Where, C = diameter of fungal growth in control

T = diameter of fungal growth in treatment

3.6.3 Sporulation

Ten ml of sterilized water with 0.1 per cent Tween 80 was added to each 10 days old culture plate of entomopathogenic fungus and gently rubbed the culture surface with the help of a sterilized spatula to prepare the spore suspension. Suspension from all fungal plates were collected in a 50 ml beaker and mixed thoroughly to get a homogenized mixture (Ujjan and Shahzad, 2012). The spore count in each suspension was recorded using the procedure mentioned in 3.4.

3.6.4 Spore viability

The spore viability was determined by spread-plate method. One ml of spore suspension (adjusted to 1 x 10^6 spores/ml) was spread plated on PDA plates. Three sterile microscope cover slips were placed on each plate and plates were incubated at room temperature and observed after 24 h under phase contrast microscope. The spores with germ tube were counted as germinated and the per cent germination or viability was determined from 100 spore counts on each cover slip (Ekesi *et al.*, 1998).

3.7 MANAGEMENT OF ROOT MEALYBUG IN POT CULTURE EXPERIMENT

The best treatments from the screening tests of entomopathogenic fungi (EPF) and chemical insecticides were evaluated alone and in combination of EPF and insecticides along with the common practice adopted by farmers against the root

mealybug, *F. polysperes*. An untreated control was also maintained. The experiment was laid out as pot experiment by planting pepper seedlings in grow bags as given in 3.4.2. The treatment details are as follows.

T_1 – entomopathogenic fungi

T_2 – chemical insecticide (I)

T_3 – chemical insecticide (II)

T_4 – chemical insecticide (I) + entomopathogenic fungi

T_5 – chemical insecticide (II) + entomopathogenic fungi

T_6 – neem cake (20 g/ bag) + Azadirachtin 1%

T_7 – untreated control

Three replications were maintained for each treatment. Treatment applications were given twice at weekly interval from one week after insect release. Observations on mortality of root mealybugs, *F. polysperes* were recorded after a week of each application.

3.8 FIELD EVALUATION OF EFFECTIVE TREATMENT

The effective treatment from the pot culture experiment was evaluated in the root mealybug infested field. Its efficacy was compared with that of chlorpyriphos as it was commonly used insecticide against mealybugs. Farmer's field at Kaniyambetta panchayat of Wayanad district was selected for the field evaluation. The experiment was laid out in Exploded Block Design in which two insecticide treatments were compared with the control. The whole pepper garden was divided into three blocks and each block was allotted for each treatment. Twenty one plants were selected in each tratment. Vines infested with root mealybugs were tagged and the number of root mealybugs on root up to 15 cm length was recorded. The treatments were applied as drenching at the rate of five litres per each vine. All the vines in each block were drenched with respective treatments. The vines in control block was drenched with five litres of water. The drenching was given two times at weekly interval. Observations on mealybug population were taken after a week of each application and

pre-treatment count was taken before each treatment application. The efficiency of treatments were expressed in terms of per cent reduction in mealybug population.

3.8.1 Statistical analysis

The treatment means were subjected to independent 't' test and was compared with corresponding 't' value.

Results

4. RESULTS

The results of the investigation on "Bionomics and management of root mealybug on black pepper" conducted in College of Horticulture, Vellanikkara and in farmer's field at Wayanad and Idukki districts, Kerala during 2013-2016 are presented in this chapter.

4.1 DOCUMENTATION OF ROOT MEALYBUGS AND OTHER ASSOCIATED FAUNA

A preliminary survey was conducted during 2013-14 in different panchayats of Kannur, Wayanad and Idukki districts to collect the root mealybugs on black pepper. Total number of panchayats surveyed included four panchayats in Kannur, six panchayats in Wayanad and five panchayats in Idukki district. Three black pepper gardens were surveyed from each panchayat. No infestation was observed in Kannur district. The details of the panchayats surveyed for documentation of root mealybugs are furnished in Table 4.

4.1.1 Identification of root mealybug species

The root mealybug samples collected from the infested pepper gardens were identified by the coccidologists of National Beaurue of Agricultural Insect Resources, Bengaluru. The identification results showed that three species of root mealybugs namely, *Formicococcus polysperes* Williams, *Dysmicoccus brevipes* (Cockerell) and *Pseudococcus* sp. were found to be infesting black pepper (Plate 3).

Among the three species, *F. polysperes* was the dominant species in both districts and was collected from all the infested gardens that were surveyed. *Pseudococcus* sp. was collected from Kaniyambetta panchayat of Wayanad and Nedumkandam panchayat of Idukki district. *D. brevipes* was collected only from Mananthavady panchayat, Wayanad.

4.1.1.1 *Formicococcus polysperes* Williams

Formicococcus polysperes belong to the family Pseudococcidae which was originally described from the specimens collected from the roots of *Macaranga triloba* in Malaysia.

Table 4: List of panchayats and locations of pepper gardens visited during preliminary survey

Districts	Panchayats	Locations	No. of gardens visited	Presence or absence of root mealybug infestation	Root mealybug species
Idukki	Santhanpara	Santhanpara	2	Present	*Formicococcus polysperes*
		Pallikkunnu	1	Absent	-
	Thopramkudi	Thopramkudi	2	Present	*Formicococcus polysperes*
		Murikkassery	1	Absent	-
	Kumily	Valiyakandam	1	Absent	-
		Kumily	2	Present	*Formicococcus polysperes*
	Vandiperiyar	Vandiperiyar	1	Absent	-
		Vallakkadavu	1	Absent	-
		Thengamala	1	Present	*Formicococcus polysperes*
	Nedumkandam	Nedumkandam	1	Present	*Formicococcus polysperes* *Pseudococcus* sp.
		Kallar	1	Absent	-
		Thannimoodu	1	Absent	-
Wayanad	Edavaka	Edavaka	1	Absent	-
		Kammanam	2	Present	*Formicococcus polysperes*
	Ambalavayal	Vaduvanchal	1	Absent	-
		Aayiramkolly	1	Absent	-
		Ambalavayal	1	Present	*Formicococcus polysperes*

Contd.

	Mullankolly	Padichira	1	Present	*Formicococcus polysperes*
		Mullankolly	1	Absent	-
		Shed kavala	1	Absent	-
	Pulpally	Kalluvayal	1	Absent	-
		Aaloorkunnu	2	Present	*Formicococcus polysperes*
	Kaniyambetta	Kariyampadi	2	Present	*Formicococcus polysperes* *Pseudococcus* sp.
		Karani	1	Absent	-
	Mananthavady	Valliyoorkkavu	1	Present	*Formicococcus polysperes* *Dysmicoccus brevipes*
		Koyileri	1	Absent	-
		Payyampalli		Absent	-
Kannur	Kurumathur	Panniyur	2	Absent	-
		Pullanniyodu	1		
	Kolachery	Kambil	1		
		Kolacheri	1		
		Palliparambu	1		
	Naduvil	Naduvil	2		
		Kaithalam	1		
	Aalakkode	Chittadi	1		
		Aalakkode	2		

a. *Formicococcus polysperes* (25x)

b. *Dysmicoccus brevipes* (20x)

c. *Pseudococcus* sp. (20x)

Plate 3: Species of root mealybugs infesting black pepper

These are known to infest below ground portions of the crops like roots, tubers and rhizomes. Adult mealybugs are oval and pink coloured with white waxy secretion on the dorsal body surface. Lateral waxy filaments are present surrounding the body margin and are short and broad. The length and width of the adult is 2.65 mm and 1.56 mm, respectively. Adult female of this species is ovoviviparous.

The main taxonomic characters of this species are the presence of multiple conical setae in most of the abdominal cerarii including anal lobe cerarii. A total of 18 pairs of cerrii are present. Anal bar is also present. Other characters are the presence of ventral oral collar tubular ducts on lateral of front coxa and also on head. The dorsal setae are conical and transluscent pores are present on hind coxa and tibia. Ventral multilocular disc pores are present in medial areas of abdominal segments IV to VIII (Firake *et al.,* 2015).

4.1.1.2 *Dysmicoccus brevipes* (Cockerell)

Dysmicocccus brevipes is commonly known as the pineapple mealybug and was originally described from specimens collected from pineapple in Jamaica. *Dysmicocccus brevipes* is oval, pink coloured mealybug with waxy coating. The wax filaments along the body margin is short and slender. Length of the adult is 2.05 mm and width is 1.36 mm. Adult female is viviparous.

The main taxonomic characters are the presence of 17 pairs of cerarii on dorsum and anal lobe cerarius with two moderately large conical setae, several slender auxiliary setae, slight cluster of trilocular pores and with slight sclerotisation of surrounding area. Discoidal type pores of variable size are present with reticulated centers scattered on dorsal surface from ninth abdominal segment to head. Tubular ducts are absent. Oral collar tubular ducts in the mid region of abdominal segments.Transluscent pores are present on hind femur and tibia (Mckenzie, 1967).

4.1.1.3 *Pseudococcus* sp.

The mealybugs of genus *Pseudococcus* generally occur on the above ground plant parts like foliage, twigs and bark. Some subterranean species are also known. The species of this genus normally produce ovisac and are oviparous. Generally 16 or

17 pairs of waxy filaments from the head to the tip of abdomen. The posterior pair of filaments are normally longest and decrease in length anteriorly to the head (Mckenzie, 1967).

This species was characterized by greyish colour and oval shaped body with powdery wax on the dorsal body surface. Short and slender waxy filaments were present along the margin with a pair of long and slender waxy caudal filament. Length and width of the adult mealybug is 2.58 mm and 1.43 mm, respectively.

4.1.2 Distribution of root mealybugs on black pepper vines

Root mealybugs were found to colonize on roots and below ground stem region of black pepper vines. But during the peak period of infestation, the root mealybugs, *F. polysperes* were also found on the adventitious roots at leaf nodes with which they attach to the standards. Colonies of *F. polysperes* were also observed on the runner shoots when it touches the soil (Plate 4).

4.1.3 Symptoms

The aerial symptoms manifested on the black pepper vine by the root mealybug infestation was the yellow discolouration of the foliage. The leaf colour was pale green in case of minor infestation whereas the leaves turned yellow in severe cases of infestation. In some infested vines, a gall like thickening was observed on runner shoots with root mealybug colonies. The infested vines were colonized by different species of ants in the rhizosphere by which the infestation could be easily identified (Plate 5).

4.1.4 Incidence of root mealybugs on black pepper in Wayanad and Idukki districts, with respect to varieties, standards used and age of the vine.

The variety, standard used for trailing and the age of infested black pepper vines were observed during the preliminary survey and per cent of root mealybug infestation was calculated with respect to these parameters and the results are presented in Table 5a, 5b and 5c, respectively.

With respect to the varieties of black pepper, highest per cent of root mealybug infestation was observed in the variety, Panniyur-1 in Wayanad (44.83) and Idukki

a. Mealybug colonies on pepper root

b. Mealybug colonies on basal stem

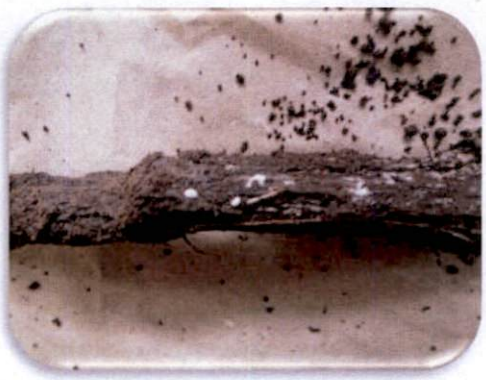
c. On runner shoots

d. Mealybug colonies on leaf nodes

Plate 4: Distribution of root mealybugs on black pepper vine

a. Pale green coloured leaves in minor infestation

b. Yellow leaves in severe infestation



c. Root mealybug colonies on pepper root

d. Gall like thickening on runner shoot

e. Ants attending mealybug colonies

Plate 5: Symptoms of root mealybug infestation on black pepper

(29.63) districts. In Wayanad, the infestation in Panniyur-1 was followed by other local varieties, Panniyur-2, Jeerakamundi and Muttiyarmundi with per cent infestation of 33.33, 25.00, 15.38 and 15.00 per cent, respectively. In Wayanad district, the lowest per cent of infestation was observed in Karimunda (13.64), whereas in Idukki district, 20.83 per cent of infestation was observed in Karimunda and 16.67 per cent in Panniyur-2 and other local varieties followed by Panchami (15.38). Lowest per cent of infestation was on Jeerakamundi (11.11) in Idukki district.

According to the results obtained on the root mealybugs incidence with respect to the standards used for trailing, highest per cent of infestation was observed on vines trailed on *Erythrina* sp. in Wayanad (55.55) and Idukki (24.49) districts. This was followed by *Artocarpus heterophyllus* L. (Jack), *Areca catechu* L. (Arecanut), *Glyricidia maculata* (Kunth) Walp and *Grevillea robusta* (Cunn.) (Silver oak) in Wayanad district with 53.85, 18.75, 17.64 and 13.63 per cent infestation, respectively. Lowest infestation of 10.00 per cent was observed in *Mangifera indica* L. (Mango). In Idukki, per cent infestation of vines trailed on *Erythrina* sp. was followed by *G. robusta* (20.00) and *A. catechu* (14.28) with lowest in *A. heterophyllus* and *G. maculata* with 12.50 per cent each.

Highest per cent of infested vines in Wayanad district belonged to the age of four to six years (30.00) followed by seven to nine years (29.16) whereas in Idukki district higher per cent of infestation was observed in vines of seven to nine years (43.75). In Wayanad district, the vines of other age groups *viz.*, less than three years, 10 to 12 years and more than 12 years were observed to be infested with varying infestation levels of 23.33, 19.05 and 11.11 per cent, respectively, whereas in Idukki district, per cent infestation of 25.00, 13.63, 12.50, and 11.76 per cent was observed in vines of four to six years, 10 to 12 years, more than 12 years, and less than three years of age, respectively.

Table 5a: Per cent infestation of root mealybugs on black pepper with respect to the varieties

Districts	Varieties of black pepper	No. of vines observed	No. of infested vines	Per cent infestation
Wayanad	Panniyur-1	29	13	44.83
	Jeerakamundi	26	4	15.38
	Karimunda	22	3	13.64
	Panniyur-2	4	1	25.00
	Muttiyarmundi	20	3	15.00
	Locl varieties	3	1	33.33
Idukki	Panniyur-1	27	8	29.63
	Jeerakamundi	18	2	11.11
	Karimunda	24	5	20.83
	Panniyur-2	12	2	16.67
	Panchami	13	2	15.38
	Local varieties	6	1	16.67

Table 5b: Per cent infestation of root mealybugs on black pepper with respect to the standards used

Districts	Standards		No. of vines observed	No. of infested vines	Per cent infestation
	Common name	Scientific name			
Wayanad	Coral tree	*Erythrina* sp.	9	5	55.55
	Jack	*Artocarpus heterophyllus*	13	7	53.85
	Glyricidia	*Glyricidia maculata*	34	6	17.64
	Silver oak	*Grevillea robusta*	22	3	13.63
	Arecanut	*Areca catechu*	16	3	18.75
	Mango	*Mangifera indica*	12	1	10.00
Idukki	Coral tree	*Erythrina* sp.	49	12	24.49
	Jack	*Artocarpus heterophyllus*	8	1	12.50
	Glyricidia	*Glyricidia maculata*	16	2	12.50
	Silver oak	*Grevillea robusta*	20	4	20.00
	Arecanut	*Areca catechu*	7	1	14.28

Table 5c: Per cent infestation of root mealybugs on black pepper with respect to the age of vine

Districts	Age of the pepper vines	No. of vines observed	No. of infested vines	Per cent infestation
Wayanad	Less than 3 years	30	7	23.33
	4 - 6 years	20	6	30.00
	7 - 9 years	24	7	29.16
	10 - 12 years	21	4	19.05
	More than 12 years	9	1	11.11
Idukki	Less than 3 years	34	4	11.76
	4 - 6 years	20	5	25.00
	7 - 9 years	16	7	43.75
	10 - 12 years	22	3	13.63
	More than 12 years	8	1	12.50

4.1.5 Extent of root mealybug infestation in Wayanad and Idukki districts, Kerala

Based on the preliminary survey, two panchayats severely infested with root mealybugs were selected from Wayanad and Idukki districts. The panchayats selected were Mullankolly and Pulpally in Wayanad district and Vandiperiyar and Nedumkandam in Idukki district. The root mealybug infestation was assessed from the selected panchayats during the period from August 2013 to July 2014 at monthly intervals. Sixty vines were observed from each garden and the per cent infestation was calculated for each district. The data on per cent infestation is given in Table 6.

In Wayanad district, the per cent infestation was found on par from August 2013 to January 2014, whereas in Idukki district, infestation was on par from August 2013 to March 2014. In both districts, highest per cent of infestation was observed in December 2013 with 16.67 per cent of infested vines. In Wayanad district, the infestation recorded in August, September, October and January was 8.33, 8.33, 13.33, 16.66 and 10.00 percent, respectively, whereas in Idukki district, the same was recorded as 8.33, 8.33, 8.33, 15.00 and 11.67 per cent, respectively. In February 2014 and March 2014, the infestation recorded was statistically on par with 5.00 per cent infestation in Wayanad district and 6.67 per cent in Idukki district. The per cent infestation in April 2014 was 3.33 per cent in Wayanad district and 5.00 per cent in Idukki district. Lowest per cent of infestation was observed in May 2014, June 2014 and July 2014 with 1.67, 3.33 and 1.67 per cent, respectively in Wayanad district and 1.67 per cent in Idukki district.

4.1.6 Natural enemies

During the survey, the infested roots were examined thoroughly for the presence of natural enemies. Root samples were collected from different locations and brought to the laboratory for observing the presence of natural enemies.

A coccinellid grub was observed to be predating on the root mealybug, *F. polysperes* which was brought to the laboratory and reared to obtain the adults. The adults were identified as *Horniolus* sp. of sub family Scymninae and tribe Scymnini (Coleoptera: Coccinellidae) (Plate 6).

Table 6: Extent of root mealybug infestation on black pepper in Wayanad and Idukki districts, Kerala

Sl. No.	Months	*Per cent infestation	
		Wayanad	Idukki
1	August 2013	8.33^{ab}	8.33^{abc}
2	September 2013	8.33^{ab}	8.33^{abc}
3	October 2013	13.33^{a}	8.33^{abc}
4	November 2013	16.66^{a}	15.00^{a}
5	December 2013	16.67^{a}	16.67^{a}
6	January 2014	10.00^{ab}	11.67^{ab}
7	February 2014	5.00^{bc}	6.67^{abcd}
8	March 2014	5.00^{bc}	6.67^{abcd}
9	April 2014	3.33^{bc}	5.00^{bcd}
10	May 2014	1.67^{c}	1.67^{d}
11	June 2014	3.33^{bc}	1.67^{cd}
12	July 2014	1.67^{c}	1.67^{d}

*Average of 60 observations from two panchayats of each district

Figures followed by the same alphabets did not differ significantly (P=0.01)

Grub

Pupa

Adult

Plate 6: Life stages of coccinellid predator of root mealybug, *Horniolus* sp. on black pepper

The adult beetle is very small with an average of 2.55 mm length and 1.78 mm width. It was convex shaped with dark brown thoracic shield and black elytra with two orange coloured patches. One patch is anterior and large and the other is small and positioned posteriorly.

The grub is cream coloured with white waxy thread like growth all over the body and possessed three pairs of well developed thoracic legs. A few predators only could be collected from the field and hence, the predators could not be mass multiplied and conduct bioefficacy studies.

4.1.7 Collateral hosts

Root mealybug infestation on weeds and other crops grown in and around the infested pepper garden were examined to document their collateral hosts. Presence of mealybug colonies was observed by destructive sampling.

Formicococcus polysperes was found to be infesting ginger, *Zingiber officinale* Rose. and elephant foot yam, *Amorphophallus paeoniifolius* (Dennst.) which were grown as intercrop in infested black pepper gardens. It was also found on many weed plants in and around the pepper garden. *F. polysperes* was observed to be infesting roots of eight weed plants belonging to seven families and they were *Ageratum conyzoides* L. *Clerodendron infortunatum* L., *Cyperus kyllinga L.*, *Phyllanthus niruri* L., *Physalis minima* L., *Synedrella nodiflora* L., and *Urtica parviflora* Roxb. *Erythrina* sp., one of the common standards used to trail the pepper vine in Idukki district was also found to be colonized by *F. polysperes* (Plate 7).

Dysmicoccus brevipes was found on roots of four plant species *viz.*, *Coffea robusta* L., *Cleome rutidosperma* (DC.), *Commelina diffusa* L. and *Cyperus kyllinga* L. (Plate 8). The details of collateral hosts of *F. polysperes* and *D. brevipes* are furnished in Table 7 and 8, respectively.

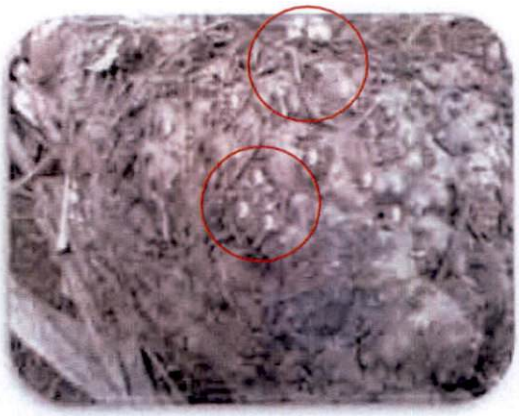
Table 7: Collateral hosts of *Formicococcus polysperes* in black pepper ecosystem

Common name	Scientific name	Family
Ginger	*Zingiber officinale* Rose.	Zingiberacae
Elephant foot yam	*Amorphophallus paeoniifolius* (Dennst.)	Araceae
Goat weed	*Ageratum conyzoides* L.	Asteraceae
Hill glory bower	*Clerodendron infortunatum* L.	Lamiaceae
Nut sedge	*Cyperus kyllinga* L.	Cyperaceae
Stone breaker	*Phyllanthus niruri* L.	Phyllanthaceae
Native goosberry	*Physalis minima* L.	Solanaceae
Cyndrella weed	*Synedrella nodiflora* L.	Asteraceae
Nettle	*Urtica parviflora* Roxb.	Urticaceae
Coral tree	*Erythrina* sp. L.	Fabaceae

Table 8: Collateral hosts of *Dysmicoccus brevipes* in black pepper ecosystem

Common name	Scientific name	Family
Coffee	*Coffea robusta* L.	Rubiaceae
Fringed spider flower	*Cleome rutidosperma* (DC.)	Cleomaceae
Tropical spiderwort	*Commelina diffusa* L.	Commelinaceae
Nut sedge	*Cyperus kyllinga* L.	Cyperaceae

a. *Zingiber officinale*



b. *Amorphophallus paeoniifolius*

c. *Ageratum conyzoides*

d. *Clerodendron infortunatum*

Plate 7: Collateral hosts of *Formicococcus polysperes* in black pepper ecosystem

Contd.

e. *Cyperus kyllinga*

f. *Phyllanthus niruri*

g. *Physalis minima*

h. *Synedrella nodiflora*

i.Urtica parviflora

j. *Erythrina* sp.

Plate 7: Collateral hosts of *Formicococcus polysperes* in black pepper ecosystem

a. *Coffea robusta*

b. *Cleome rutidosperma*

c. *Cyperus kyllinga*

d. *Commelina diffusa*

Plate 8: Collateral hosts of *Dysmicoccus brevipes* in black pepper ecosystem

4.1.8 Associated organisms

During the survey, association of root mealybugs with other organisms like, fungi, nematodes and ants were observed.

4.1.8.1 *Fungi*

Root samples of infested vines were brought to the laboratory for observing the presence of plant parasitic fungi. Root samples were kept in cold water for 24 hours and incubated in low temperature to check the development of sporangia of *Phytophthora* sp. The samples were also inoculated in PDA medium and observed daily for the growth of microbes, if any. But the presence of any plant parasitic fungi could not be observed during the present study.

4.1.8.2 *Nematodes*

Soil samples were collected from the root zone of infested pepper vines of the selected pepper gardens and assessed the plant parasitic nematode population using Cobb's decanting and sieving technique.

Rotylenchulus reniformis was the only plant parasitic nematode species observed during the survey. It was observed only in the month of September 2013 from Wayanad district and its association with mealybugs could not be studied.

4.1.8.3 *Ants*

Ants were collected from the rhizosphere of infested vines and the collected specimens were identified by Dr. K. A. Karmaly, Taxonomist, Dept. of Zoology, St. Xavier's College for Women, Aluva, Ernakulam. The list of ants identified are presented in Table 9.

Four ant species were found to be associated with the root mealybug colonies and they were *Anoplolepis gracilipes* Smith, *Crematogaster rogenhoferi* Mayr, *Lophomyrmex quadrispinosus* Jerdon and *Paratrechina* sp. (Plate 9).

Among the four species, *A. gracilipes* was observed to be associated with *D. brevipes* only. *C. rogenhoferi* and *L. quadrispinosus* were observed to be associated with *F. polysperes* and *D. brevipes* while *Paratrechina* sp. was seen with *F. polysperes* and *Pseudococcus* sp.

Table 9: Ant species associated with root mealybugs in black pepper

Ant species	Family	Sub family	Associated mealybug species
Anoplolepis gracilipes Smith	Formicidae	Formicinae	*D. brevipes*
Crematogaster rogenhoferi Mayr	Formicidae	Myrmicinae	*F. polysperes* *D. brevipes*
Lophomyrmex quadrispinosus Jerdon	Formicidae	Myrmicinae	*F. polysperes* *D. brevipes*
Paratrechina sp.	Formicidae	Formicinae	*F. polysperes* *Pseudococcus* sp.

4.1.9 Population dynamics of root mealybugs on black pepper

Population dynamics of root mealybugs, *F. polysperes* was studied in an infested pepper garden in Mananthavady panchayat of Wayanad district, Kerala during the period from February 2015 to January 2016. Sixty vines were selected at random and marked. Observations were made on these marked vines at monthly intervals. The mealybugs present on the roots were recorded to a length of 15 cm and expressed as number of mealybugs per 15 cm root length. The number of infested vines was also observed and the per cent infestation was worked out. The details of the observations are presented in Table 10.

The average mealybug population observed in the month of February 2015 was 8.18 mealybugs/15 cm root length which was followed by the population in March (7.20 mealybugs /15 cm root length) and were statistically on par. Thereafter a gradual decline was observed in population from the month of April 2015 (4.20 mealybugs/15 cm root length) to May 2015 (2.87 mealybugs/15 cm root length) with lowest population recorded in June 2015 and July 2015 (2.83 and 2.43 mealybugs per 15 cm root length, respectively) which were on par with each other. The population was observed to be increasing from August 2015 (4.62 mealybugs/15cm root length) and September 2015(6.00 mealybugs/15 cm root length) with highest population of

Anoplolepis gracilipes

Crematogaster rogenhoferi

Lophomyrmex quadrispinosus

Paratrechina sp.

Plate 9: Ant species associated with root mealybugs in black pepper

Table 10: Root mealybug population and per cent infestation on black pepper

Sl. No.	Months	Per cent infestation	*No. of mealybugs/15 cm root length
1	February 2015	18.33	8.18^{bc}
2	March 2015	16.67	7.20^{bcd}
3	April 2015	16.67	4.20^{de}
4	May 2015	13.33	2.87^{e}
5	June 2015	10.00	2.83^{e}
6	July 2015	11.67	2.43^{e}
7	August 2015	21.67	4.62^{de}
8	September 2015	23.33	6.00^{cd}
9	October 2015	23.33	8.71^{bc}
10	November 2015	26.67	9.94^{b}
11	December 2015	26.67	13.31^{a}
12	January 2016	23.33	10.21^{b}

*Average of sixty observations

Figures followed by the same alphabets did not differ significantly (P=0.01)

13.31 mealybugs/15 cm root length in the month of December 2015. The population observed in December was significantly different from the populations recorded in the rest of the months. This was followed by the population recorded in months of January 2016 and November 2015 with 10.21 and 9.94 mealybugs/15 cm root length, respectively which were statistically on par with each other and also with the population observed in October 2015 (8.71 mealybugs/15 cm root length).

In case of per cent of infested vines, 18.33 per cent of vines was found to be infested in February 2015 and gradually declined with 16.67 per cent in March 2015 and April 2015 and 13.33 per cent in May 2015. The lowest per cent of infested vines was observed in June 2015 with 10.00 followed by July 2015 with 11.67 per cent. Thereafter an increase was observed in per cent of infested vine from August 2015 (21.67 per cent) with highest per cent of 26.67 in months of December 2015 and November 2015 followed by 23.33 per cent in September 2015, October 2015 and January 2016.

4.1.10 Correlation of root mealybug population with soil and weather parameters

The relationship between the mealybug population and soil parameters like soil temperature, soil moisture and also weather parameters (rainfall, relative humidity and number of rainy days) was studied using correlation analysis. The correlation coefficients of each parameter is given in Table 11.

There was a significant negative correlation between the root mealybug population and soil temperature *viz.*, minimum and maximum soil temperature with coefficients of -0.707 and -0.735, respectively. The correlation between the root mealybug population and other parameters were not significant. The correlation coefficients obtained for other parameters like soil moisture, rainfall and number of rainydays were -0.569, -0.529 and -0.333, respectively. Even though, the correlation coefficient for the population and relative humidity was positive (0.444), the correlation between them was non significant.

Table 11: Correlation coefficients of soil and weather parameters

Sl. No.	Parameters	Correlation coefficients
1	Minimum soil temperature	-0.707*
2	Maximum soil temperature	-0.735*
3	Soil moisture	-0.569
4	Rainfall	-0.529
5	Rainy days	-0.333
6	Relative humidity	0.444

*Significant at 5% level

4.2 BIOLOGY OF THE ROOT MEALYBUG, *Formicococcus polysperes*

Among the three species of root mealybugs documented during survey, *F. polysperes* was the dominant species and hence, its biology was studied on cut portions of two noded pepper cuttings during February to April 2015. The pepper cuttings with one day old first instar nymphs were kept in Petri plates with a layer of wet absorbent cotton lined at bottom and observed daily for recording the number of young ones delivered and number and duration of nymphal instars and the results are presented in Table 12. Morphometric characters of all the stages were measured using Stereo Zoom Microscope (Lieca®) with image analyzer facility and the results are furnished in Table 13.

4.2.1 Reproductive period

In mealybugs with oviparity, the reproductive period is the total duration of pre oviposition, oviposition and post oviposition. Oviparity was absent in *F. polysperes* and it exhibited ovoviviparity. Hence, the term larviposition is used to express the reproductive period and fecundity.

Observations on pre larviposition, larviposition and post larviposition period revealed that it varied from 21 to 29, 4 to 15 and 3 to 6 days with an average of 23.65 ± 2.01, 9.6 ± 3.34 and 4.15± 0.93 days, respectively.

Table 12: Biology of *Formicococcus polysperes* on black pepper

Stages of *F. polysperes*	Duration (days)	
	Range	*Mean
Development period		
First instar nymph	6 -14	8.4 ± 2.46
Second instar nymph	5 -13	6.35 ± 1.95
Third instar female nymph	6 -13	8.4 ± 1.87
Pre pupa	1-2	1.4 ± 0.50
Pupa	6 - 9	7.15 ± 0.88
Adult		
Male	1-3	1.8 ± 0.52
Female	30 - 41	37.4 ± 3.10
Reproductive period		
Pre larviposition period	21 - 29	23.65 ± 2.01
Larviposition period	4 -15	9.6 ± 3.34
Post larviposition period	3 - 6	4.15 ± 0.93
Number of crawlers/female	76 -357	136.15 ± 74.93
Total life cycle		
Male	20 - 31	23.7 ± 3.01
Female	49 - 70	60.55 ± 5.36

*Average of 20 replications

Table 13: Morphometrics of different life stages of *Formicococcus polysperes*

Stages of *F. polysperes*	Length (mm)		Width (mm)	
	Range	*Mean	Range	*Mean
First instar	0.64 - 0.98	0.89 ± 0.09	0.35 - 0.59	0.51 ± 0.06
Second instar	1.02 - 1.69	1.39 ± 0.25	0.56 - 0.99	0.80 ± 0.14
Third instar female nymph	1.71 - 2.47	2.10 ± 0.26	0.91 - 1.82	1.25 ± 0.22
Pre pupa	1.01 - 1.62	1.29 ± 0.21	0.55 - 0.86	0.65 ± 0.11
Pupa	1.56 - 2.41	2.03 ± 0.27	0.49 - 0.92	0.82 ± 0.13
Adult female	2.10 - 3.25	2.65 ± 0.32	1.30 - 1.94	1.56 ± 0.24
Adult male	0.78 - 1.57	1.13 ± 0.26	0.24 - 0.46	0.33 ± 0.06

*Mean of 20 observations

4.2.1.1 *Larviposition (Number of crawlers/female)*

The adult females of *F. polysperes* delivered the first instar nymphs (crawlers). Before delivering nymphs, females produced cottony threads similar to ovisacs from the posterior part of the body into which the nymphs were deposited. Adult female deposited 76 to 357 crawlers with an average of 136.15 ± 74.93 crawlers and sex ratio was 1: 2.71 which was expressed as male: female.

4.2.2 Development period

Males and females of *F. polysperes* exhibited variation in its development stages. The female had three nymphal instars while the male had two nymphal, a pre pupal and a pupal instar (Plate 10a and 10b).

First instar (25 x)

Second instar (25 x)

Third instar (25 x)

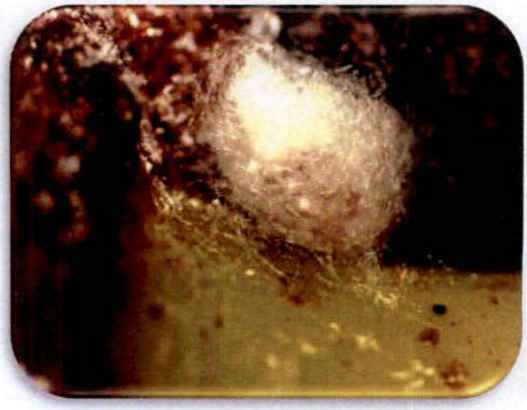
Adult (20 x)

Plate 10a: Life stages of female *Formicococcus polysperes*

First instar (25 x)

Second instar (25 x)

Pre pupa (25 x)



Pupa (25 x)

Adult (25 x)

Plate 10b: Life stages of male *Formicococcus polysperes*

4.2.2.1 *First nymphal instar*

The freshly delivered first instar nymphs were oval in shape, light pink in colour with three pairs of legs and a pair of filiform antennae. Body colour changed from pink to pale white within a day after larviposition. Length of the first instar nymphs ranged from 0.64 to 0.98 mm with an average of 0.89 ± 0.09 mm and width ranged from 0.35 to 0.59 mm with an average of 0.51 ± 0.06 mm. Duration of first nymphal instar lasted 6 to 14 days with a mean of 8.4 ± 2.46 days.

4.2.2.2 *Second nymphal instar*

The second instar nymphs resembled first instar in appearance and morphological characteristics except in body size. Wax coating was absent on body and secreted after about 24 hours of moult. Length and width of the second instar nymphs ranged from 1.02 to 1.69 mm and 0.56 to 0.99 mm with an average of 1.39 ± 0.25 mm and 0.80 ± 0.14 mm, respectively. Duration of the second instar lasted for 5 to 13 days with a mean of 6.35 ± 1.95 days.

4.2.2.3 *Third nymphal instar*

Males and females could be distinguished from the third instar onwards. A fine silken waxy thread was formed by males at the end of second instar and known as pre pupal stage which was absent in females. Hence, from this stage onwards, the observations were taken separately for males and females.

4.2.2.4 *Third instar female nymph*

Waxy filaments along the body margin were prominently visible from third instar onwards and nymphs were similar to adult females except in body size. Length of third instar female nymph varied from 1.71 to 2.47 mm with an average of 2.10 ± 0.26 mm whereas width was 0.91 to 1.82 mm with an average of 1.25 ± 0.22 mm. Duration of third instar was ranged from 6 to 13 days with an average of 8.4 ± 1.87 days.

4.2.2.5 *Pre pupa*

This stage was identified by the presence of fine waxy threads which was later formed into complete cocoon. Duration of this instar lasted from 1 to 2 days with an

average of 1.4 ± 0.50 days. Morphometics of pre pupal instar was similar to that of second instar with length and width ranging from 1.01 to 1.62 mm and 0.55 to 0.86 mm with an average of 1.29 ± 0.21 mm and 0.65 ± 0.11 mm, respectively.

4.2.2.6 *Pupa*

Male nymphs secreted waxy threads to form cocoon which covers the entire body. Cocoon was cylindrical shaped and exuviae was present outside with which moulting was confirmed. The male nymph inside the cocoon were dark pink in colour, slender, with a pair of ten segmented antennae which was directed backwards along the body margin and with wing pads. Waxy coating was absent (Plate 11). Duration of pupal instar lasted for 6 to 9 days with an average of 7.15 ± 0.88 days. Length and width of male pupa was 1.56 to 2.41 mm and 0.49 to 0.92 mm with an average of 2.03 ± 0.27 mm and 0.82 ± 0.13 mm, respectively.

4.2.3 Adult female

Adult females of *F. polysperes* were apterous, soft bodied, oval shaped and pink in colour. Body segmentation was visible with powdery wax secretion. Waxy filaments surrounding the body margin were short and thick, the morphometric measurements of adult female was 2.10 to 3.25 mm length with an average of 2.65 ± 0.32 and 1.30 to 1.94 mm width with an average of 1. 56 ± 0. 24 mm.

4.2.4 Male

Males were slender, delicate, elongated and reddish brown in colour with a pair of well developed, pale white and opaque wings and a pair of long waxy caudal filaments. A pair of long, ten segmented antennae was the other morphological characteristic of male. Measurements of male were 0.78 to 1.57 mm length with an average of 1.13 ± 0.26 mm and 0.24 to 0.46 mm width with an average of 0.33 ± 0.06 mm.

4.2.5 Adult longevity

Males were short lived when compared to the mature females. Longevity of males ranged from 1 to 3 days with an average of 1.8 ± 0.52 days and that of females were 30 to 41 days with an average of 37.4 ± 3.10 days.

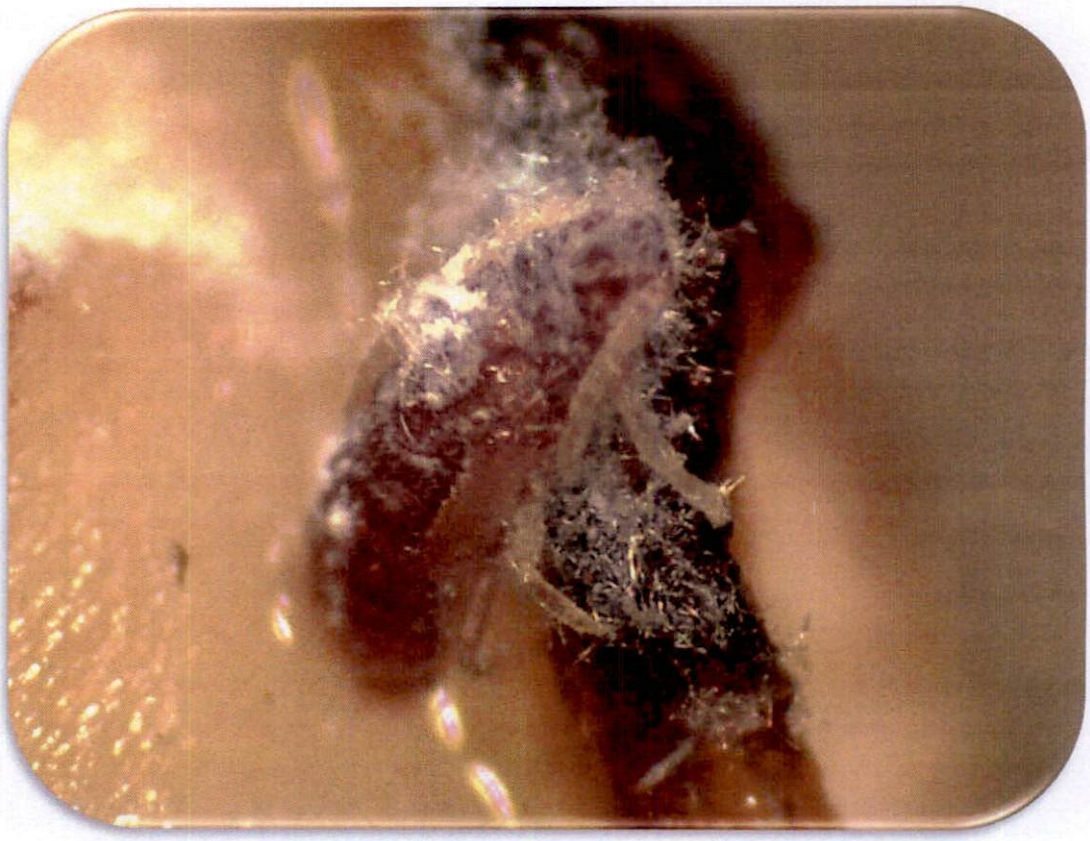


Plate 11: Male nymph inside the cocoon

4.2.6 Total life cycle

Males had shorter life cycle than that of females and it ranged from 20 to 31 days with an average of 23.7 ± 3.01 days. Total life cycle of females was 49 to 70 days with an average of 60.55 ± 5.36 days.

4.3 SUSCEPTIBILITY OF POPULAR PEPPER VARIETIES

Four popular varieties of black pepper namely, Panniyur-1, Panniyur-2, Panniyur-8 and Karimunda were evaluated to test their susceptibility to root mealybugs, *F. polysperes*. The experiment was laid out as pot experiment in Completely Randomized Block Design. One month old pepper seedlings were artificially infested by releasing five gravid females at collar region. Observations on number of progenies were recorded after 45 days of release by adopting destructive sampling method (Plate 12) so that the progenies will be at third instar, which are easy to count by naked eye. The results are presented in Table 14.

Roots and the below ground stem region of all the four varieties were colonized by the third instar nymphs. Out of the four varieties, Panniyur-2 supported significantly higher number of mealybugs (81.58) than other three varieties and was followed by Panniyur-1 by recording an average of 44.5 mealybugs/plant. Karimunda supported lower number of mealybugs (17.67 mealybugs/plant) which was statistically on par with Panniyur-8 on which 25.67 mealybugs was recorded.

Table 14: Number of mealybug nymphs on different varieties of black pepper

Sl. No.	Pepper varieties	No.of mealybug nymphs/ plant
1	Panniyur-1	44.5^{b} (6.59)
2	Panniyur-2	81.58^{a} (9.02)
3	Panniyur-8	25.67^{c} (5.06)
4	Karimunda	17.67^{c} (4.19)

*Average of four replications
Figures followed by the same alphabets did not differ significantly (P=0.01)
Figures in parentheses are square root transformed values

a. Panniyur-1

b. Panniyur-2

c. Panniyur-8

d. Karimunda

Plate 12: Mealybug colonies on different pepper varieties

4.4 EVALUATION OF ENTOMOPATHOGENIC FUNGI AGAINST ROOT MEALYBUG

Efficacy of four entomopathogenic fungi *viz., Beauveria bassiana, Lecanicillium lecanii, Metarhizium anisopliae* and *Paecilomyces lilacinus* (Plate 13) each at 2 $x10^6$, 2 $x10^7$ and 2 x 10^8 spores/ml were evaluated against root mealybug, *F. polysperes.*

4.4.1 Pathogenicity test of entomopathogenic fungi in laboratory

Pathogenicity test of each entomopathogenic fungus at three different concentrations were tested in the laboratory. Ten third instar mealybug nymphs were released on cut portions of single noded pepper cuttings kept in Petri dishes and spore suspension of each entomopathogenic fungi at each concentrations were applied on pepper cuttings. Mortality due to mycosis was confirmed by the presence of fungal growth on dead mealybugs (Plate 14). Mortality was recorded at five and seven days after inoculation and the results are presented in Table 15.

All the three fungal bioagents were found to be pathogenic to the root mealybugs and the mortality increased with increase in spore concentration. At five days after the application of treatments, *L. lecanii* caused highest mortality of 50 per cent at $2x10^8$ spores/ml, 46.67 per cent at $2x10^7$ spores/ml and 33.33 per cent mortality at $2x10^6$ spores/ml and were statistically on par with each other. *B. bassiana* at $2x10^8$ spores/ml caused 20 per cent mortality followed by *M. anisopliae* at $2x10^8$ spores/ml and *P. lilacinus* at $2x10^8$ spores/ml and $2x10^7$ spores/ml causing 16.67 per cent mortality. *B. bassiana* at $2x10^6$ spores/ml and $2x10^7$ spores/ml and *P. lilacinus* at $2x10^6$ spores/ml were on par by causing 13.33 per cent mortality. *M. anisopliae* caused 10 per cent mortality at $2x10^6$ spores/ml and $2x10^7$spores/ml which was on par with the control in which zero per cent mortality was recorded.

At seven days after application, all the three entomopathogenic fungi at all the three concentrations were significantly superior to control. *L. lecanii* caused highest mortality of 56.67 and 50 per cent at $2x10^8$ and $2x10^7$spores/ml, respectively and were significantly superior to all other treatments. *L. lecanii* at $2x10^6$spores/ml caused 33.33 per cent mortality followed by *B. bassiana* at $2x10^8$spores/ml (30 per cent) and *M. anisopliae* at $2x10^6$spores/ml (26.67) which was on par with the treatments like

a. *Beauveria bassiana*

b. *Metarhizium anisopliae*

c. *Lecanicillium lecanii*

d. *Paecilomyces lilacinus*

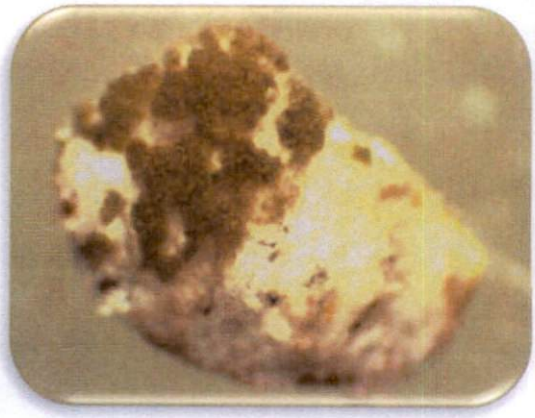
Plate 13: Different entomopathogenic fungi used for evaluation against root mealybugs

Table 15: Per cent mortality of root mealybug, *Formicococcus polysperes* due to entomopathogenic fungi in the laboratory

Treatments	* Per cent mortality	
	Five days after application	Seven days after application
T_1: *Beauveria bassiana* at $2x10^6$ spores/ml	13.33^{cd}	20.00^{bc}
T_2: *B. bassiana* at $2x10^7$ spores/ml	13.33^{cd}	20.00^{bc}
T_3: *B. bassiana* at $2x10^8$ spores/ml	20.00^{bc}	30.00^{bc}
T_4: *Lecanicillium lecanii* at $2x10^6$ spores/ml	33.33^{ab}	33.33^{b}
T_5: *L. lecanii* at $2x10^7$ spores/ml	46.67^{a}	50.00^{a}
T_6: *L. lecanii* at $2x10^8$ spores/ml	50.00^{a}	56.67^{a}
T_7: *Metarhizium anisopliae* at $2x10^6$ spores/ml	10.00^{cd}	26.67^{bc}
T_8: *M. anisopliae* at $2x10^7$ spores/ml	10.00^{cd}	16.67^{c}
T_9: *M. anisopliae* at $2x10^8$ spores/ml	16.67^{bcd}	20.00^{bc}
T_{10}: *Paecilomyces lilacinus* at $2x10^6$ spores/ml	13.33^{cd}	16.67^{c}
T_{11}: *P. lilacinus* at $2x10^7$ spores/ml	16.67^{bcd}	20.00^{bc}
T_{12}: *P. lilacinus* at $2x10^8$ spores/ml	16.67^{bcd}	20.00^{bc}
T_{13}: Control	0.00^{d}	0.00^{d}

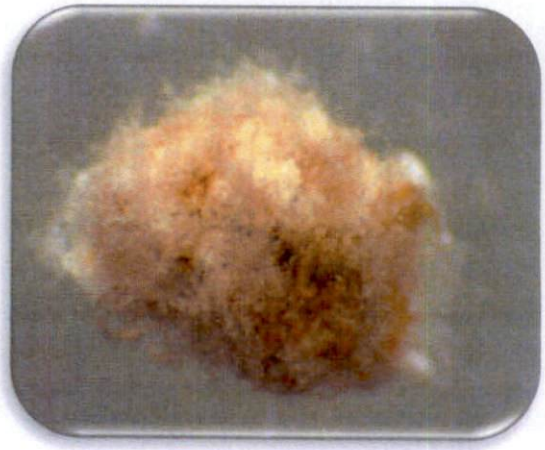
*Average of three replications
Figures followed by the same alphabets did not differ significantly (P=0.01)

a. *Beauveria bassiana*



b. *Metarhizium anisopliae*

c. *Lecanicillium lecanii*



d. *Paecilomyces lilacinus*

Plate 14: Mycosed mealybugs due to different entomopathogenic fungi

B. bassiana and *P. lilacinus* at $2x10^8$ and $2x10^7$spores/ml and *M. anisopliae* at $2x10^8$spores/ml causing 20 per cent mortality. The lowest mortality of 16.67 per cent was recorded in *M. anisopliae* at $2x10^7$spores/ml and *P. lilacinus* at $2x10^6$ spores/ml.

4.4.2 Evaluation of entomopathogenic fungi against root mealybug, *F. polysperes* in pot culture experiment

One month old pepper seedlings of variety, Panniyur-2 maintained in grow bags were used for this experiment. Twenty five third instar mealybug nymphs were released at collar region of pepper seedlings. Treatments were applied as drenching after one week of insect release and were given two times at one week interval. The results obtained are presented in Table 16.

Application of all the fungal bioagents caused significant mortality of root mealybugs when compared to the mortality in control (2.78 per cent). Among the three entomopathogenic fungi, *L. lecanii* at $2x10^8$spores/ml caused highest mortality of 21.11 per cent at one week after first drenching and was on par with *L. lecanii* at $2x10^7$spores/ml (18.89 per cent). The treatments, *B. bassiana* ($2x10^8$spores/ml), *L.lecanii* ($2x10^6$ spores/ml) and *P. lilacinus* ($2x10^8$spores/ml) were statistically on par by causing mortality of 17.78, 17.22 and 16.67 per cent, respectively. These treatments did not show significant difference from the treatments, *B. bassiana* at $2x10^7$spores/ml (16.11) and *M. anisopliae* at $2x10^8$ (13.89) and $2x10^6$ spores/ml (12.22). *B. bassiana* at $2x10^6$spores/ml and *M. anisopliae* at $2x10^7$spores/ml caused mortality of 11.11 and 11.67 per cent, respectively and was statistically on par with *P. lilacinus* which caused lowest mortality of 10.56 per cent at concentrations of $2x10^6$and $2x10^7$ spores/ml.

At one week after second drenching, *L. lecanii* at $2x10^8$spores/ml was significantly superior to all the other treatments by causing 28.33 per cent mortality, followed by *L. lecanii* at $2x10^7$spores/ml (22.78). *B. bassiana* ($2x10^8$spores/ml) caused 19.44 per cent of mortality and was on par with the treatments *viz., B. bassiana* at $2x10^7$spores/ml, *L. lecanii* ($2x10^6$spores/ml) and *P. lilacinus* ($2x10^8$spores/ml) which caused a mortality of 16.67, 17.78 and16.67 per cent, respectively. The treatments, *B. bassiana* ($2x10^6$ spores/ml), *M. anisopliae* ($2x10^8$, $2x10^7$ and $2x10^6$

Table 16: Mortality of root mealybug, *Formicococcus polysperes* caused by entomopathogenic fungi in pot experiment

Treatments	*Per cent mortality	
	One week after first drenching	One week after second drenching
T_1: *Beauveria bassiana* at $2x10^6$ spores/ml	11.11^{e} (3.41)	16.11^{cde} (4.07)
T_2: *B. bassiana* at $2x10^7$ spores/ml	16.11^{bcd} (4.05)	16.67^{cd} (4.14)
T_3: *B. bassiana* at $2x10^8$ spores/ml	17.78^{abc} (4.27)	19.44^{bc} (4.46)
T_4: *Lecanicillium lecanii* at $2x10^6$ spores/ml	17.22^{abc} (4.21)	17.78^{cd} (4.27)
T_5: *L. lecanii* at $2x10^7$ spores/ml	18.89^{ab} (4.39)	22.78^{b} (4.82)
T_6: *L. lecanii* at $2x10^8$ spores/ml	21.11^{a} (4.64)	28.33^{a} (5.37)
T_7: *Metarhizium anisopliae* at $2x10^6$ spores/ml	12.22^{de} (3.56)	12.22^{ef} (3.55)
T_8: *M. anisopliae* at $2x10^7$ spores/ml	11.67^{e} (3.47)	12.22^{ef} (3.55)
T_9: *M. anisopliae* at $2x10^8$ spores/ml	13.89^{cde} (3.79)	13.89^{def} (3.79)
T_{10}: *Paecilomyces lilacinus* at $2x10^6$ spores/ml	10.56^{e} (3.29)	11.67^{f} (3.48)
T_{11}: *P. lilacinus* at $2x10^7$ spores/ml	10.56^{e} (3.29)	11.11^{f} (3.39)
T_{12}: *P. lilacinus* at $2x10^8$ spores/ml	16.67^{abc} (4.14)	16.67^{cd} (4.14)
T_{13}: Control	2.78^{f} (1.79)	7.78^{g} (2.81)

*Average of three replications
Figures followed by the same alphabets did not differ significantly (P=0.01)
Figures in parentheses are square root transformed values

spores/ml) were found to cause 16.11, 13.89, 12.22 and 12.22 per cent mortality, respectively and was on par with each other. *P. lilacinus* at $2x10^6$and $2x10^7$ spores/ml caused lowest mortality of 11.67 and 11.11 per cent respectively. Mortality of mealybugs recorded in control was 7.78 per cent and was significantly different from all the other treatments.

4.5 EVALUATION OF CHEMICAL INSECTICIDES AGAINST ROOT MEALYBUG

Eight chemical insecticides were tested against the root mealybug in the laboratory and in pot experiment and the results are presented in Table 17 and 18, respectively.

4.5.1 Efficacy of chemical insecticides against root mealybugs in laboratory

Eight chemical insecticides were tested against the root mealybugs, *F. polysperes* in the laboratory and the observations on mortality caused by each chemical was recorded.

Out of the eight insecticides tested in the laboratory, chlorpyriphos 20 EC at 300 g a.i/ha and imidacloprid 17.8 SL at 25 g a.i/ha were found to be superior and caused highest mortality of 80 per cent which was on par with thiamethoxam 25 WG, bifenthrin 10 EC and fipronil 5 EC causing 73.33, 66.67 and 53.33 per cent mortality. Thiacloprid 21.7 SC caused 40 per cent mortality of mealybugs, followed by cartap hydrochloride 50 SP (33.33) and emamectin benzoate 5 SG (30.00) and was on par with each other. The lowest mortality of 3.33 per cent was recorded in control.

4.5.2 Efficacy of chemical insecticides against root mealybugs, *F. polysperes* in pot experiment

In the pot experiment, all the insecticides caused significantly higher per cent mortality than that of control. Similar to the results obtained in the laboratory experiment, imidacloprid 17.8 SL at 25 g a.i/ha and chlorpyriphos 20 EC at 300 g a.i/ha caused highest mortality of 59.44 and 55.56 per cent at one week after first drenching and were statistically on par. These treatments were followed by thiacloprid 21.7 SC at 30 g a.i/ha (51.11), thiamethoxam 25 WG at 25 g a.i/ha (50.56) and bifenthrin 10 EC at 60 g a.i/ha (48.33) which were at par with each other. The

Table 17: Mortality of root mealybug, *Formicococcus polysperes* caused by chemical insecticides in the laboratory at 24 hours after treatment

Treatments	*Per cent mortality
T1: Bifenthrin 10 EC at 60 g a.i/ha	66.67^{ab} (7.16)
T2: Fipronil 5 EC at 25 g a.i/ha	53.33^{ab} (8.33)
T3: Imidacloprid 17.8 SL at 25g a.i/ha	80.00^{a} (8.94)
T4: Thiacloprid 21.7 SC at 30 g a.i/ha	40.00^{ab} (5.35)
T5: Thiamethoxam 25 WG at 25 g a.i/ha	73.33^{a} (8.58)
T6: Emamectin benzoate 5 SG at 6 g a.i/ha	30.00^{ab} (5.38)
T7: Cartap hydrochloride 50 SP at 500 g a.i/ha	33.33^{bc} (4.96)
T8: Chlorpyriphos 20 EC at 300 g a.i/ha	80.00^{a} (8.93)
T9: Control	3.33^{c} (1.55)

*Average of three replications
Figures followed by the same alphabets did not differ significantly (P=0.01)
Figures in parentheses are square root transformed values

Table 18: Mortality of root mealybug, *Formicococcus polysperes* caused by chemical insecticides in pot experiment

Treatments	*Per cent mortality	
	One week after first drenching	One week after second drenching
T1: Bifenthrin 10 EC at 60 g a.i/ha	48.33^{ab} (6.98)	55.56^{ab} (7.46)
T2: Fipronil 5 EC at 25 g a.i/ha	42.22^{bc} (6.53)	46.67^{b} (6.86)
T3: Imidacloprid 17.8 SL at 25g a.i/ha	59.44^{a} (7.74)	63.89^{a} (8.02)
T4: Thiacloprid 21.7 SC at 30 g a.i/ha	51.11^{ab} (7.18)	58.33^{ab} (7.66)
T5: Thiamethoxam 25 WG at 25 g a.i/ha	50.56^{ab} (7.14)	52.78^{ab} (7.28)
T6: Emamectin benzoate 5 SG at 6 g a.i/ha	33.89^{c} (5.86)	45.00^{b} (6.73)
T7: Cartap hydrochloride 50 SP at 500 g a.i/ha	36.67^{c} (6.08)	52.22^{ab} (7.25)
T8: Chlorpyriphos 20 EC at 300 g a.i/ha	55.56^{a} (7.46)	62.78 ^{a} (7.94)
T9: Control	6.11^{d} (2.44)	7.78^{c} (2.75)

*Average of three replications
Figures followed by the same alphabets did not differ significantly (P=0.01)
Figures in parentheses are square root transformed values

insecticide, fipronil 5 EC at 25 g a.i/ha caused 42.22 per cent mortality which was on par with cartap hydrochloride 50 SP at 500 g a.i/ha (36.67) and emamectin benzoate 5 SG at 6 g a.i/ha (33.89) and was significantly different from the mortality recorded in the control (6.11).

At one week after second drenching, imidacloprid 17.8 SL at 25 g a.i/ha caused highest mortality of 63.89 per cent, followed by chlorpyriphos 20 EC at 300 g a.i/ha (62.78) and both treatments were on par with thiacloprid 21.7 SC at 30 g a.i/ha, bifenthrin 10 EC at 60 g a.i/ha, thiamethoxam 25 WG at 25 g a.i/ha and cartap hydrochloride 50 SP at 500 g a.i/ha with 58.33, 55.56, 52.78 and 52.22 per cent mortality, respectively. The next higher mortality was recorded in the treatment of fipronil 5 EC at 25 g a.i/ha with 46.67 per cent mortality which was on par with emamectin benzoate 5 SG at 6 g a.i/ha (45.00). The mortality recorded in the control was 7.78 per cent.

4.6 COMPATIBILITY OF EFFECTIVE ENTOMOPATHOGENIC FUNGUS WITH PESTICIDES

The most effective entomopathogenic fungus identified against the root mealybug from the pot experiment namely, *Lecanicillium lecanii,* was tested for its compatibility with all the insecticides tested in the present investigation and two fungicides which were commonly used for disease management in black pepper. The results obtained on radial growth and per cent inhibition of fungal colony in poisoned media are presented in Table 19.

4.6.1 *In vitro* evaluation on compatibility of *Lecanicillium lecanii* with selected pesticides

The results on the effect of pesticides on the radial growth of fungal colony showed that all the treatments induced a significant reduction in the fungal growth (Plate 15). At five days after inoculation, the radial growth in control was 2.40 cm. The fungal growth in the treatment with thiacloprid 21.7 SC at 30 g a.i/ha was 2.00 cm which was on par with control. This was followed by imidacloprid 17.8 SL at 25

Table 19: Mycelial growth of *Lecanicillium lecanii* on poisoned Potato Dextrose Agar media

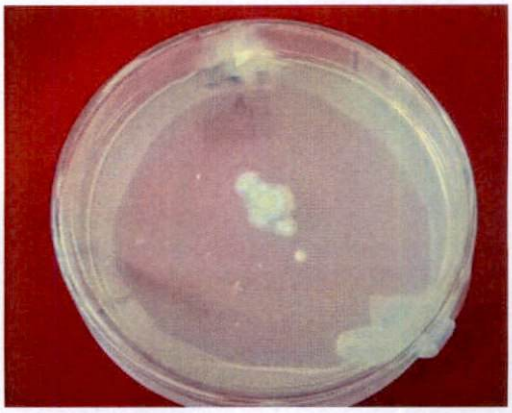
Treatments	*Radial growth of *L. lecanii* (cm)			*Per cent inhibition
	5 DAI	7 DAI	10 DAI	
T1: Bifenthrin 10 EC at 60 g a.i/ha	0.50^{f}	0.50^{ef}	0.50^{e}	89.59^{a}
T2: Fipronil 5 EC at 25 g a.i/ha	1.27^{de}	2.03^{cd}	2.03^{cd}	57.08^{abc}
T3: Imidacloprid 17.8 SL at 25g a.i/ha	1.90^{bc}	3.13^{ab}	3.70^{b}	25.52^{c}
T4: Thiacloprid 21.7 SC at 30 g a.i/ha	2.00^{ab}	2.60^{bc}	2.83^{bcd}	39.94^{bc}
T5: Thiamethoxam 25 WG at 25 g a.i/ha	1.63^{bcd}	2.17^{bcd}	2.90^{bcd}	38.66^{bc}
T6: Emamectin benzoate 5 SG at 6 g a.i/ha	1.57^{bcde}	1.90^{d}	1.93^{d}	61.62^{ab}
T7: Cartap hydrochloride 50 SP at 500 g a.i/ha	1.17^{e}	2.03^{de}	2.07^{cd}	55.36^{abc}
T8: Chlorpyriphos 20 EC at 300 g a.i/ha	1.77^{bc}	2.93^{abc}	2.93^{bcd}	37.54^{bc}
T9: Copper hydroxide 77 WP at 1%	1.53^{cde}	2.20^{bcd}	3.20^{bc}	34.71^{bc}
T10: Carbendazim 50 WP at 0.1%	0.00^{g}	0.00^{f}	0.00^{e}	100.00^{a}
T11: Control	2.40^{a}	3.80^{a}	5.17^{a}	-

DAI: Days After Inoculation

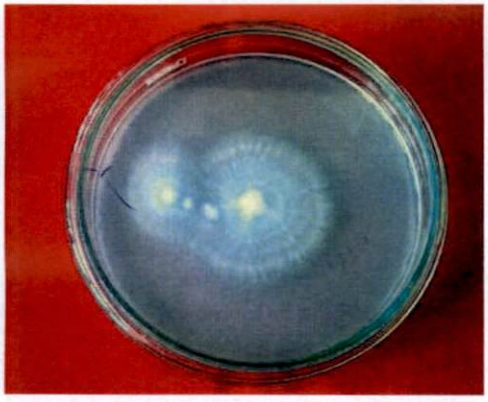
*Average of three replications

Figures followed by the same alphabets did not differ significantly (P=0.01)

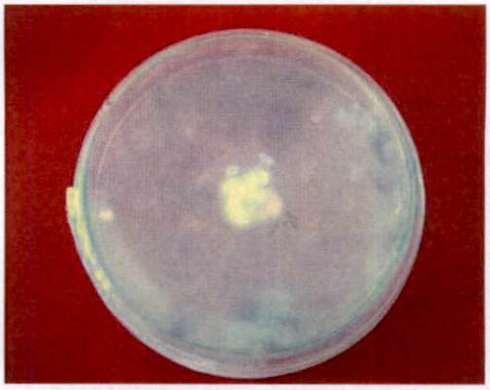
a. Bifenthrin



b. Fipronil



c. Imidacloprid



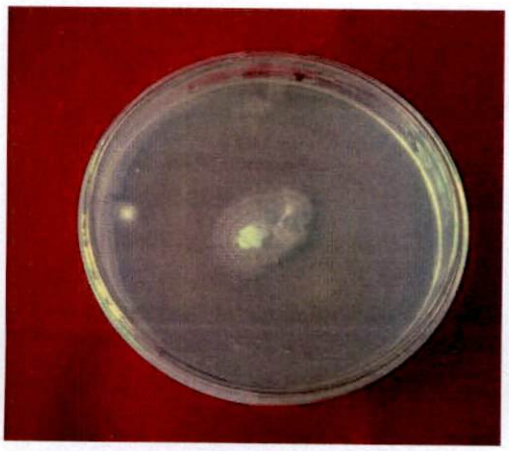
d. Thiacloprid

e. Thiamethoxam

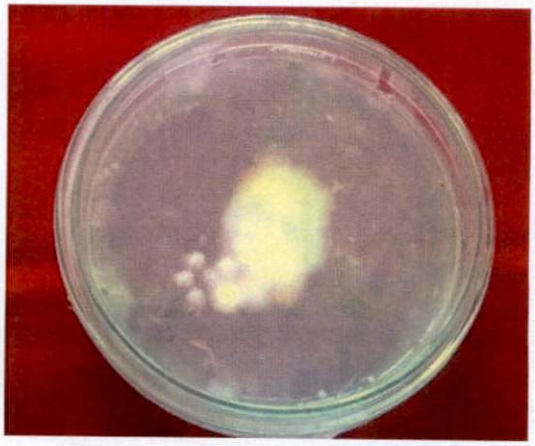
f. Emamectin benzoate

Plate 15: Mycelial growth of *Lecanicillium lecanii* in solid media poisoned with different pesticides (at 10 days after inoculation)

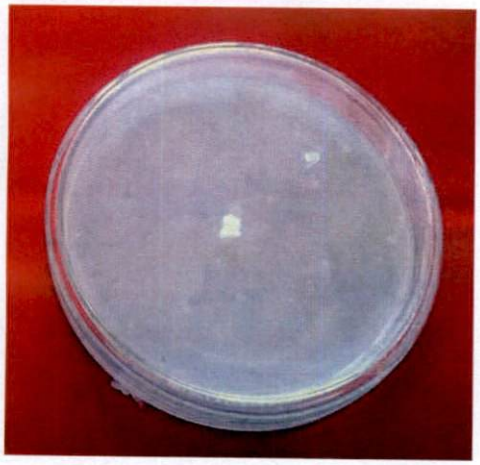
Contd.



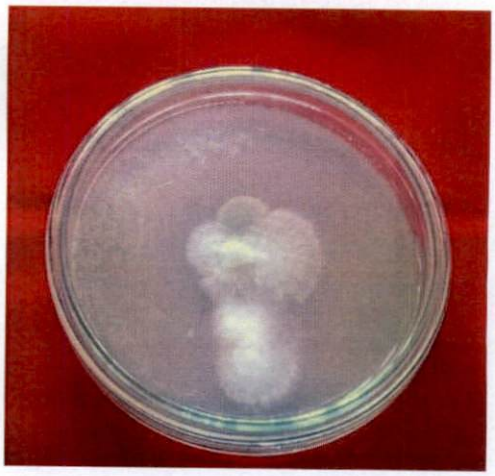
g. Cartap hydrochloride



h. Chlorpyriphos



i. Carbendazim



j. Copper hydroxide

k. Control

Plate 15: Mycelial growth of *Lecanicillium lecanii* in solid media poisoned with different pesticides (at 10 days after inoculation)

g a.i/ha and chlorpyriphos 20 EC at 300 g a.i/ha in which the radial growth recorded were 1.90 and 1.77 cm, respectively and were on par with each other. In the media poisoned with pesticides like thiamethoxam 25 WG at 25 g a.i/ha, emamectin benzoate 5 SG at 6 g a.i/ha and copper hydroxide 77 WP at 1%, the diameter of fungal colony was 1.63, 1.57 and 1.53 cm, respectively. Radial growth observed in the treatments with fipronil 5 EC at 25 g a.i/ha was 1.27 cm and that of cartap hydrochloride 50 SP at 500 g a.i/ha was 1.17 cm and both the treatments were on par. Minimum growth of 0.50 cm was recorded in the media poisoned with bifenthrin 10 EC at 60 g a.i/ha, which was significantly different from all other treatments. Carbendazim 50 WP at 0.1% completely inhibited the fungal growth.

After seven days of inoculation, the fungal growth in control increased to 3. 80 cm and was on par with treatments like imidacloprid 17.8 SL at 25 g a.i/ha (3.13 cm), chlorpyriphos 20 EC at 300 g a.i/ha (2.93cm), thiacloprid 21.7 SC at 30 g a.i/ha (2.60 cm), copper hydroxide 77 WP at 1% (2.20 cm) and thiamethoxam 25 WG at 25 g a.i/ha (2.17 cm) which were again statistically on par with each other. The fungal growth recorded in treatments like fipronil 5 EC at 25 g a.i/ha, cartap hydrochloride 50 SP at 300 g a.i/ha and emamectin benzoate 5 SG at 6 g a.i/ha was 2.03, 2.03 and 1.90 cm, respectively. Bifenthrin 10 EC at 60 g a.i/ha inhibited the fungal growth to 0.50 cm and was on par with carbendazim 50 WP at 0.1% which caused complete inhibition.

Even at 10 days after inoculation, the treatments bifenthrin 10 EC at 60 g a.i/ha and carbendazim 50 WP at 0.1% caused no further fungal growth in which the radial growth was 0.50 cm and no growth, respectively and both were on par. Among the chemicals, maximum growth was recorded in media treated with imidacloprid 17.8 SL at 25 g a.i/ha (3.70 cm), copper hydroxide 77 WP at 1% (3.20), chlorpyriphos 20 EC at 300 g a.i/ha (2.93 cm), thiamethoxam 25 WG at 25 g a.i/ha (2.90 cm) and thiacloprid 21.7 SC at 30 g a.i/ha (2.83 cm) which were on par with each other but significantly different from control in which the fungal growth of 5.17 cm was observed. The fungal growth in treatments, cartap hydrochloride 50 SP at 500 g a.i/ha, fipronil 5 EC at 25 g a.i/ha and emamectin benzoate 5 SG at 6 g a.i/ha was 2.93, 2.07, 2.03 and 1.93 cm, respectively which were on par with each other.

4.6.2 Inhibition of fungal growth in poisoned media

Effect of pesticides on growth of *L. lecanii* was calculated in terms of per cent inhibition (Table 19) and the results shown that carbendazim 50 WP at 0.1% caused 100 per cent inhibition of fungal growth followed by bifenthrin 10 EC at 60 g a.i/ha with 89.59 per cent. Both the pesticides were statistically on par with each other and also with treatments, emamectin benzoate 5 SG at 6 g a.i/ha, fipronil 5 EC at 25 g a.i/ha and cartap hydrochloride 50 SP at 500 g a.i/ha which caused growth inhibition of 61.62, 57.08 and 55.36 per cent, respectively and were on par. The inhibition of fungal growth caused by pesticides like chlorpyriphos 20 EC at 300 g a.i/ha, thiacloprid 21.7 SC at 30 g a.i/ha, thiamethoxam 25 WG at 25 g a.i/ha and copper hydroxide 77 WP at 0.1% was 37.54, 39.94, 38.66 and 34.71 per cent, respectively and were on par with each other. Minimum inhibition of fungal growth was induced by imidacloprid 17.8 SL at 25 g a.i/ha with 25.52 per cent.

4.6.3 Sporulation

The details on the spore count and per cent reduction of sporulation induced by different pesticides are given in Table 20. All the tested pesticides significantly reduced the spore production of *L. lecanii,* among which, the insecticide, imidacloprid 17.8 SL at 25 g a.i/ha and fungicide, copper hydroxide 77 WP at 1% induced only slight reduction of 10.43 and 10.32 per cent with an average spore count of 6.86 x 10^6 spores/ml and 6.87 x 10^6 spores/ml, respectively. Both the pesticides were statistically on par. Thiacloprid 21.7 SC at 30 g a.i/ha and thiamethoxam 25 WG at 25 g a.i/ha caused 39.41 and 36.67 per cent reduction, respectively. The spore count obtained in these treatments were, 4.64 x 10^6 spores/ml in thiacloprid 21.7 SC and 4.85 x 10^6 spores/ml in thiamethoxam 25 WG. These were followed by chlorpyriphos 20 EC at 300 g a.i/ha with spore count of 4.01 x 10^6 spores/ml and causing 47.62 per cent reduction in sporulation. The incecticides, fipronil 5 EC at 25 g a.i/ha, emamectin benzoate 5 SG at 6 g a.i/ha and cartap hydrochloride 50 SP at 500 g a.i/ha caused 66.87, 71.36 and 67.16 per cent reduction with sporulation of 2.54 x 10^6 spores/ml, 2.19 x 10^6 spores/ml and 2.51 x 10^6 spores/ml, respectively. Carbendazim 50 WP induced

Table 20: Effect of selected pesticides on sporulation and spore viability of *Lecanicillium lecanii*

Treatments	Sporulation		Spore viability	
	*Spore count ($x10^6$ spores/ml)	Per cent reduction	*Per cent germination	Per cent reduction
T1: Bifenthrin 10 EC at 60 g a.i/ha	1.08 ± 1.65^{f}	85.85	8.56 ± 1.38^{f}	90.20
T2: Fipronil 5 EC at 25 g a.i/ha	2.54 ± 1.76^{e}	66.87	8.67 ± 1.33^{f}	90.08
T3: Imidacloprid 17.8 SL at 25g a.i/ha	6.86 ± 4.71^{b}	10.43	83.67 ± 3.93^{a}	4.19
T4: Thiacloprid 21.7 SC at 30 g a.i/ha	4.64 ± 3.19^{c}	39.41	69.33 ± 5.68^{cd}	20.61
T5: Thiamethoxam 25 WG at 25 g a.i/ha	4.85 ± 2.71^{c}	36.67	66.67 ± 9.07^{bc}	23.66
T6: Emamectin benzoate 5 SG at 6 g a.i/ha	2.19 ± 1.94^{e}	71.36	21.33 ± 2.31^{e}	75.57
T7: Cartap hydrochloride 50 SP at 500 g a.i/ha	2.51 ± 6.27^{e}	67.16	25.56 ± 8.77^{e}	70.74
T8: Chlorpyriphos 20 EC at 300 g a.i/ha	4.01 ± 2.34^{d}	47.62	51.33 ± 7.37^{d}	41.22
T9: Copper hydroxide 77 WP at 1%	6.87 ± 1.84^{b}	10.32	78.33 ± 3.51^{ab}	10.30
T10: Carbendazim 50 WP at 0.1%	0.00 ± 0.00^{g}	100.00	0.00 ± 0.00^{g}	100.00
T11: Control	7.66 ± 3.13^{a}	0.00	87.33 ± 4.16^{a}	0.00

*Average of nine replications

Figures followed by the same alphabets did not differ significantly (P=0.01)

complete inhibition of spore production (100 per cent) followed by bifenthrin 10 EC at 60 g a.i/ha (85.85 per cent) with a spore count of 1.08 x 10^6 spores/ml.

4.6.4 Spore viability

The results obtained on the effect of pesticides on spore germination of *L. lecanii* is presented in Table 20 and the results showed that, imidacloprid 17.8 SL caused only slight reduction of 4.19 per cent in the spore germination with 83.67 per cent of spore viability which was on par with that of control (87.33 per cent). This was followed by treatments *viz.*, copper hydroxide 77 WP, thiacloprid 21.7 SC and thiamethoxam 25 WG which were on par with 10.30, 20.61 and 23.66 per cent reduction with spore germination of 78.33, 69.33 and 66.67 per cent, respectively. Chlorpyriphos 20 EC caused 41.22 per cent reduction with an average viability of 51.33 per cent. Spore viability of 25.56 and 21.33 per cent were recorded in treatments, cartap hydrochloride 50 SP and emamectin benzoate 5 SG with 70.74 and 75.57, per cent reduction of spore germination, respectively and were on par with each other. Complete inhibition of spore germination was caused by the fungicide, carbendazim 50 WP and was followed by fipronil 5 EC and bifenthrin 10 EC with 8.67 and 8.56 per cent viability and 90.08 and 90.20 per cent reduction, respectively. Fipronil 5 EC and bifenthrin 10 EC was statistically on par and at the same time significantly different from that of carbendazim 50 WP which caused complete inhibition.

4.7 MANAGEMENT OF ROOT MEALYBUG IN POTS

The best treatments from the screening tests of entomopathogenic fungi, *L. lecanii* and chemical insecticides were evaluated alone and in combination of entomopathgenic fungi and insecticides along with the common practice adopted by farmers against the root mealybug. The experiment was conducted using pepper seedlings in grow bags and twenty five third instar mealybugs released on each seedling. Treatments were applied as drenching at one week after release and were given twice at weekly interval. The results obtained from the experiment is furnished in Table 21.

All the treatments caused significant mortality of mealybugs at one week after first drenching, when compared to that of control in which 6.11 per cent mortality was

Table 21: Mortality of root mealybug caused by enotmopathogenic fungus, insecticides and their combinations in pot experiment

Treatments	*Per cent mortality	
	One week after first drenching	One week after second drenching
T1: *Lecanicillium lecanii* 2x10^{8}spores/ml	23.88^c (4.92)	36.67^d (6.09)
T2: Imidacloprid 17.8 SL at 25 g a.i/ha	56.67^a (7.56)	65.00^a (8.09)
T3: Chlorpyriphos 20 EC at 300 g a.i/ha	53.89^a (7.36)	60.00^{ab} (7.77)
T4: Imidacloprid 17.8 SL at 25 g a.i/ha + *Lecanicillium lecanii* at 2x10^8 spores/ml	53.89^a (7.36)	58.89^{ab} (7.69)
T5: Chlorpyriphos 20 EC at 300 g a.i/ha + *Lecanicillium lecanii* at 2x10^8 spores/ml	46.11^{ab} (6.82)	51.11^{bc} (7.17)
T6: Neem cake + Azadirachtin 1% (Farmer's practice)	37.78^{ab} (6.18)	46.67^c (6.87)
T7: Control	6.11^d (2.43)	7.22^e (2.65)

*Average of three replications

Figures followed by the same alphabets did not differ significantly (P=0.01)

Figures in parentheses are square root transformed values

recorded. Among the treatments, the highest mortality of 56.67 per cent was recorded in imidacloprid 17.8 SL at 25 g a.i/ha and was statistically on par with the treatments,chlorpyriphos 20 EC at 300 g a.i/ha and imidacloprid 17.8 SL at 25 g a.i/ha + *L. lecanii* at 2x 10^8spores/ml, both of which caused 53.89 per cent mortality each. This was followed by the combination treatment, chlorpriphos 20 EC at 300 g a.i/ha + *L. lecanii* at 2x 10^8spores/ml in which 46.11 per cent mortality was recorded and was on par with the treatment, neem cake + azadirachtin 1% (37.78 per cent). Lowest mortality of 23.88 per cent was caused by *L. lecanii* at 2x 10^8spores/ml alone and was significantly inferior to all other treatments.

A similar trend was shown by the treatments at one week after second drenching also. All the treatments were significantly different from the control in which 7.22 per cent mortality of root mealybugs was recorded. Highest per cent of mortality was caused by imidacloprid 17.8 SL at 25 g a.i/ha (65.00) followed by chlorpyriphos 20 EC at at 300 g a.i/ha (60.00) and imidacloprid 17.8 SL at 25 g a.i/ha + *L. lecanii* at 2x 10^8 spores/ml (58.89) which were at par with each other. Chlorpyriphos 20 EC at 300 g a.i/ha + *L. lecanii* at 2x 10^8spores/ml as well as neem cake + azadirachtin 1% recorded 51.11 and 46.67 per cent mortality, respectively. *Lecanicillium lecanii* at 2x 10^8spores/ml caused the lowest mortality of 36.67 per cent and was significantly inferior to other treatments and control.

4. 8 FIELD EVALUATION OF EFFECTIVE TREATMENT

The effective treatments from the pot experiment, namely, imidacloprid 17.8 SL and chlorpyriphos 20 EC were evaluated in the root mealybug infested field at Kaniyambetta panchayat of Wayanad district. The treatment means were compared using independent 't' test and the significant difference between treatments were determined based on the 't' value. The results obtained on the field evaluation of effective treatments against root mealybugs are presented in Table 22 along with the 't' values.

Imidacloprid 17.8 SL at 25 g a.i/ha caused 97.98 per cent reduction in the root mealybug population at one week after first drenching whereas, chlorpyriphos 20 EC

Table 22: Efficacy of imidacloprid and chlorpyriphos against root mealybugs on black pepper in field condition

Treatments	Per cent reduction in root mealybug population			
	First drenching		Second drenching	
	7 DAT	14 DAT	7 DAT	14 DAT
T_1: Imidacloprid 17.8 SL at 25 g a.i/ha	97.98	100.00	-	-
T_2: Chlorpyriphos 20 EC at 300 g a.i/ha	79.89	86.06	94.54	-
T_3: Control	-34.07	-34.07	-15.74	-15.74
T_1 vs T_2	2.97*	2.96*	NS	NS
T_1 vs T_3	7.88*	8.02*	8.21*	8.21*
T_2 vs T_3	6.43*	6.92*	7.21*	7.21*

NS = Non significant

*Statistically significant at 5% level

Negative sign (-) in control: Per cent increase in population

at 300 g a.i/ha caused 79.89 per cent reduction. Out of the two insecticides, imidacoprid 17.8 SL was significantly superior to chlorpyriphos 20 EC with t value 2.97 and both the treatments were significantly superior to the control in which the increase in population of 34.07 per cent was recorded. (t = 7.88 with imidacloprid 17.8 SL and 6.43 with chlorpyriphos 20 EC).

At two weeks after first drenching, imidacloprid 17.8 SL at 25 g a.i/ha caused 100 per cent reduction and chlorpyriphos 20 EC at 300 g a.i/ha caused the population reduction of 86.06 per cent. Imidacloprid 17.8 SL and chlorpyriphos 20 EC was significantly different from each other (t= 2.96) and from control (34.07 per cent increase in population) with t value 8.02 and 6.92 for imidacloprid 17.8 SL and chlorpyriphos 20 EC, respectively.

At one week after second application, the root mealybug population was reduced to 94.54 per cent with the application of chlorpyriphos 20 EC at 300 g a.i/ha whereas in the treatment of imidacloprid 17. 8 SL at 25 g a.i/ha, the mealybug population was not recorded. Imidacloprid 17.8 SL and chlorpyriphos 20 EC were on par and were significantly different from control in which the population increase of 15.74 per cent was recorded (t value of 8.21 for imidacloprid 17.8 SL and 7.21 for chlorpyriphos 20 EC).

At two weeks after second drenching, the population in the blocks treated with imidacloprid 17.8 SL at 25 g a.i/ha and chlorpyriphos 20 EC at 300 g a.i/ha remained to same as in one week after second drenching. Imidacloprid and chlorpyriphos 20 EC were statistically on par. There was no population change in the control also.

Discussion

5. DISCUSSION

Investigation was carried out on "Bionomics and management of root mealybug on black pepper" which included documentation of root mealybug species infesting black pepper and its associated fauna, biology of the predominant root mealybug species, susceptibility of popular pepper varieties and their management. The results of the investigation carried out in College of Horticulture, Vellanikkara and farmer's field in Wayanad and Idukki disricts are discussed in this chapter.

5.1 DOCUMENTATION OF ROOT MEALYBUGS AND OTHER ASSOCIATED FAUNA

5.1.1 Identification of root mealybug species

A preliminary survey was carried out in different panchayats of Kannur, Wayanad and Idukki districts, Kerala, to collect and identify the root mealybug species infesting black pepper. No infestation was observed in Kannur district. Three mealybug species were found to be infesting the below ground region of black pepper in Wayanad and Idukki districts and they were *Formicococcus polysperes* Williams, *Dysmicoccus brevipes* Cockerell and *Pseudococcus* sp.

Among the three species, *F. polysperes* was the dominant species and was collected from all the infested gardens visited during survey. *Formicococcus polysperes* was already reported to be infesting the roots of black pepper in Kerala (Williams, 2004). Williams described *F. polysperes* from roots of *Macaranga triloba* (Thunburg) Muller Agroviensis in Malaysia and provided details of host plants and distribution. This species was found on roots of *Macaranga triloba, Macaranga conifera* and *Sapium baccatum* (Euphorbiaceae) from Malaysia, on roots of *Zingiber officinale* (Zingiberaceae), *Cocos nucifera* and *Rhapis excelsa* (Aracaceae) from Philippines, on roots of *Z. officinale* from Thailand and on roots of *Lansium domesticum* from Vietnam. In India, it has been reported on roots of *Piper nigrum* (Kerala), *P. betle* (Madhya Pradesh, Uttar Pradesh, and West Bengal), on pods of *Arachis hypogaea* (Orissa) and on *Areca catechu* (Uttar Pradesh).

Infestation of *D. brevipes* was also reported on black pepper in Kerala along with other four species including, *Ferrisia virgata, Planococcus citri, P. lilacinus* and

an unidentified species of *Planaococcus* (Devasahayam *et al.*, 2010). *Dysmicoccus brevipes* is commonly known as pink pineapple mealybug as it is a serious pest of pineapple (Beardsley, 1993a) and was found infesting pineapple roots, leaves, fruits, blossom cups and crowns (Gonzales – Hernandez *et al.*, 1999). Hypogeic forms of *D. brevipes* was observed on the root and rhizobium nodules of soybean (Thippaiah and Kumar, 1999) and on the basal part and roots of some groundnut (Huang *et al.*, 2002).

The root mealybug , *Pseudococcus* sp. identified from black pepper ecosystem is reported for the first time from the underground portion of black pepper whereas another species of *Pseudococcus* was reported to infest leaves, shoots and berries of black pepper along with other six species of mealybugs (Koya *et al.* 1996). Even though the mealybugs classified under the genus *Pseudococcus* are known to be an aerial pest, some of the hypogeic species of *Pseudococcus* were reported. Williams (1985b) described a species *P. mandio* from roots of Cassava in Paraguay, Bolivia and Brazil. Forbes described *P. sorghiellus* in 1985 and recorded on roots of sorghum, corn and various other grasses in Illinois (Ferris, 1953).

5.1.2 Distribution of root mealybugs on black pepper vines

Root mealybugs were found to colonize on roots and below ground stem region of black pepper vines. But during the peak period of infestation *i.e.* in cooler months, the root mealybugs were also found on the adventitious roots at nodes with which they attach to the standards. These were also observed on the runner shoots when it touches the soil. Devasahayam *et al.* (2010) observed the root mealybug infestation on main, secondary and tertiary roots and basal stem region of rooted pepper cuttings. The presence of root mealybugs on adventitious roots of black pepper is being reported for the first time.

5.1.3 Symptoms

The aerial symptoms of root mealybug infestation on the black pepper vine was the yellow discolouration of the lower leaves. The leaf colour was found to be pale green in case of minor infestation whereas the leaves turned into yellow in severe cases of infestation. Similar symptoms of leaf yellowing were observed due to root

mealybug infestation in banana (Smitha, 2007), groundnut (Huang *et al.*, 2002) and black pepper (Devasahayam *et al.*, 2010).

A gall like thickening also was observed on some infested runner shoots. None of the earlier workers have reported gall formation in the case of pepper root mealybug infestation. However, Williams and Miller (1999) reported that 23 species in 14 genera of pseudococcids are known to be gall formers.

The infested vines were colonized by different species of ants at rhizosphere by which the infestation could be easily identified. Many researchers observed the presence of ant colonies in the root zone of root mealybug infested plants as an identifiable character of root mealybug infestation. For example, in soybean infested by *Dysmicoccus* sp., ants were found to be actively associated with the mealybugs during the summer (Thippaiah and Kumar, 1999). Devasahayam *et al.* (2010) also reported that the infested black pepper vines could be easily distinguished by the activity of associated ant species.

5.1.4 Incidence of root mealybugs on black pepper in Wayanad and Idukki districts with respect to varieties, standards used and age of the vine.

The variety, standards used for trailing and the age of infested black pepper vines were observed during the preliminary survey and per cent of root mealybug infestation was calculated with respect to these parameters. Higher incidence of root mealybugs was observed in the variety, Panniyur-1 in Wayanad (44.83) and Idukki (29.63) districts. The lowest per cent of infestation was observed in Karimunda (13.64) in Wayanad and Jeerakamundi (11.11) in Idukki district. According to Devasahayam *et al.* (2010), 19.60 per cent infestation was observed on variety, Balankotta, 15.7 per cent on Karimunda and 13.2 per cent on Panniyur-1, in Wayanad whereas in Kodagu district of Karnataka, per cent infestation in Karimunda was 29.1 per cent and Panniyur-1 was 8.2 per cent (Fig 1).

The root mealybug infestation with respect to the standards used for trailing pepper vines, showed variation. The highest per cent of infestation was observed on vines trailed on coral tree, *Erythrina* sp. in Wayanad (55.55) and Idukki (24.49) districts followed by jack, *Artocarpus heterophyllus* L. (53.85) in Wayanad district

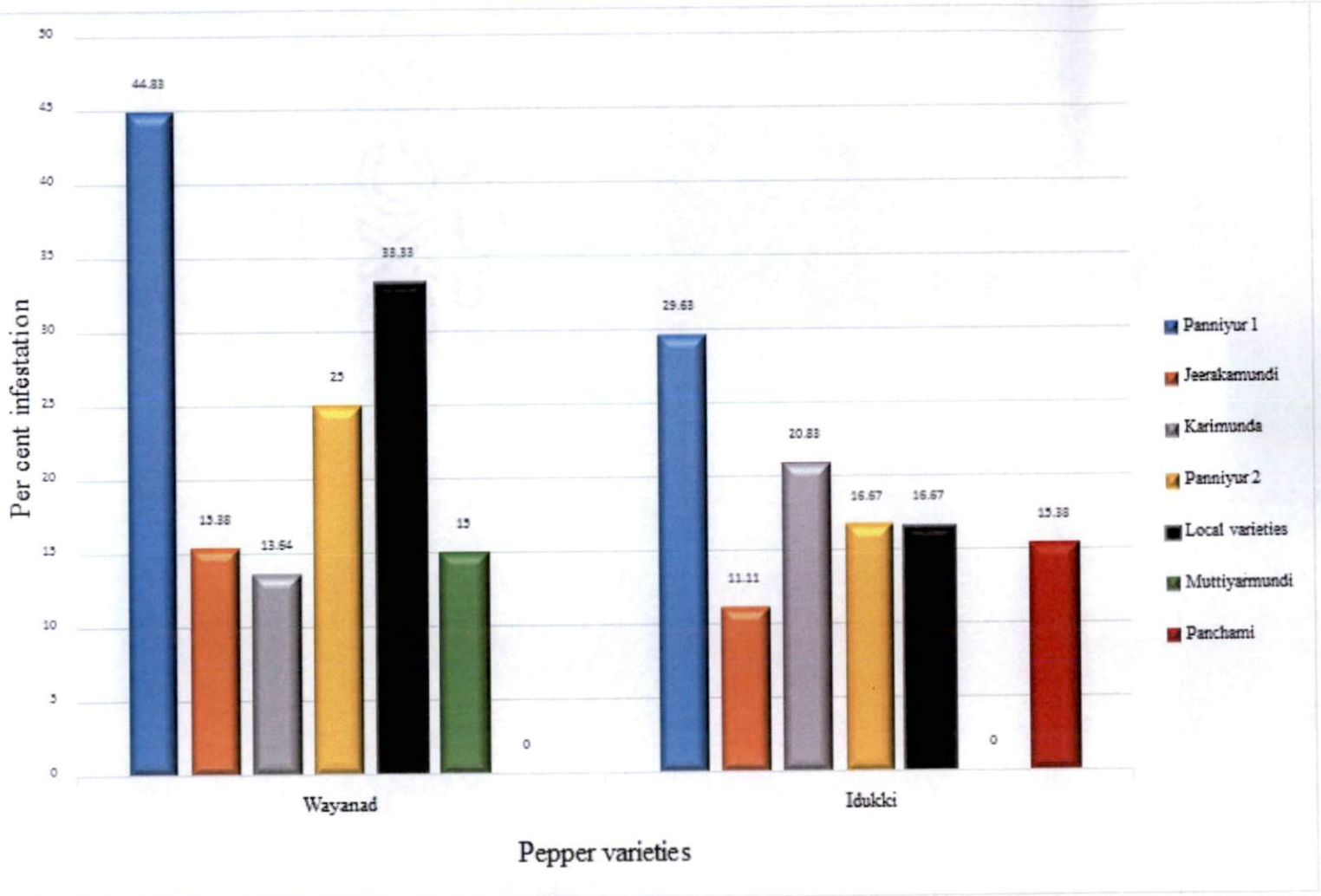


Fig 1: Root mealybug incidence with respect to the varieties of Black pepper

and silver oak, *Grevillea robusta* (20.00) in Idukki district (Fig. 2). Devasahayam *et al.* (2010) also observed higher infestation on vines trailed on silver oak in Wayanad and on *Erythrina* sp. in Kodagu, Karnataka.

In case of the root mealybug incidence with respect to the age of vines, the black pepper vines of all age groups were observed to be infested. Higher incidence of root mealybugs was observed on the vines of four to six years (30 per cent) and seven to nine years age (43.75 per cent) in Wayanad and Idukki districts, respectively (Fig. 3). Devasahayam *et al.* (2010) also reported that the vines of all age groups were infested by root mealybugs.

The contradictions in the results obtained in the present study and that of Devasahayam *et al.* (2010) may be due to the variations in number of observations taken for each parameter and the variations in the popularity of pepper varieties and standards among the farmers.

5.1.5 Extent of root mealybug infestation in Wayanad and Idukki districts, Kerala

Based on the preliminary survey, two panchayats severely infested with root mealybugs were selected from each district. The assessment of infestation was done from August 2013 to July 2014 at monthly intervals and the per cent infestation was calculated for each district (Fig. 4).

The results showed that there was no significant difference in the per cent infestation recorded in Wayand and Idukki districts whereas Devasahayam *et al.* (2010) observed highest per cent of infestation in Wayanad with 8.0 to 21.1 per cent and lowest in Idukki with 0 to 3 per cent infestation.

In the present investigation, the root mealybug infestation was found to increase from August 2013 and September 2013 *i.e* after the south west monsoon with highest infestation in cooler months like December 2013 followed by November 2013, October 2013 and January 2014. The infestation was found to be

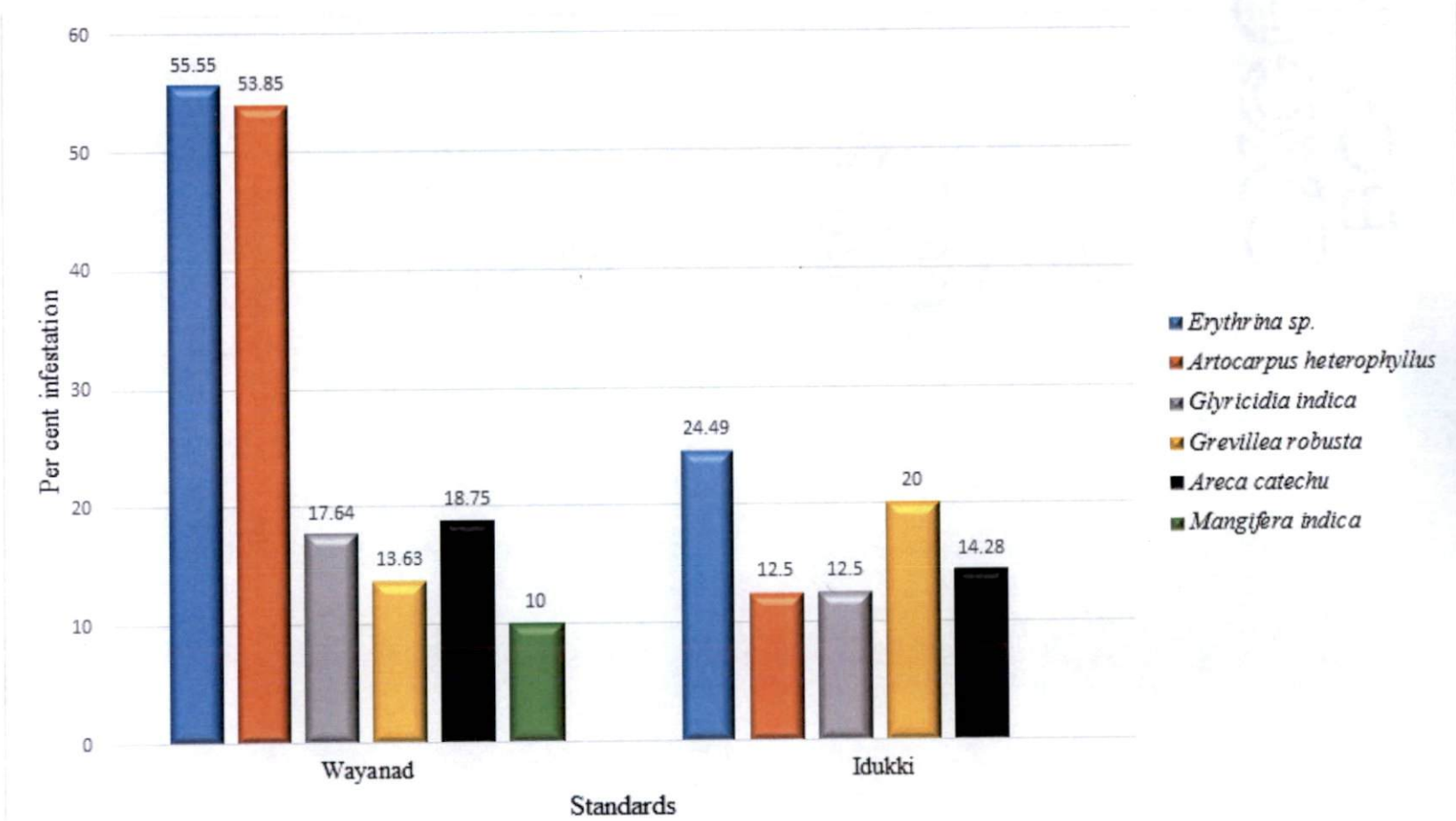


Fig 2: Root mealybug incidence with respect to the standards used

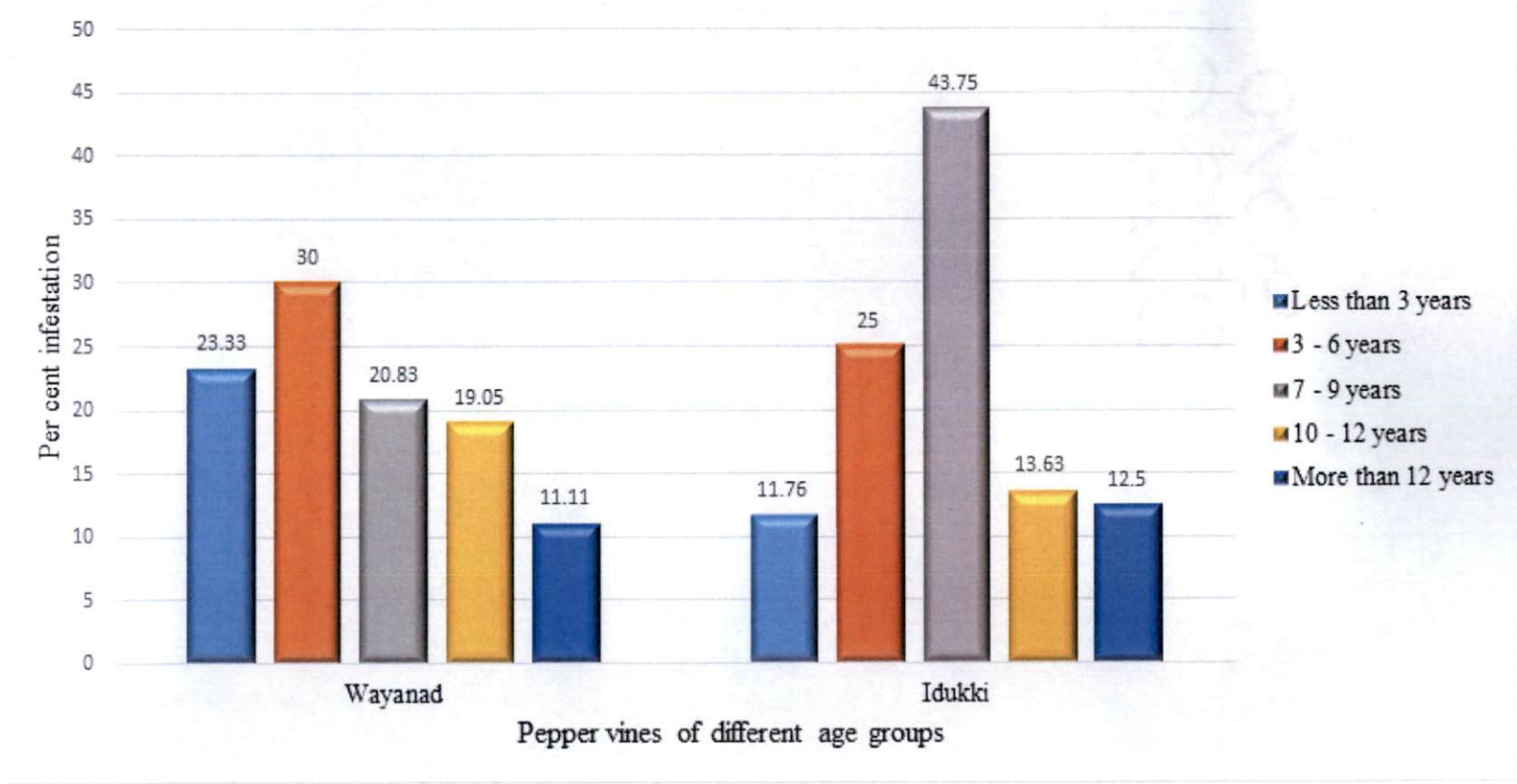


Fig 3: Root mealybug incidence with respect to the age of the black pepper vine

Fig 4: Per cent infestation of root mealybugs on black pepper from August 2013 to July 2014 in Wayanad and Idukki Districts

decreased from February 2014 to May 2014 with lowest per cent of infestation in rainy months (June 2014 and July 2014).

A similar trend of infestation was observed by Firake *et al.* (2015) in ginger by *Formicococcus polysperes,* one of the three species identified in the present investigation. According to them, the incidence of mealybug started after early August 2013 and found to increase till harvesting period (January 2014) with highest population from October 2013 to January 2014. No mealybug infestation was observed before July.

5.1.6 Natural enemies

During the survey in farmer's field of Wayanad and Idukki districts, grubs of the lady beetle, *Horniolus* sp. were observed to predate on root mealybug colonies. *Horniolus* sp. is classified under the sub family Scymninae and tribe Scymnini (Coleoptera : Coccinellidae) which are known to be the predators of aphids, mealybugs and scale insects. There are reports of other workers on the predation by coccinellid beetles.Two species of *Horniolus viz., H. vietnamicus* (Irulandi, 2001) and *H. sororius* (Poorani, 2015) were found to be predating on the coffee mealybug, *Planococcus lilacinus.* Biao (2012) reported another species, *H. hismatsui* predating on *D. brevipes. Scymnus* is another genus of same tribe, Scymnini and a species of *Scymnus* was found to be feeding on banana root mealybug, *Geococcus citrinus* (Smitha and Mathew, 2010c) and Tohamy *et al.* (2008) recorded presence of *S. syriacus* with sugarcane mealybug, *Saccharicoccus sacchari.*

5.1.7 Collateral hosts

Root mealybug infestation on weeds and other crops grown in and around the infested pepper garden were examined to document their collateral hosts and the results showed the presence of *F. polysperes* on two crops grown as intercrop and on eight weed plants in the pepper garden whereas colonies of *D. brevipes* were observed on roots of four plants.

The collateral hosts of *F. polysperes* were *Zingiber officinale* Rose., *Amorphophallus paeoniifolius* (Dennst.) *Ageratum conyzoides* L. *Clerodendron infortunatum* L., *Cyperus kyllinga L. Phyllanthus niruri* L. *Physalis minima* L.,

Synedrella nodiflora L., *Urtica parviflora* Roxb., and *Erythrina* sp. Among these hosts, *Zingiber officinale* was already reported as host of *F. polysperes* (Williams, 2004; Watson, 2007 and Firake *et al.*, 2015). Other host plants of *F. polysperes* that were already reported are *Macaranga triloba, Macaranga conifera, Sapium baccatum, Cocos nucifera, Rhapis excelsa, Lansium domesticum, Piper Betle, Arachis hypogaea* and *Areca catechu* (Williams, 2004). Other hosts recorded in the present study are new additions to the host range of *F. ploysperes.*

Devasahayam *et al.* (2010) also listed *Ageratum conyzoides* L., *Clerodendron infortunatum* L., *Phyllanthus niruri* L. and *Erythrina* sp. as collateral hosts of root mealybugs in black pepper which was observed to be colonized by root mealybugs in the present study also.

Collateral hosts of *D. brevipes* observed in the present study were *Cyperus kyllinga* L., *Commelina diffusa* L., *Coffea robusta* L. and *Cleome rutidosperma* (DC.). *Dysmicoccus brevipes* is a polyphagous species which was reported on many hosts. *C. kyllinga* and *Coffea robusta* were already reported as its hosts (Scalenet, 2013). Perusal of literature shows that *Commelina diffusa* L. and *Cleome rutidosperma* (DC.) are new hosts for *D. brevipes.*

5.1.8 Associated organisms

Root samples and soil samples from the infested pepper gardens were examined for the presence of plant parasitic fungi and nematodes, if any. Presence of plant parasitic fungi could not be observed during the period of investigation but a plant parasitic nematode species, *Rotylenchulus reniformis* was observed in the infested field of Wayanad district. Ramana, 1987 as cited by Ravindra *et al.* (2014) reported this nematode as a pest of black pepper. Devasahayam *et al.* (2010) observed the presence of *Phytophthora capsici* and nematodes, *Meloidogyne incognita* and *Radopholus similis* on the infested black pepper vines of Wayanad district but their association with root mealybug was not reported.

Ant colonies were collected from the root zone of infested vines and four species were identified to be associated with root mealybugs. The species identified

were *Anoplolepis gracilipes* Smith, *Crematogaster rogenhoferi* Mayr, *Lophomyrmex quadrispinosus* Jerdon and *Paratrechina* sp.

Devasahayam *et al.,* 2010 also reported the presence of *Anoplolepis* sp., and *Crematogaster* sp., along with *Technomyrmex* sp. and two other unidentified ant species in the root zone of infested black pepper vines. Venkataramaiah and Rehman (1989) reported nine species of ants in association with mealybugs on coffee, out of which two were *Anoplolepis longipes* and *Paratrechina longicornis.*

5.1.9 Population dynamics of root mealybugs on black pepper

The study of population dynamics of root mealybugs in black pepper showed highest root mealybug population of 13.31 mealybugs/15 cm root length in December 2015 followed by 10.21 mealybugs in January 2016 and 9.94 mealybugs/15 cm root length in November 2015 *i.e.* in cooler months. Lowest population was observed in rainy months, June 2015 and July 2015 with mealybug population of 2.83 and 2.43 mealybugs/15 cm root length, respectively. Highest per cent of infested vines was also observed in December and November 2015 and lowest per cent in June 2015 (Fig. 5).

These results agree with that of Biao (2012) in which the natural population of *D. brevipes* was reported to be developed faster from October to December in province of China. In most of the mealybug species, lowest population was reported to be observed in rainy season, *i.e.* in the months of June and July which was observed in the present study also. Basavaraju *et al.* (2013) studied seasonal incidence of *D. brevipes* on arecanut and recorded the higher population during the period of December – July and remained low in rainy months. *Stictococcus vayssieri,* a root mealybug of cassava was also reported to be severe in the dry season than in the wet season (Ngeve, 2003). But in contradiction to these observations, the population of *Geococcus* sp. was reported to be increased with the commencement of South- West monsoon in June and reached a peak in July (Smitha and Mathew, 2010c).

5.1.10 Correlation of root mealybug population with soil and weather parameters

The correlation analysis of the mealybug population with soil temperature, soil moisture and weather parameters (rainfall, relative humidity and number of rainy

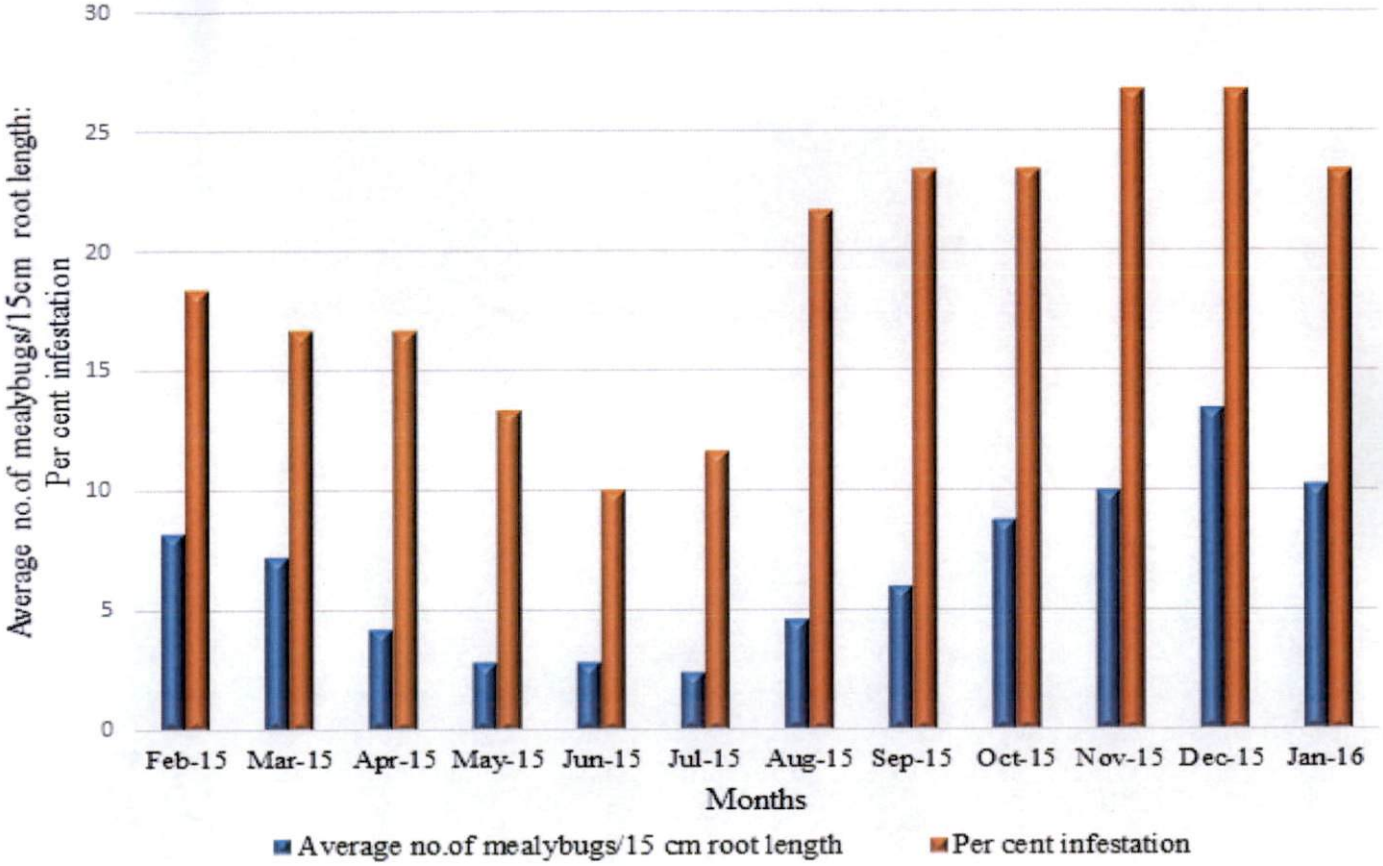


Fig 5: Population of root mealybugs and Per cent infestation on black pepper during different months of observation

days) showed that a significant negative correlation was observed between root mealybug population and soil temperature with correlation coefficients of -0.707 (minimum soil temperature) and -0.735 (maximum soil temperature). Correlation existed between the mealybug population and all other abiotic parameters were non significant (Fig. 6). These findings were similar to that of Liu and Chang (1984) who reported a negative correlation between the population of *Planococcus citri* and temperature. The population of *P. citri* on guava was observed to be highest during cool and dry months from November to April, and the lowest in warm and wet months from July to September.

5.2 BIOLOGY OF THE ROOT MEALYBUG, *Formicococcus polysperes*

Biology of *Formicococcus polysperes,* the dominant species among the three root mealybug species reported during the investigation was studied in laboratory condition. Its biology has not been studied so far and hence, the present study is the first report on biology of *F. polysperes.* Morphometric characters of each developmental stage were recorded using Stereo Zoom microscope with image analyser facility.

5.2.1 Reproductive period

Oviparity was absent in *F. polysperes*, instead the females reproduced ovoviviparously and hence, eggs were not observed during the study. The pre larviposition, larviposition and post larviposition period ranged from 21 to 29, 4 to 15 and 3 to 6 days, respectively.

The observation on its ovoviviparous condition was confirmed by the report of Trapeznikova and Gavrilov (2008) in which *F. polysperes* was listed as ovoviviparous species in which eggs will hatch inside the reproductive system of females itself and deliver young ones. Another species of *Formicococcus*, namely, *F. njalensis* also was reported to reproduce ovoviviparously. Pre larviposition period of

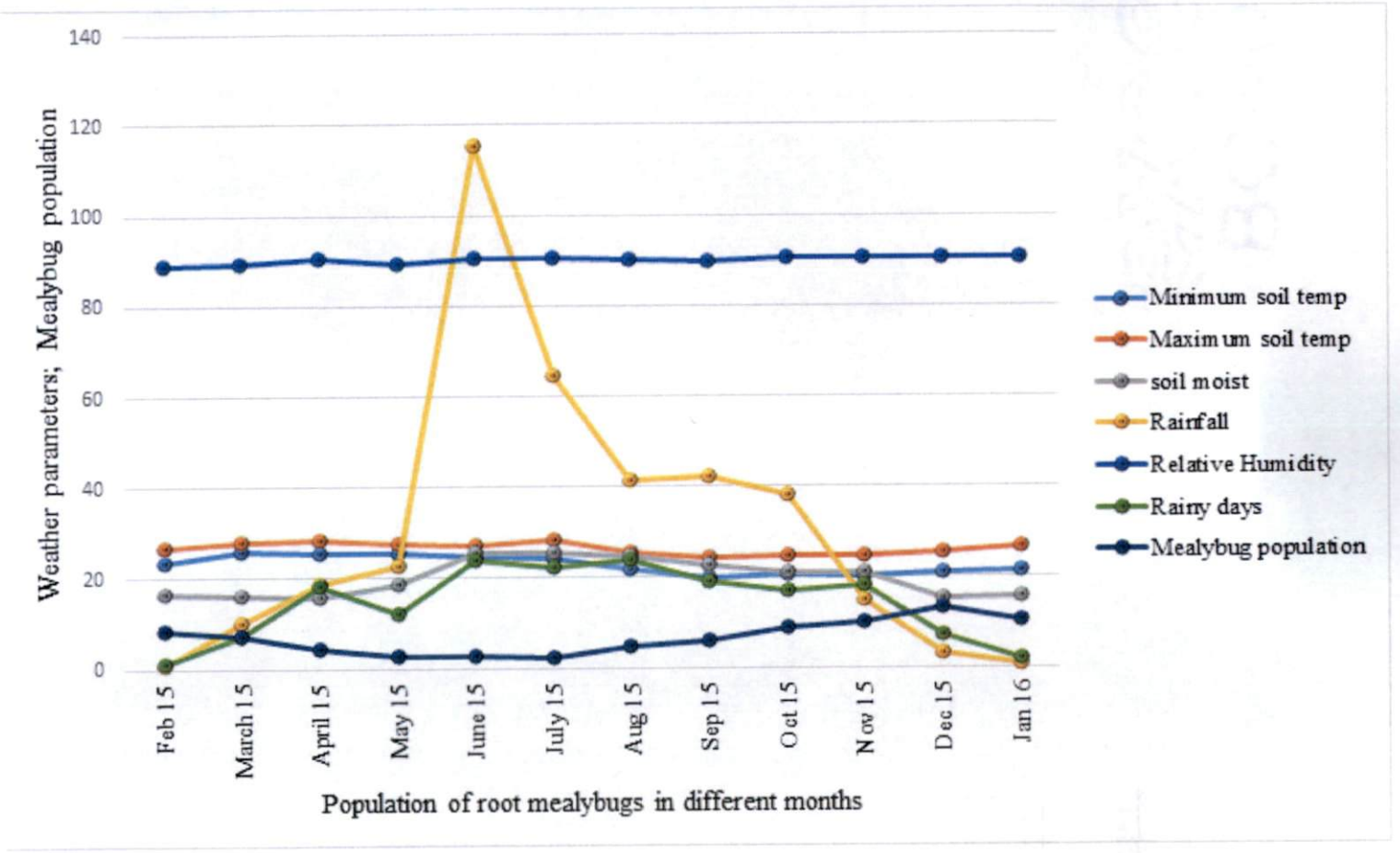


Fig 6: Root mealybug population as influenced by soil and weather parameters

F. njalensis recorded was an average of 23 days which was similar to that of *F. polysperes,* observed during present study (Strickland, 1951).

The record of pre larviposition and post larviposition period was also similar to that of pink form of *Pseudococcus brevipes* (which is now called as *Dysmicoccus brevipes*) with 27 and 5 days, respectively whereas the larviposition period was lesser than that of *P. brevipes* in which 25 days was recorded (Ito, 1938).

5.2.1.1 *Larviposition (Number of crawlers/female)*

Adult female of *F. polysperes* deposited 76-357 crawlers with an average larviposition of 136.15 ± 74.93 crawlers. This observation was similar to the average fecundity recorded in some other mealybugs like *Planococcus citri* with 31 to 310 eggs, an unidentified species of *Planococccus* infesting black pepper, with 22 to 322 eggs (IISR, 2006), *Cataenococcus ensete* with 253 ±17.4 nymphs/female (Addis *et al.* 2008b) and *Geococcus citrinus* with 128. 2 eggs (Mathew *et al.,* 2011).

The sex ratio of *F. polysperes* recorded during the present study was 1: 2.71 (male: female). The sex ratio was observed to be different in different species of mealybugs as evidenced from the studies of Lim (1973) who recorded a sex ratio of 1:1 in bisexual race of *D. brevipes* whereas in *G. citrinus* 1:22.5 was recorded (Mathew *et al.,* 2011).

5.2.2 Development period

The number of developmental stages in females and males varied in *F. polysperes* with three nymphal instars in females and two nymphal, a pre pupal and a pupal instar in males.

This finding is similar to that of *Planococccus citri* (IISR, 2006) and bisexual race of *D. brevipes* (Lim, 1973) in which three nymphal instars in females and two nymphal instars, a pre pupal and a pupal instar in males were reported. In *G. citrinus* (Mathew *et al.,* 2011) and *Rhizoecus amorphophalli* (Sreerag *et al.,* 2014) also, three nymphal instars were reported in female and male mealybugs, with an additional pupal stage in case of males.

5.2.2.1 *First nymphal instar*

Freshly delivered first instar nymphs of *F. polysperes* were oval in shape and light pink in colour. Body colour changed from pink to pale white within a day after larviposition. Duration of the first nymphal instar was lasted 6 to 14 days, which was similar to that of *F. njalensis* in which the average duration of 7 days was reported (Strickland, 1951), whereas the average duration of the first instar in *D. brevipes* was 10 days (Lim, 1973). A similar change in the body colour was also observed in the case of *Phenacoccus solenopsis* on cotton (Rajasekhar *et al.*, 2014).

Length of the first instar nymphs ranged from 0.64 to 0.98 with an average of 0.89 ± 0.09 mm whereas width was 0.35 to 0.59 with an average of 0.51 ± 0.06 mm. Addis *et al.* (2008b) recorded a similar observation of 0.79 ± 0.04 mm length and 0.41 ± 0.09 mm width of *C.ensete* on ensete corms.

5.2.2.2 *Second nymphal instar*

Duration of second instar lasted for 5 to 13 days with an average of 6.35 ± 1.95 days. Strickland (1951) and Ito (1938) recorded almost similar duration of 5 and 6.7 days for the second nymphal instar of *F. njalensis* and *D. brevipes,* repectively.

Length and width of second instar nymphs were ranged from 1.02 to 1.69 mm and 0.56 to 0.99 mm with an average of 1.39 ± 0.25 mm and 0.80 ± 0.14mm respectively. These were similar to that of *C. ensete* with 1.71 ± 0.03 length and 1.28 ± 0.15 width in second instar (Addis *et al.*, 2008b).

5.2.2.3 *Third instar female nymph*

Nymphs were similar to adult females except in body size. Duration of third instar ranged from 6 to 13 days with an average of 8.4 ± 1.87. This is similar to the report of Strickland (1951) and Lim (1973) in which the duration of third instar was recorded as 7.0 and 7.9 days in *F. njalensis* and *D. brevipes.*

Length of third instar female nymph varied from 1.71 to 2.47 mm with an average of 2.10 ± 0.26 mm whereas width was 0.91 to 1.82 mm with average of 1.25 ± 0.22 mm. Addis *et al.* (2008b) recorded a bigger measurements of 2.46 ± 0.03 mm length and 1.64 ± 0.15 mm width in third instar of *C. ensete.*

5.2.2.4 *Pre pupa*

Presence of fine waxy threads over the body surface was an important morphological characteristic of this stage. Duration of this instar lasted from 1 to 2 days with an average of 1.4 ± 0.50 days. Morphometric characters of pre pupa was similar to that of second instar with length and width ranges from 1.01 to 1.62 mm and 0.55 to 0.86 mm with an average of 1.29 ± 0.21 mm and 0.65 ± 0.11 mm, respectively. This is in agreement with the study conducted by Lim (1973) who reported a pre pupal stage in the life cycle of males of *D. brevipes* with 2.5 days of duration.

5.2.2.5 *Pupa*

Male nymphs formed a cylindrical waxy cocoon which covered the entire body. The male nymph inside the cocoon was devoid of wax coating and with a pair of ten segmented antennae which was directed backwards along the lateral side of body and with wing pads. Duration of pupal instar lasted for 6 to 9 days with an average of 7.15 ± 0.88 days. Length and width of male pupa was 1.56 to 2.41 mm and 0.49 to 0.92 mm with an average of 2.03 ± 0.27 and 0.82 ± 0.13 mm respectively. Lim (1973) and Mathew *et al.* (2011) recorded a shorter pupal period of 3.7 days in *D. brevipes* and 5.0 days in *G. citrinus,* respectively.

5.2.3 Adult female

Adult females were apterous, soft bodied, oval shaped and pink in colour. Body segmentation was clearly visible with powdery wax coating. Waxy filaments surrounding the body margin were short and thick. The morphometric measurements of adult female varied from 2.1 to 3.25 mm in length with an average of 2.65 ± 0.32 and 1.3 to 1.94 mm in width with an average of 1.56 ± 0.24 mm.

Addis *et al.* (2008b) recorded morphometric measurements of *C. ensete* with 3.31 ± 0.07 mm length and 2.95 ± 0.27 width which is in agreement with that of *F. polysperes* in the present study.

5.2.4 Male

Males were morphologically different from females with slender, delicate and elongated body, reddish brown in colour with a pair of well developed, pale white and opaque wings and a pair of long waxy caudal filaments. A pair of long, ten segmented antennae was another morphological characteristics of male. Length and width of male were 0.78 to 1.57 mm with an average of 1.13 ± 0.26 mm and 0.24 to 0.46 mm with an average of 0.33 ± 0.06 mm, respectively.

Similar observations were recorded by Mathew *et al.* (2011) in which males of *G. citrinus* were also winged with a pair of narrow and elongate opaque wings. Average length and breadth were 1.64 mm and 0.19 mm, respectively.

5.2.5 Adult longevity

Males were short lived when compared to the mature females with an average longevity of 1.8 ± 0.52 days ranged from 1 to 3 days whereas females lived for an average of 37.4 ± 3.10 days ranging from 30 to 41 days. Lim (1973) recorded adult longevity of 1 to 3 days and 17 to 49 days respectively, in males and females of *D. brevipes.*

5.2.6 Total life cycle

Life cycle of males was shorter than that of females which ranged from 20 to 31 days with an average of 23.7 ± 3.01 whereas life cycle of females ranged from 49 to 70 days with an average of 60.55 ± 5.36 days.

Mathew *et al.* (2011) also recorded a shorter life cycle in males of *G. citrinus* than that of females. According to them females lived for 15.1 days and males for 5.0 days.

5.3 SUSCEPTIBILITY OF POPULAR PEPPER VARIETIES

The reaction of four popular varieties of black pepper to mealybugs as shown in Fig. 7 revealed that Panniyur-2 was highly susceptible by supporting significantly higher number of mealybugs (81.58) than other three varieties. Panniyur-2 was followed by Panniyur-1 with an average of 44.5 mealybugs/plant. Out of the four varieties, Karimunda was found to be the least susceptible with

lower number of mealybugs (17.67 mealybugs/plant) and Panniyur-8 supported 25.67 mealybugs/plant. During the field survey also, higher incidence of root mealybugs were observed on Panniyur-1 and Panniyur-2 (Fig. 7).

5.4 EVALUATION OF ENTOMOPATHOGENIC FUNGI AGAINST ROOT MEALYBUG

Four entomopathogenic fungi *viz., Beauveria bassiana, Metarhizium anisopliae, Paecilomyces lilacinus* and *Lecanicillium lecanii* were evaluated at three different spore concentrations of 2 $x10^6$, 2 $x10^7$ and 2 x 10^8 spores/ml to test their efficacy against the root mealybugs. The experiment was conducted in both laboratory and as pot experiment.

Under laboratory conditions, *L. lecanii* was effective at 2 x 10^8 spores/ml which caused a per cent mortality of 50 and 56.67, respectively at five and seven days after treatment. This was followed by *L. lecanii* at 2 $x10^6$ and 2 $x10^7$spores/ml (Fig. 8). This result was similar to the report of Banu *et al.* (2010) in which mortality of adults of *Phenacoccus solenopsis* caused by *V. lecanii* at 5g/l (2 x 10^8 cfu/gm) was 55.56 per cent at 48 hours after the treatment in the laboratory.

In pot experiment also, *L. lecanii* at 2 x 10^8 spores/ml was found to be superior to other entomopathogenic fungi with a per cent mortality of 21.11 and 28. 33, respectively at one week after first and second drenching, respectively (Fig. 9). The findings of IISR (2006) is in conformation with the results obtained in the present investigation. Accordingly the natural isolate of *V. lecanii* caused 20.10 and 27.70 per cent mortality of the root mealybug, *Planococcus* sp on black pepper respectively, at 15 and 30 days after treatment.

Smitha and Mathew (2010a) also found that *Cephalosporium lecanii* (*L. lecanii*) as the best among the three fungi screened, *viz.*, *B. bassiana*, *Hirsutella sp.* and *C. lecanii*. They recorded 1.95 mealybug colonies per sample in *C. lecanii* treated banana plants at five months after planting.

The low per cent mortality obtained during present study may be the unfavourable environmental conditions prevailed for the development of *L. lecanii* during the experiment period.

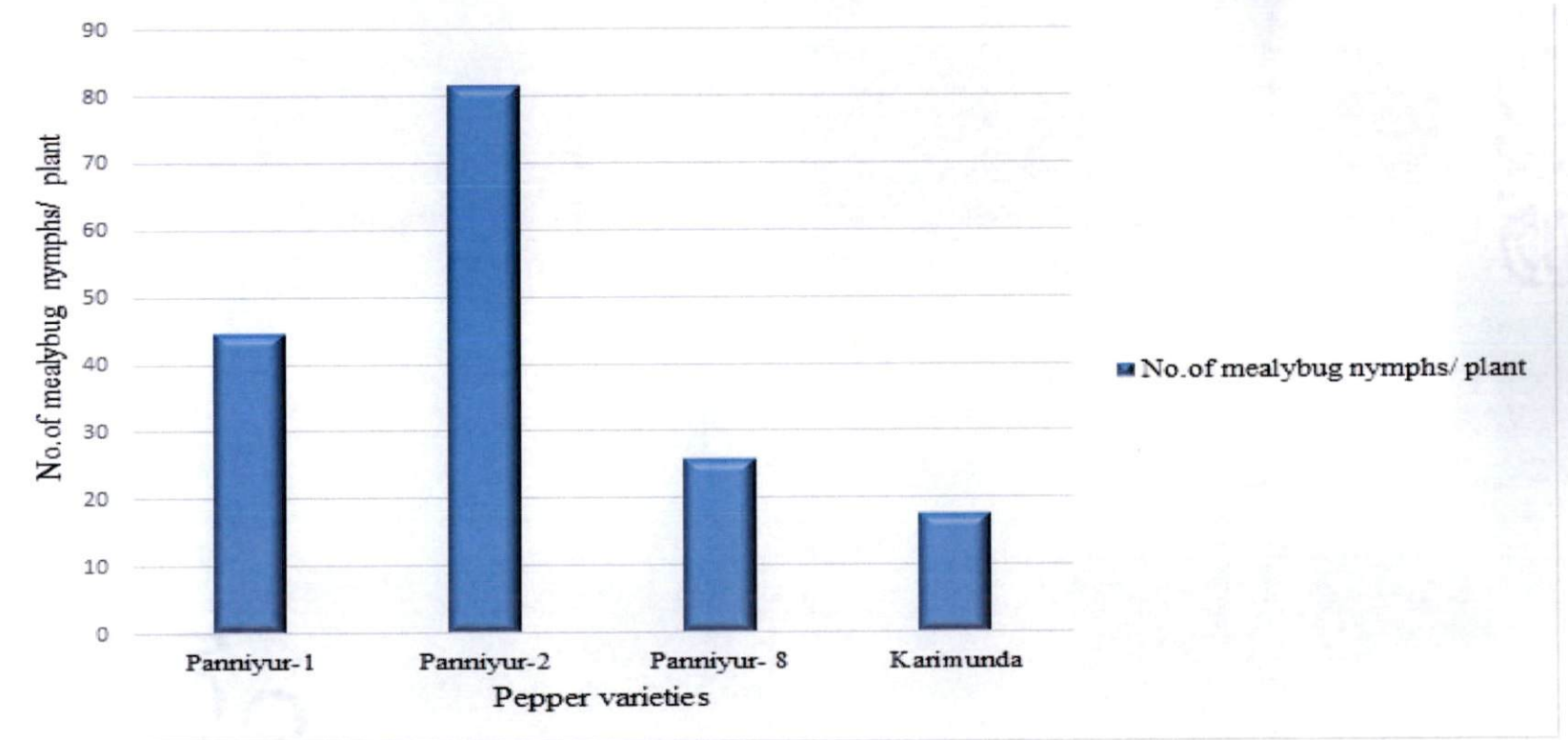


Fig 7: Number of mealybugs on different pepper varieties

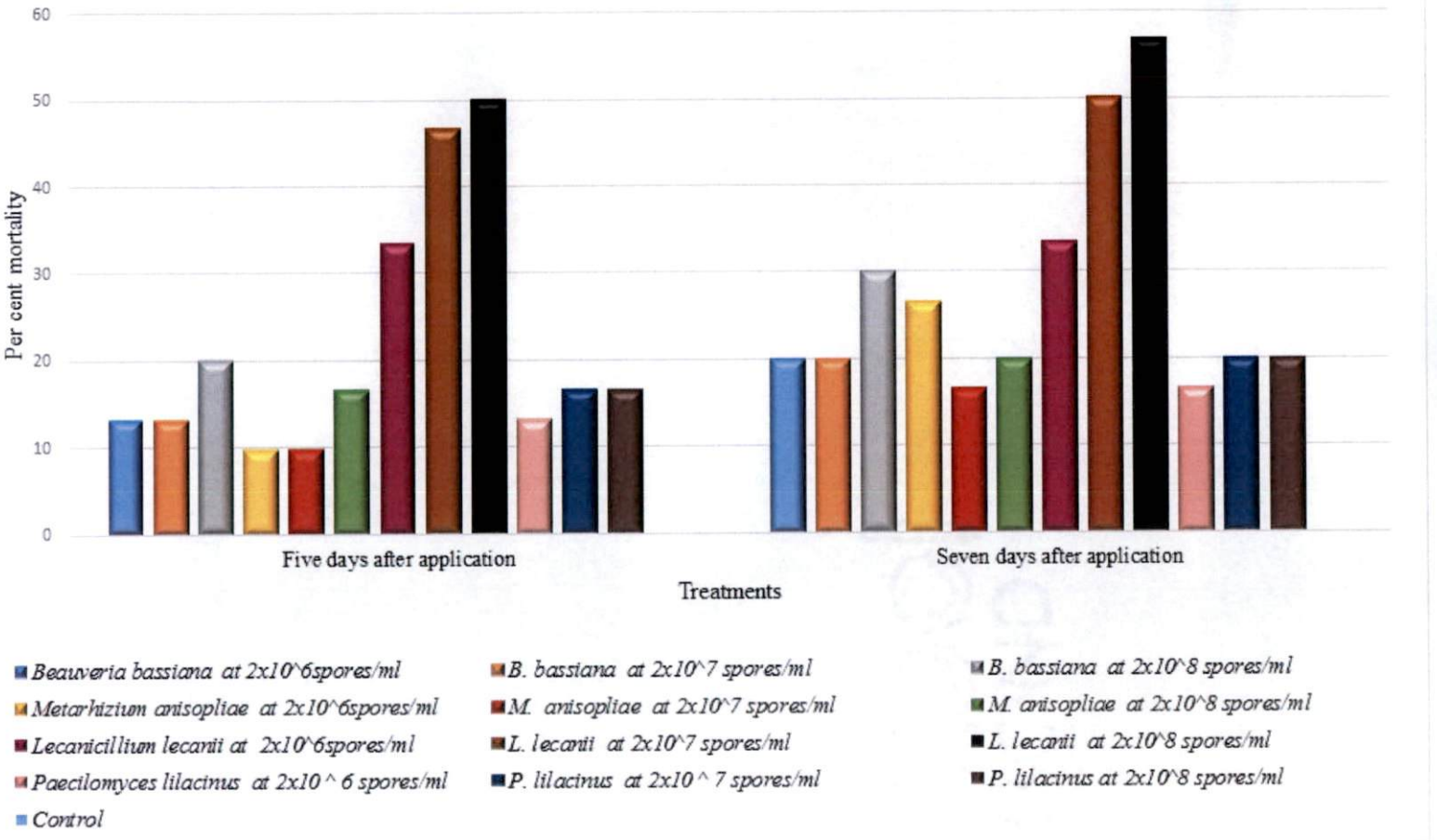


Fig 8: Mortality of root mealybugs by different entomopathogenic fungi in laboratory

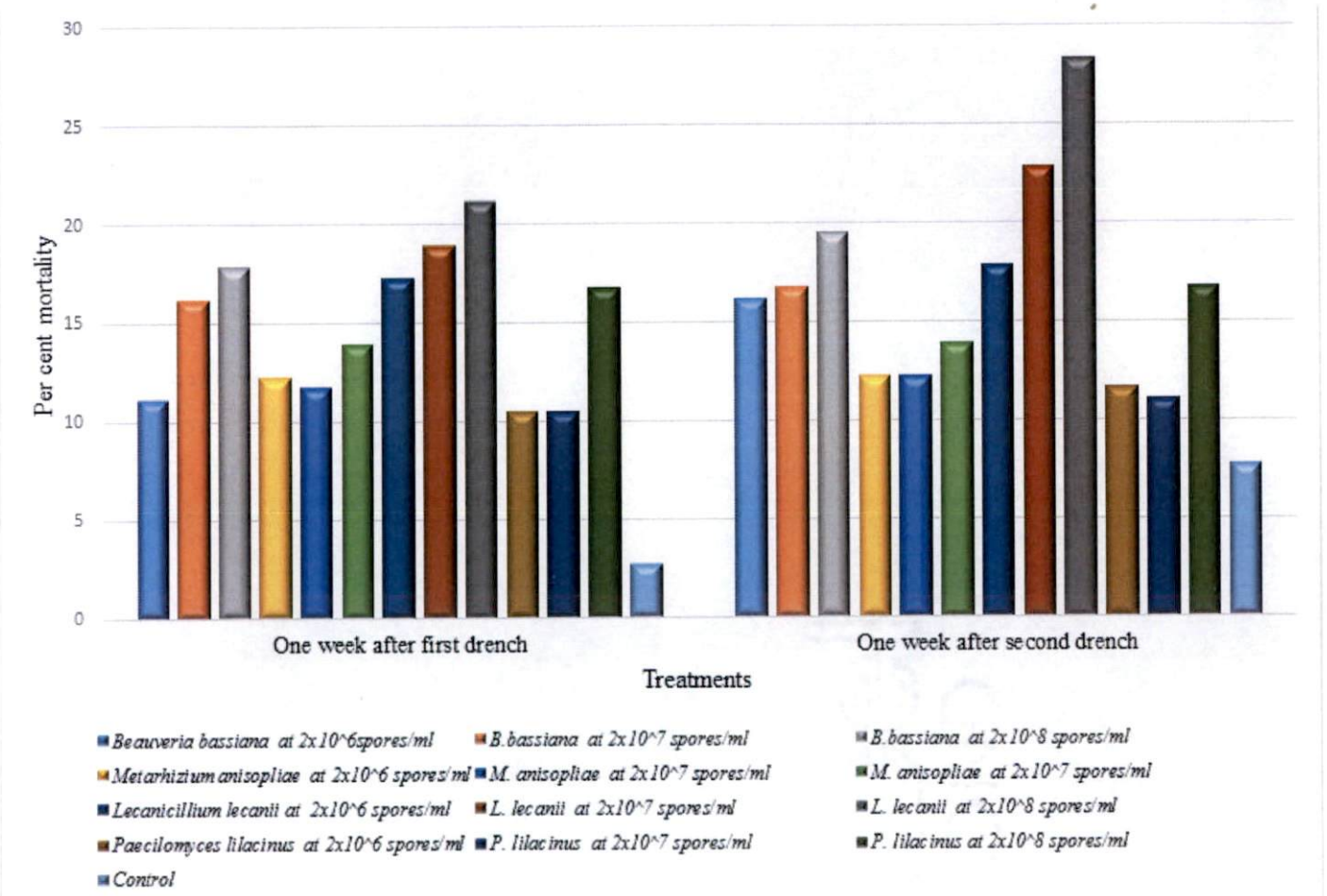


Fig 9: Mortality of root mealybugs by different entomopathogenic fungi in pot experiment

population in banana. Tadesse *et al.* (2010b) also reported that chlorpyriphos 48 EC @ 0.002 ml/l

Walstad *et al.* (1970) cited by Tehri *et al.* (2015) reported that the entomopathogenic fungi require relative humidity above 92.5 per cent and temperature between 15 to 35° C for spore germination, mycelial growth and sporulation. The weather data on maximum and minimum temperature observed during the present study period were 31.5 and 23.7° C, respectively with relative humidity of 83.2 per cent in morning and 65.6 per cent in evening.

5.5 EVALUATION OF CHEMICAL INSECTICIDES AGAINST ROOT MEALYBUG

Efficacy of eight chemical insecticides were evaluated against the root mealybug in the laboratory and pot experiment. In the laboratory, chlorpyriphos 20 EC @ 300 g a.i/ha and imidacloprid 17.8 SL @ 25 g a.i/ha caused highest mortality of 80 per cent at one day after treatment (Fig. 10). In pot experiment also, imidacloprid 17.8 SL @ 25 g a.i/ha and chlorpyriphos 20 EC @ 300 g a.i/ha caused highest mortality of 59.44 and 55.56 per cent, respectively at one week after first drenching. After one week of second drenching, imidacloprid 17.8 SL @ 25 g a.i/ha and chlorpyriphos 20 EC 300 g a.i/ha caused mortality of 63.89 and 62.78 per cent respectively, which was higher than the other treatments (Fig. 11).

IISR (2006) also reported similar results, in which imidacloprid 0.005 per cent was effective against *Planococcus* sp. in black pepper causing 90 per cent population reduction at 30 days after treatment in laboratory evaluation. According to the report, drenching the affected vines in the field with imidacloprid 0.0125 per cent, was also found to be effective in reducing the population of root mealybugs up to 60 days after treatment. De Souza *et al.* (2007) reported that imidacloprid 700 WG caused 100 per cent mortality of coffee root mealybug, *Dysmicoccus taxensis* in a single application. They reported that imidacloprid applied at 0.525 g a.i/vine was found to be effective in reducing more than 99 per cent of *Pseudococcus* sp. population in vineyards.

In the present study, chlorpyriphos 20 EC @ 300 g a.i/ha was also found controlling root mealybugs, *F. polysperes* in black pepper. Its efficacy was recorded

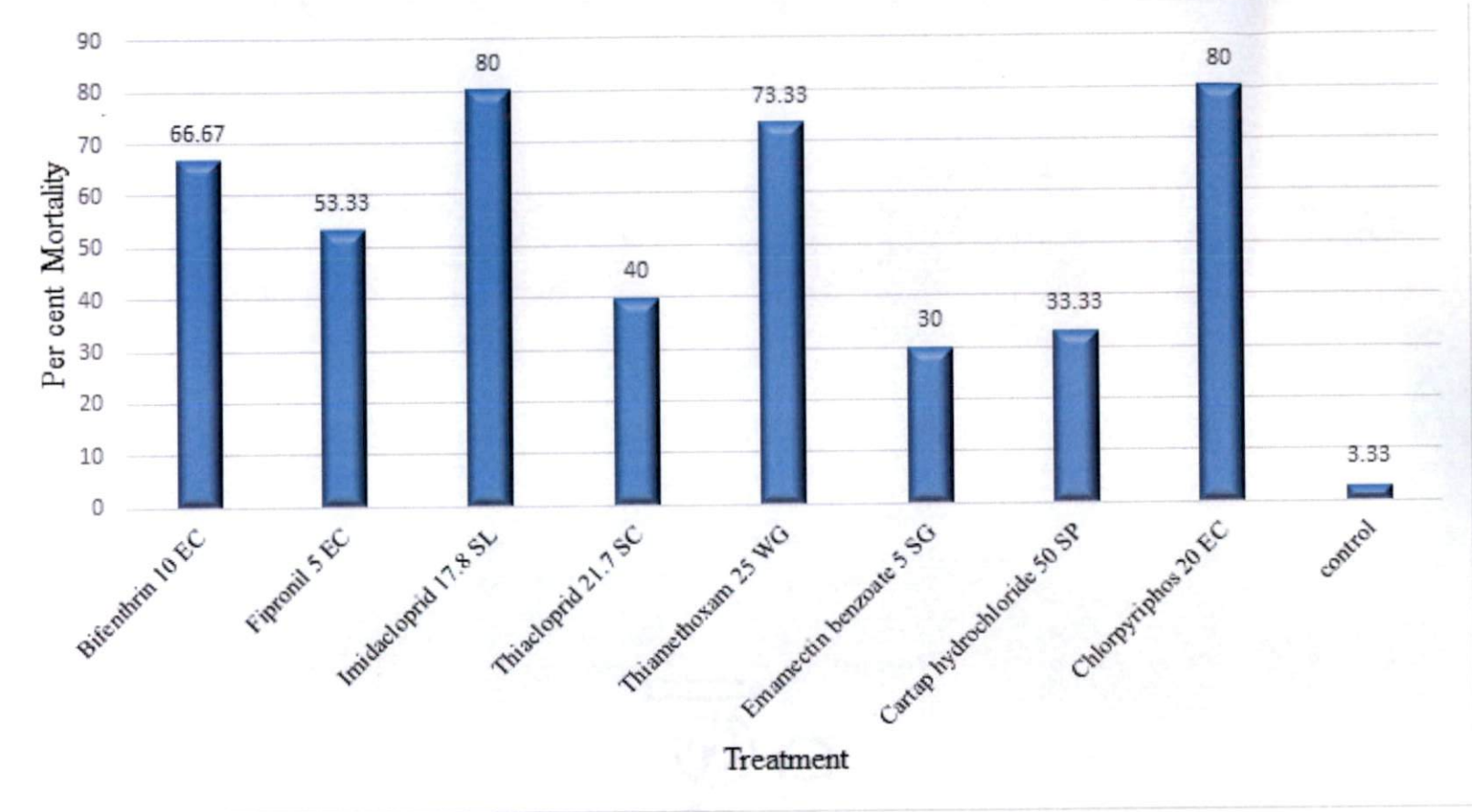


Fig 10: Mortality of root mealybugs by different chemical insecticides in laboratory

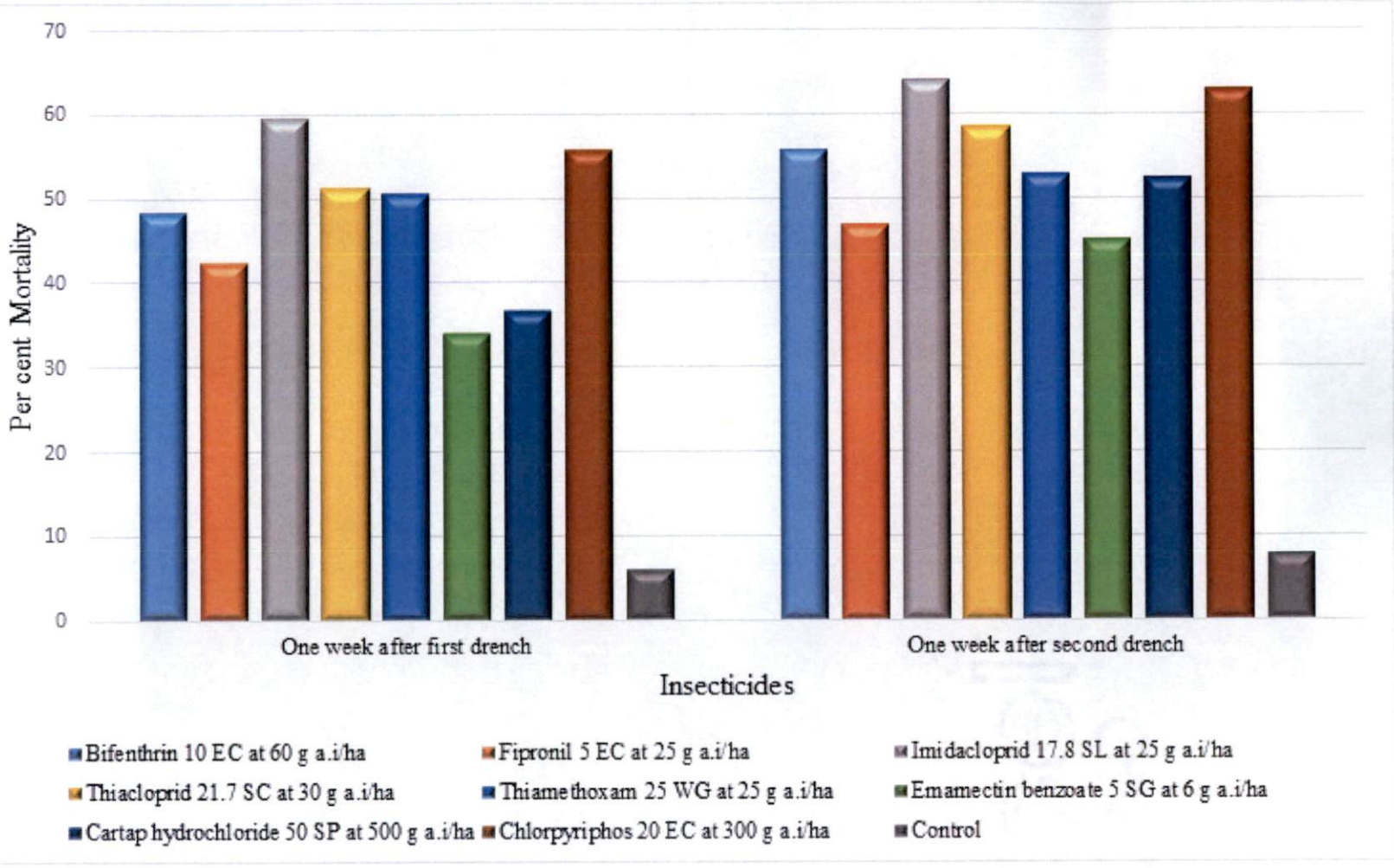


Fig 11: Mortality of root mealybugs by different chemical insecticides in pot experiment

by Smitha and Mathew (2010a) also. According to them, drenching of chlorpyriphos (0.05%) at monthly intervals @ 2.5 ml/l effectively reduced the root mealybug caused 98 per cent mortality of ensete root mealybug under field and greenhouse conditions. According to Mathew and Mani (2016), drenching the affected vines with chlorpyriphos 0.075 per cent was found to be effective in controlling the pepper root mealybug infestation.

5.6 COMPATIBILITY OF EFFECTIVE ENTOMOPATHOGENIC FUNGUS WITH INSECTICIDES

The most effective entomopathogenic fungus (*L. lecanii*) identified from the pot experiment was tested for its compatibility with all the insecticides tested in the present investigation and two fungicides which were commonly used for disease management in black pepper. The results obtained with respect to the radial growth, per cent inhibition, sporulation and spore viability of fungus showed that the insecticide, imidacloprid 17. 8 SL and fungicide copper hydroxide 77 WP were compatible with *L. lecanii* (Fig. 12).

Imidacloprid 17.8 SL at 25 g a.i/ha and copper hydroxide 77 WP at 1 % were found to cause 25.52 and 34.72 per cent inhibition in the growth of *L. lecanii* with radial growth of 3.70 and 3.20 cm, respectively. The per cent reduction induced in sporulation and spore viability was 10.43 and 4.19, respectively by imidacloprid 17.8 SL and 10.32 and 10.30, respectively by copper hydroxide 77 WP. The fungicide, carbendazim completely inhibited the growth of *L. lecanii* on solid media.

This result was similar to that of Gonzalez *et al.* (2013) in which imidacloprid was found to be compatible with *L. lecanii* with respect to growth inhibition, spore production capacity and conidial germination. According to them, imidacloprid had no effect on conidial germination. XiaoMan *et al.* (2013) also reported that imidacloprid 25 WP had the lowest effect on conidial germination and the inhibition rate recorded was 39.7 per cent. Krishnamoorthy *et al.* (2007) found that carbendazim was highly toxic to *L. lecanii* by inducing complete inhibition of its mycelial growth and germination. Carbendazim is a systemic fungicide whereas copper hydroxide is a

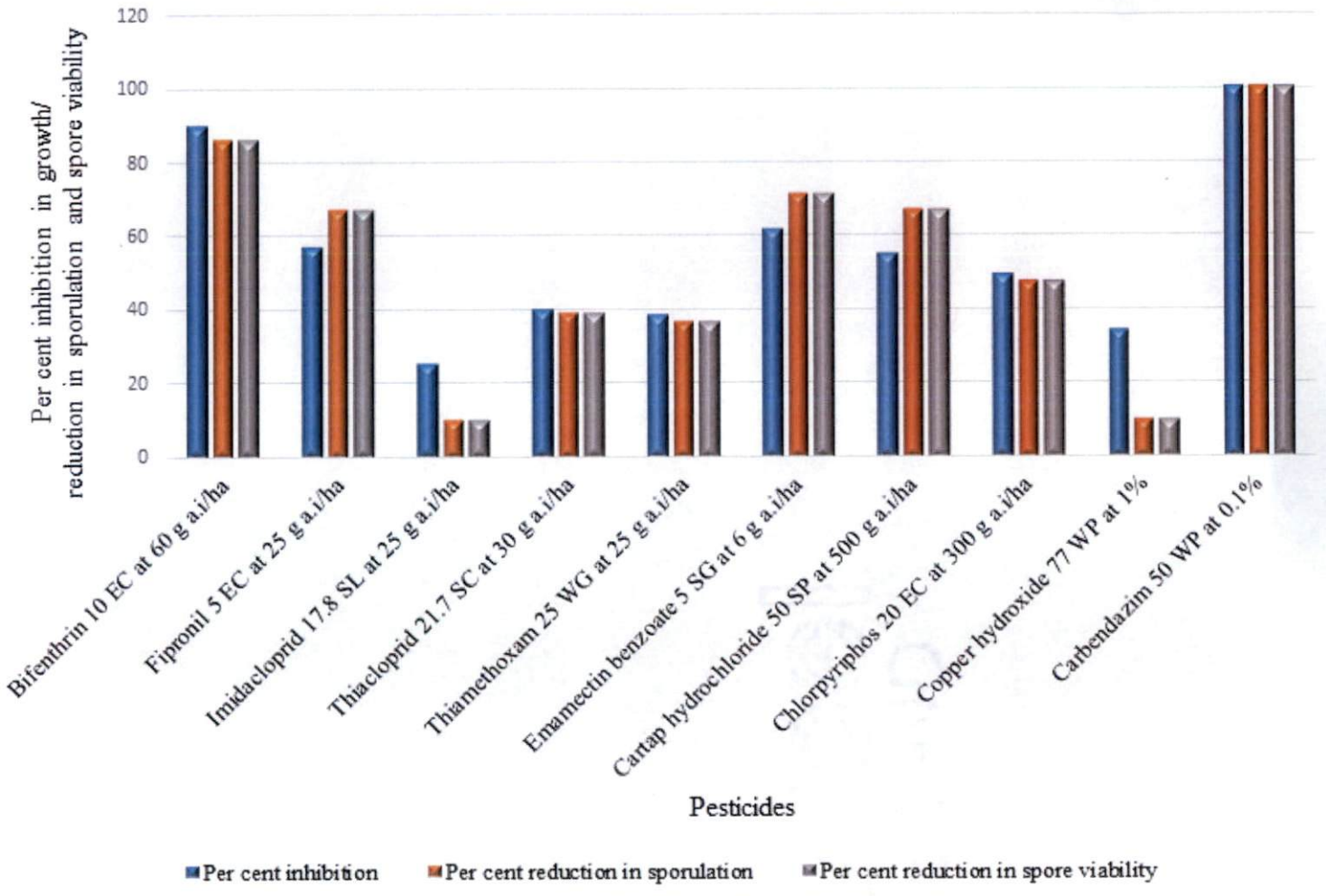


Fig 12: Effect of different chemical insecticides on *Lecanicillium lecanii* with respect to growth inhibition, sporulation and spore viability

contact fungicide. So carbendazim will be more effective in inhibiting the growth of hyaline fungi.

5.7 MANAGEMENT OF ROOT MEALYBUG IN POT CULTURE EXPERIMENT

The best treatments from the screening tests of entomopathogenic fungi and chemical insecticides were evaluated alone and in combination of entomopathgenic fungi and insecticides along with the common practice adopted by farmers against the root mealybug, *F. polysperes*.

In the present experiment, imidacloprid 17. 8 SL caused highest mortality of 56.67 per cent followed by chlorpyriphos 20 EC and combination treatment of imidacloprid 17. 8 SL + *L. lecanii* at 2x 10^8spores/ml both of which caused 53.89 per cent mortality at one week after first drenching. After one week of second drenching also, highest per cent of mortality was caused by imidacloprid 17. 8 SL (65.00) and followed by chlorpyriphos 20 EC and imidacloprid 17. 8 SL + *L. lecanii* at 2x 10^8spores/ml with 60.00 and 58.89 per cent mortality of root mealybugs, respectively. Combination treatment of chlorpyriphos 20 EC + *L. lecanii* at 2x 10^8spores/ml caused mortality of 46.11 and 51.11 per cent, respectively at one week after first and second drenching (Fig. 13).

Similar results were obtained by Smitha and Mathew (2010a) in an experiment in which various treatments *viz.,* sodium silicate, *V. lecanii,* NSKE and chlorpyriphos were evaluated singly and in combinations against banana root mealybug. According to them, treatment with chlorpyriphos and various combination treatments with chlorpyriphos were found to be superior to other treatments and treatment combinations. In the present study, combination of the insecticides, imidacloprid 17. 8 SL and chlorpyriphos 20 EC with *L. lecanii* did not add to the toxicity of insecticides. It may be due to the inhibition effect induced by the insecticides, imidacloprid 17.8 SL and chlorpyriphos 20 EC on *L. lecanii.* In the compatibility test during present study also, an inhibition of 25 per cent was recorded in the growth of *L. lecanii* which is in confirmation with the results obtained by XiaoMan *et al.* (2013) who recorded 39.7 per cent inhibition in conidial germination of *L. lecanii* by imidacloprid.

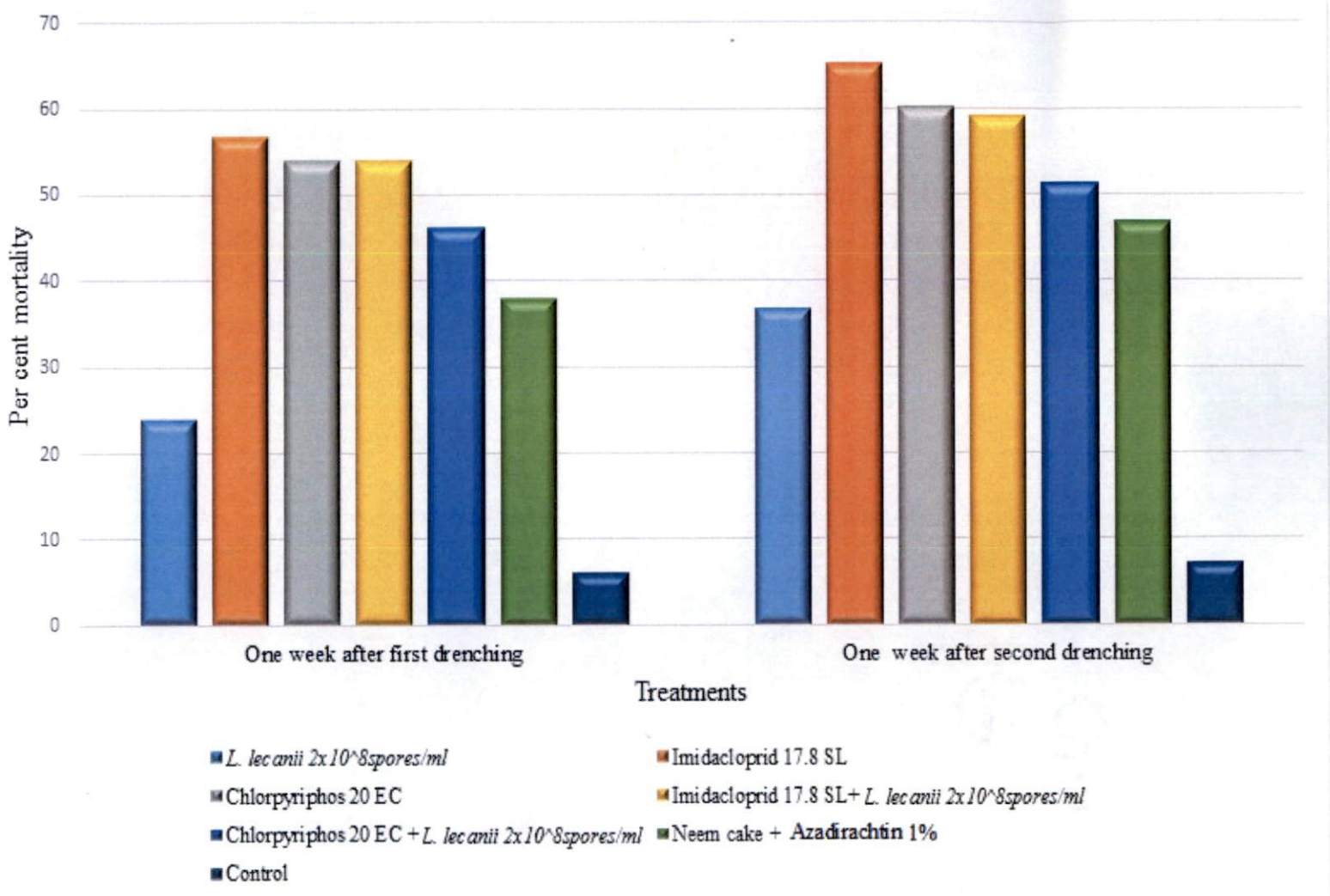


Fig 13: Mortality of root mealybugs due to different treatments of pot experiment

The combination treatment with neem cake and Azadirachtin (1%) caused 37.78 and 46.67 per cent mortality of root mealybugs at one week after first and second drenching, respectively. IISR (2006) reported that various neem products *viz.,* Nimbicidine (1%), Neemgold (1 %), neem oil (1%) and neem seed kernel extract (5%) caused reduction of 52.6, 17.8, 21.8 and 40.3 per cent, respectively in root mealybug population which is almost similar to the results obtained during present study.

Lowest mortality was recorded in treatment with *L. lecanii* alone at 2x 10^8spores/ml causing 23.88 and 36.67 per cent mortality respectively, at one week after the first and second drenching. Smitha and Mathew (2010a) also reported that the treatment with *V. lecanii* was not effective aginst banana root mealybugs which recorded only 31.54 per cent reduction.

5. 8 FIELD EVALUATION OF EFFECTIVE TREATMENTS

The best treatment from the pot experiment, imidacloprid 17.8 SL at 25 g a.i/ha was evaluated in the root mealybug infested field at Kaniyambetta panchayat of Wayanad district and compared with the efficacy of chlorpyriphos 20 EC at 300 g a.i/ha in field. The mealybugs were counted on 15cm root length and the population was expressed as number of mealybugs on 15 cm root length.

The results obtained during the present study showed that both treatments caused significant reduction in root mealybug population, out of which, imidacloprid 17.8 SL at 25 g a.i/ha was found to be superior to chlorpyriphos 20 EC @ 300 g a.i /ha. At one week after first drenching, 97.98 per cent reduction of mealybug population was recorded in treatment imidacloprid 17.8 SL whereas in chlorpyriphos 20 EC, 79.89 per cent reduction was recorded. At two weeks after first drenching, 100 per cent reduction was recorded in treatment with imidacloprid 17. 8 SL whereas in chlorpyriphos 20 EC, the per cent reduction recorded was 86.06 at two weeks after first drenching and 94.54 per cent at one week and two weeks after second drenching (Fig. 14).

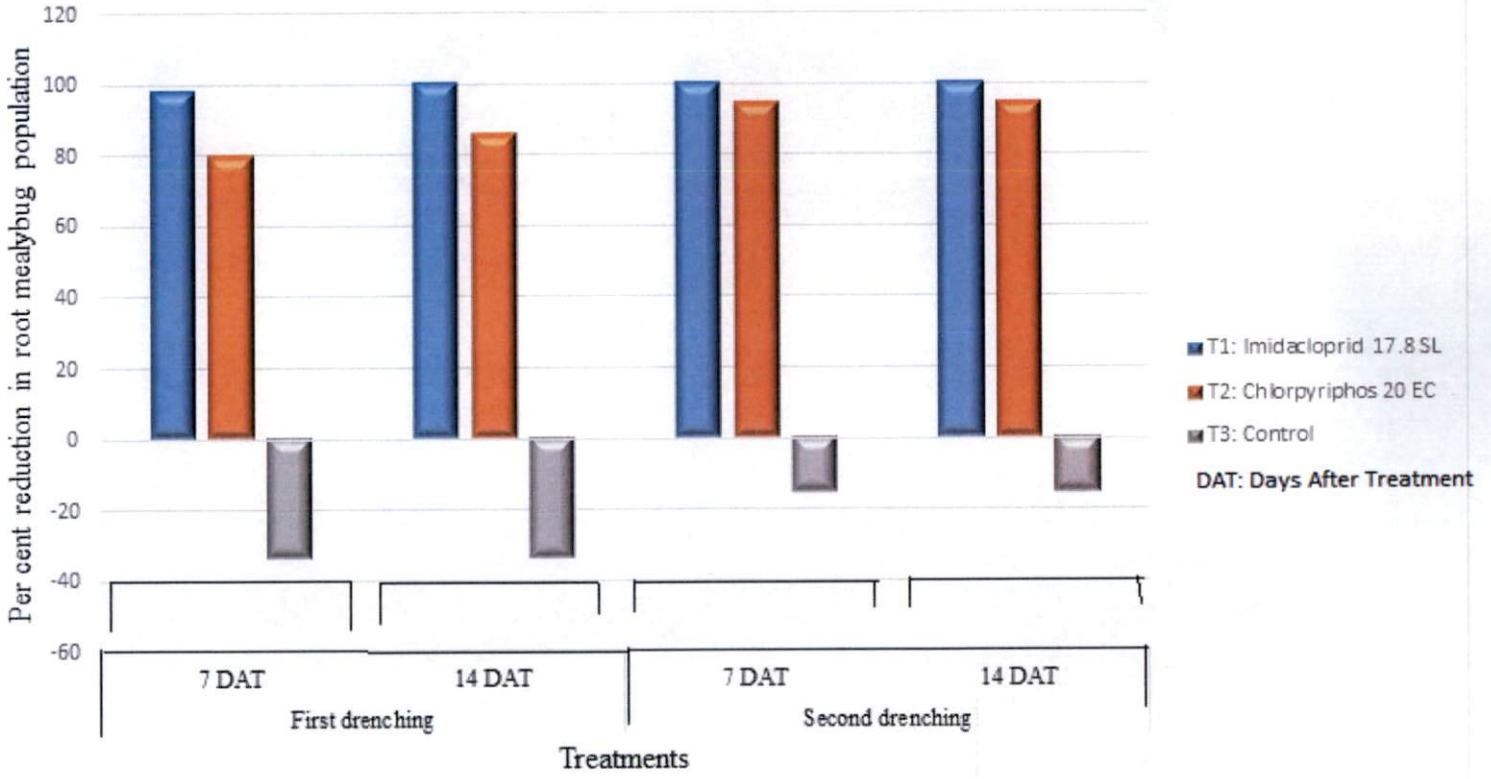


Fig 14: Per cent reduction in root mealybug population in different treatments of field evaluation

IISR (2006) also observed similar results when different insecticides *viz.*, imidacloprid (0.0125%), acetamiprid (0.0125%), carbosulfan (0.075%) and chlorpyriphos (0.075%) were evaluated against root mealybugs in infested black pepper garden. According to the report, zero mealybugs were recorded on 3 cm root length upto 60 days after treatment with imidacloprid while the treatment with chlorpyriphos controlled root mealybugs up to 30 days after treatment and recorded 6.3 mealybugs/3 cm root length at 60 days after treatment.

The results thus obtained during the present investigation showed that three root mealybug species namely, *Formicococcus polysperes, Dysmicoccus brevipes* and *Pseudococcus* sp. were found to be infesting the black pepper in Wayanad and Idukki districts leading to yellow discolouration of leaves. Among the three species, *F. polysperes* was found to be the dominant species and the mealybugs were found to colonize the roots of pepper and other plants like intercrops and weeds in black pepper garden. They were also associated with four different species of ants and a coccinellid grub of *Horniolus* sp. was found to be predating on root mealybugs.

The root mealybug population was negatively correlated with soil temperature with its peak in cooler months (November and December) and lowest population in rainy monthsn (June and July).

Biology of the dominant root mealybug species, *F. polysperes* was studied and found that the females exhibit ovoviviparity. The development period of females included three nymphal instars whereas males had two nymphal, a pre pupal and a pupal instar. Males were short lived than females and lifecycle of males were shorter than that of females. Sexual dimorphism was present in this species, in which males were winged whereas females were wingless.

Pepper varieties showed variation in susceptibility to the root mealybugs and Panniyur-2 was highly susceptible followed by Panniyur-1 and the least susceptible was Karimunda.

Among the different entompathogenic fungi evaluated against root mealybugs, *L. lecanii* at 2x 10^8spores/ml was effective whereas in chemicals, imidacloprid 17. 8 SL at 25 g a.i/ha and chlorpyriphos 20 EC at 300 mg a.i/ha were superior. Imidacloprid

was found to be compatible with *L. lecanii* with respect to the mycelial growth, sporulation and spore viability.

On evaluating the best entomopathogenic fungi and chemical insecticides alone and in combinations along with farmer's common management practice, imidacloprid 17. 8 SL at 25 g a.i/ha was found to be highly effective and superior in field evaluation.

Summary

6. SUMMARY

A complex of species of mealybugs was found to infest the roots of black pepper in Kerala and the infestation was reported to be serious in high altitudes of Kerala. Hence, an investigation was carried out to document the root mealybug species infesting black pepper and their associated fauna, to study the biology of dominant root mealybug species, susceptibility of popular pepper varieties and management of root mealybugs in black pepper. Laboratory studies and pot experiments were carried out at College of Horticulture, Vellanikkara and studies on population dynamics and field evaluation of management practices were conducted at farmer's field at Mananthavady and Kaniyambetta panchayats of Wayanad district.

A preliminary survey was conducted during the period of August to December 2013 in different panchayats of Kannur, Wayanad and Idukki districts of Kerala to collect and identify the root mealybug species infesting black pepper. During the survey, infestation was observed in Wayanad and Idukki districts only. Three species of mealybugs were found to be infesting the below ground parts of black pepper and they were, *Formicococcus polysperes* Williams, *Dysmicoccus brevipes* Cockerell and *Pseudococcus* sp.

Out of the three species, *F. polysperes* was found to be the dominant one infesting black pepper. *D. brevipes* was collected from Manathavady panchayat of Wayanad district only, where the infestation of *F. polysperes* was also present. The third species, *Pseudococcus* sp. was found to be infesting black pepper in Nedumkandam panchayat of Idukki district and Kaniyambetta panchayat of Wayanad district along with *F. polysperes.*

The root mealybugs were found to colonize roots and basal stem region of black pepper. The runner shoots that touches the soil were also observed to be colonized with root mealybugs. In severe cases of infestation, the root mealybugs were also found on the adventitious roots at nodes with which they are attached to the standards.

The leaves of infested vines were found to be pale green in colour whereas in severe cases leaf colour changed in to yellow. In some infested vines, gall like

thickening of runner shoots was also observed. Activity of ants in the rhizosphere of vines was an identifiable symptom of root mealybug infestation.

The root mealybug infestation with respect to the variety of black pepper, standard used for trailing and age of the vine were observed during preliminary survey. Highest per cent infestation was observed on Panniyur-1 variety in both the districts. With respect to the standard used, vines trailed on *Erythrina* sp. and *Graviella robusta* was observed with highest per cent infestation in Wayanad and Idukki districts, respectively. In Wayanad, vines of four to six year old was found to be highly infested whereas in Idukki highest infestation was on vines of seven to nine years age.

The assessment of infestation was done in Wayanad and Idukki districts by selecting two panchayats from each. The per cent infestation recorded from August 2013 to July 2014 at monthly intervals showed that there was no significant difference in infestation recorded in Wayanad and Idukki districts. The root mealybug infestation increased from August and September 2013 *i.e* after the south west monsoon with peak infestation in December 2013 followed by November 2013, October 2013 and January 2014. The infestation was found to be decreased from February to May 2014 with lowest per cent of infestation recorded in June and July, 2014.

During the survey, the infested roots were examined thoroughly for the presence of natural enemies and a coccinellid grub was observed to be predating on the root mealybugs. The grubs were brought to the laboratory and reared to obtain the adults which was identified as *Horniolus* sp. of sub family Scymninae and tribe Scymnini (Coccinellidae: Coleoptera).

The grub was cream coloured with white waxy thread like growth all over the body and possessed three pairs of well-developed thoracic legs whereas the adult beetle was convex shaped with dark brown thoracic shield and black elytra with two orange coloured patches. One patch is anterior in position and large and the other is small and positioned posteriorly.

Root mealybug infestation on weeds and other crops grown in and around the infested pepper garden were examined to document their collateral hosts. It was found

that *F. polysperes* colonized the roots of two intercrops, ginger, *Zingiber officinale* Rose., and elephant foot yam, *Amorphophallus paeoniifolius* (Dennst.) and weeds, *Ageratum conyzoides* L., *Clerodendron infortunatum* L., *Cyperus kyllinga L.*, *Phyllanthus niruri* L., *Physalis minima* L., *Synedrella nodiflora* L. and *Urtica parviflora* Roxb. and a standard, *Erythrina* sp.

Dysmicoccus brevipes was observed on the roots of *Coffea robusta* L., *Cleome rutidosperma* (DC.), *Commelina diffusa* L. and *Cyperus kyllinga* L.

Root samples and soil samples from the infested pepper gardens were examined and no plant parasitic fungi was observed but presence of a nematode species, *Rotylenchulus reniformis* was observed in an infested field of Wayanad.

Ants were collected from the rhizosphere of infested vines and four ant species *viz., Anoplolepis gracilipes* Smith, *Crematogaster rogenhoferi* Mayr, *Lophomyrmex quadrispinosus* Jerdon and *Paratrechina* sp. were found to be associated with the root mealybug colonies. Among the four species, *C. rogenhoferi* and *L. quadrispinosus* were observed to be associated with *F. polysperes* and *D. brevipes* while *Paratrechina* sp. was seen with *F. polysperes* and *Pseudococcus* sp. *A. gracilipes* was associated with only one species of mealybug, *D. brevipes.*

Population dynamics of root mealybugs was studied in an infested pepper garden in Mananthavady panchayat of Wayanad district, Kerala and showed that highest root mealybug population was observed in cooler months like December 2015 (13.31 mealybugs/15 cm root length), January 2016 (10.21 mealybugs) and November 2015 (9.94 mealybugs/15 cm root length). The lowest population was observed in rainy months, June 2015 (2.83) and July 2015 (2.43). Highest per cent of infested vines were also observed in December 2015 (26.67) and November 2015 (26.67) and lowest in June 2015 (10.00).

Correlation studies on mealybug population and weather factors showed that a significant negative correlation was observed between root mealybug population and soil temperature (-0.707 for minimum soil temperature and -0.735 for maximum soil temperature). No correlation existed between the mealybug population and other parameters like soil moisture, relative humidity and number of rainy days.

The biology of *F. polysperes,* the dominant species among the three root mealybug species was studied in laboratory condition. Morphometric characters of each developmental stage also were recorded. Females exhibited ovoviviparity with an average pre larviposition, larviposition and post larviposition period of 23.65, 9.60 and 4.15 days, respectively.

Adult female deposited an average of 136.15 crawlers into an ovisac like waxy secretion from the posterior part of the body. The sex ratio was 1: 2.71 (male: female). Males and females of *F. polysperes* varied in its development stages with three nymphal instars in the life cycle of females and males with two nymphal, a pre pupal and a pupal instar. The biology is being reported for the first time.

First instar nymphs were oval in shape, light pink in colour which turned into pale white within 24 hours of larviposition due to waxy coating. First nymphal instar lasted up to an average of 8.4 days. Length of the first instar nymphs was 0.89 mm whereas width was 0.51 mm.

Second instar nymphs were similar to the first instar nymphs in appearance and morphological characteristics except in body size with 1.39 mm length and 0.80 mm width. Average time taken for moulting was 6.35 days.

Males and females could be distinguished from third instar onwards with a fine silken waxy thread formed by males at the end of second instar which was absent in females. In third nymphal instar of females, waxy filaments along the body margin were prominently visible and was similar to adult females. Length of third instar female nymph was 2.10 mm whereas width was 1.25 mm. Average duration of third instar was 8.4 days.

Pre pupal stage of male mealybugs was identified by the presence of fine waxy threads over the body which was later formed into a complete cocoon and lasted for an average period of 1.4 days. Body size of pre pupal instar was similar to that of second instar with length and width of 1.29 mm and 0.65 mm.

Pupal stage of males were characterised by formation of cylindrical shaped waxy cocoon. Male nymph inside the cocoon were dark pink in colour devoid of waxy coating, slender, with a pair of ten segmented antennae and a pair of wing pads. Length

and width of male pupa was 2.03 mm and 0.82 mm. Adult males emerged out in 7.15 days.

Adult females of *F. polysperes* were apterous, soft bodied, oval shaped and pink in colour with clear body segmentation and powdery wax coating. Wax filaments surrounding the body margin were short and thick. The adult female was 2.65 mm in length and 1.56 mm in width.

Males were slender, delicate, elongated and reddish brown in colour with a pair of well developed, pale white and opaque wings, a pair of long waxy caudal filaments and a pair of long, ten segmented antennae. Length of males were 1.13 mm and width was 0.33 mm.

Longevity of males was shorter than females with an average of 1.8 days and that of females was 37.4 days. Males had shorter life cycle than that of females with an average of 23.7 days and total life cycle of females was 60.55 days.

Varietal reaction to the infestation of *F. polysperes* showed that Panniyur-2 was the most susceptible (81.58 mealybugs/plant) followed by Panniyur-1 (44.5 mealybugs/plant). Karimunda supported lower number of mealybugs (17.67 mealybugs/plant).

Efficacy of four entomopathogenic fungi *viz., Beauveria bassiana, Metarhizium anisopliae, Paecilomyces lilacinus* and *Lecanicillium lecanii* at three different doses of 2×10^6, 2×10^7 and 2×10^8 spores/ml were evaluated against root mealybug in laboratory and in pot experiment. *Lecanicillium lecanii* at 2×10^8 spores/ml was effective in both laboratory and pot experiment. *Lecanicillium lecanii* at 2×10^8 spores/ml caused per cent mortality of 50.00 and 56.67, respectively at five and seven days after the treatment application under laboratory conditions while in pot experiment, a per cent mortality of 21.11 and 28. 33 at one week after first and second drenching, respectively was observed.

Efficacy of eight chemical insecticides were tested against the root mealybug in the laboratory and in pot experiment. In the laboratory, chlorpyriphos 20 EC and imidacloprid 17.8 SL caused highest mortality of 80 per cent at one day after treatment. In pot experiment, imidacloprid 17.8 SL caused highest mortality of 59.44

per cent at one week after first drenching and 63.89 per cent at one week after second drenching.

Lecanicillium lecanii, the most potential entomopathogenic fungus identified against the root mealybug from the pot experiment was tested for its compatibility with all the insecticides tested in the present investigation and two fungicides which were commonly used for disease management in black pepper. Imidacloprid 17. 8 SL caused lowest per cent of inhibition (25.52) in the growth of *L. lecanii,* followed by copper hydroxide 77 WP (34.72). The per cent reduction in sporulation and spore viability also was lowest in imidacloprid 17.8 SL (10.43 and 4.19, respectively) followed by copper hydroxide 77 WP caused 10.32 and 10.30 per cent reduction, respectively.The fungicide, carbendazim 50 WP completely inhibited the growth and sporulation of *L. lecanii* on solid media.

The best treatments from the screening tests of entomopathogenic fungi and chemical insecticides were evaluated alone and in combination along with the common practice adopted by farmers against the root mealybug. The result showed that the highest per cent mortality was caused by imidacloprid 17. 8 SL (56.67) followed by chlorpyriphos 20 EC and combination treatment of imidacloprid 17. 8 SL + *L. lecanii* at 2x 10^8spores/ml (53.89) at one week after first drenching. The same trend was seen at one week after second drenching also with highest mortality by imidacloprid 17.8 SL (65.00 per cent) followed by chlorpyriphos 20 EC (60.00 per cent) and combination treatment of imidacloprid 17. 8 SL + *L. lecanii* at 2x 10^8spores/ml (58.89 per cent).

Field evaluation of the best treatment of the pot experiment with imidacloprid 17.8 SL was conducted in a root mealybug infested field at Kaniyambetta panchayat of Wayanad district and its efficacy was compared with that of chlorpyriphos 20 EC. The results obtained showed that imidacloprid 17. 8 SL at 25 g a.i/ha was found to be superior to chlorpyriphos 20 EC with 97.98 per cent reduction in mealybug population at one week after first drenching and 100 per cent reduction at two weeks after first drenching.

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Appendices

APPENDIX – I

MEDIA COMPOSITION

Composition of Potato Dextrose Agar media (PDA)

Potato – 200g

Dextrose – 20g

Agar – 20g

Distilled Water – 1 litre

APPENDIX – II

Monthly mean of soil and weather parameters in the infested black pepper garden of Wayanad district during February 2015 to January 2016

Months	Soil temperature		Soil moisture (%)	Rainfall (cm)	Relative Humidity (%)	Rainy days
	Minimum (°C)	Maximum (°C)				
February 2015	23.60	26.80	16.35	0.5	89.04	1
March 2015	25.80	27.90	16.25	10.14	89.35	7
April 2015	25.25	28.25	15.50	18.56	90.33	18
May 2015	25.40	27.40	18.34	22.70	89.29	12
June 2015	24.50	27.00	25.52	115.17	90.47	24
July 2015	24.250	28.34	25.40	64.50	90.32	22
August 2015	21.80	25.34	24.45	41.22	90.10	24
September 2015	19.84	24.25	22.50	42.29	89.50	19
October 2015	20.50	24.50	21.00	37.90	90.35	17
November 2015	20.34	24.83	21.00	14.94	90.50	18
December 2015	20.84	25.40	15.30	3.26	90.55	7
January 2016	21.25	26.80	15.50	0.65	90.58	2

BIONOMICS AND MANAGEMENT OF ROOT MEALYBUG ON BLACK PEPPER

by

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ABSTRACT OF THESIS

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Abstract

ABSTRACT

Mealybugs are one of the important pests of black pepper and a specific group called as 'root mealybugs' are known to infest the underground parts of the crop in Kerala. The infestation was reported to be serious in high altitude region. Hence, an investigation was carried out on the "Bionomics and management of root mealybug on black pepper" with the objectives to document the species of root mealybugs and associated fauna, to study the biology of the dominant species, susceptibility of popular pepper varieties to the pest and management of mealybug on black pepper. The present study was conducted in the College of Horticulture and farmer's fields at Wayanad and Idukki districts, Kerala.

A preliminary survey was conducted during 2013 in different panchayats of Wayanad, Idukki and Kannur districts of Kerala to document the root mealybug species infesting black pepper. No infestation was observed in Kannur district, while three species of mealybugs, namely, *Formicococcus polysperes* Williams, *Dysmicoccus brevipes* Cockerell and *Pseudococcus* sp. were found to be infesting the underground parts of black pepper in Wayanad and Idukki districts.

The collateral hosts of *F. polysperes,* recorded were two intercrops in pepper garden *viz.,* ginger, *Zingiber officinale* Rose. and elephant foot yam, *Amorphophallus paeoniifolius* (Dennst.), and weeds, *Ageratum conyzoides* L., *Clerodendron infortunatum* L., *Cyperus kyllinga L., Phyllanthus niruri* L., *Physalis minima* L., *Synedrella nodiflora* L., *Urtica parviflora* Roxb. and a pepper standard, *Erythrina* sp. The collateral hosts of *D. brevipes* were *Coffea robusta* L., *Commelina diffusa* L. *Cleome rutidosperma* (DC.) and *C. kyllinga* L. The infestation of *F. polysperes* on ginger is the first report from South India and its other hosts are being reported for the first time globally.

During the survey, a coccinellid grub was observed to be predating on the root mealybugs which was identified as *Horniolus* sp. (Coccinellidae: Coleoptera). Four ant species *viz., Anoplolepis gracilipes* Smith, *Crematogaster rogenhoferi* Mayr, *Lophomyrmex quadrispinosus* Jerdon and *Paratrechina* sp. were also found to be associated with root mealybug colonies.

The study on population dynamics of root mealybugs showed that the highest root mealybug population was in cooler months (November to January) and lowest population in rainy months (June and July). A significant negative correlation existed between root mealybug population and soil temperature.

The biology and morphometrics of *F. polysperes,* were studied in laboratory condition in which females exhibited ovoviviparity mode of reproduction with pre larviposition, larviposition and post larviposition period of 23.65, 9.60 and 4.15 days, respectively. An adult female deposited an average of 136.15 crawlers with a sex ratio of 1: 2.71 (male: female). Life cycle of females consisted of three nymphal instars and adult and that of males had two nymphal, a pre-pupal, a pupal instar and an adult instar. Average duration of first and second nymphal instars was 8.4 and 6.35 days, respectively. Males and females were distinguishable from third instar onwards with a fine silken waxy thread formed by males at the end of second instar. Duration of third female instar was 8.4 days and that of pre-pupa and pupa of male was 1.4 and 7.15 days, respectively. Adult females are apterous with white powdery waxy coating and wax filaments surrounding the body margin are short and thick. Males are winged with a pair of long waxy caudal filaments. Males are short lived with an average life span of 1.8 days and females lived for 37.4 days. The biology of *F. polysperes* is being reported for the first time.

Four popular pepper varieties, namely, Panniyur- 1, Panniyur- 2, Panniyur- 8 and Karimunda were tested for their susceptibility to root mealybugs and Panniyur- 2 was found to be most susceptible and recorded significantly higher number of mealybugs on artificial inoculation.

Entomopathogenic fungi (EPF), chemical insecticides and their combinations were evaluated for the management of root mealybugs on black pepper. Four species of entomopathogenic fungi were tested at three different concentrations each and out of which, *Lecanicillium lecanii* at 2 x 10^8 spores/ml was found effective under both laboratory and pot experiment. Out of the eight insecticides evaluated against root mealybugs, chlorpyriphos 20 EC at 300 g a.i/ha and imidacloprid 17.8 SL at 25 g a.i/ha

were equally superior in laboratory tests whereas, imidacloprid 17.8 SL at 25 g a.i/ha was the most effective in pot culture experiment.

Compatibility test of *L. lecanii* with pesticides indicated that imidacloprid 17.8 SL (25 g a.i/ha) and copper hydroxide 77 WP (1%) was compatible with respect to per cent growth inhibition, sporulation and spore viability.

The best treatments of EPF and chemical insecticides were evaluated alone and in combinations, with common farmer's management practice in pot experiment and the result showed that imidacloprid 17.8 SL at 25 g a.i/ha was effective in managing root mealybugs and the same was evaluated in an infested field at Wayanad and compared with chlorpyriphos 20 EC @ 300 g a.i/ha. The results showed that imidacloprid 17.8 SL @ 25 g a.i/ ha was superior with 97.98 per cent reduction in population at one week after first drenching when compared to that of chlorpyriphos (79.89 per cent).