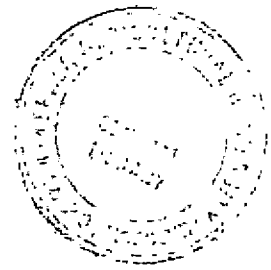
BIOECOLOGY AND MANAGEMENT OF GINGER RHIZOME MAGGOTS

By

SANDHYA P. T.

(2012-11-140)



THESIS

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DEPARTMENT OF AGRICULTURAL ENTOMOLOGY

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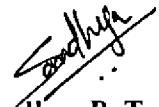
KERALA, INDIA

2015

DECLARATION

I, hereby declare that the thesis entitled **"Bioecology and management of ginger rhizome maggots"** is a bonafide record of research work done by me during the course of research and that it 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.



Sandhya P. T.

Place: Vellanikkara

Date: 05.06.2015

CERTIFICATE

Certified that the thesis entitled **"Bioecology and management of ginger rhizome maggots"** is a bonafide record of research work done independently by **Ms. Sandhya P. T.** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, associateship or fellowship to her.

Place: Vellanikkara

Date: 05.06.2015

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We, the undersigned members of the advisory committee of **Ms. Sandhya P. T. (2012-11-140)** a candidate for the degree of Master of Science in Agriculture, with major field in Agricultural Entomology, agree that the thesis entitled **"Bioecology and management of ginger rhizome maggots"** may be submitted by Ms. Sandhya P. T. in partial fulfilment of the requirement for the degree.

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Sandhya

Sandhya P. T.

Arise, awake, and stop

not till

the goal is reached .....

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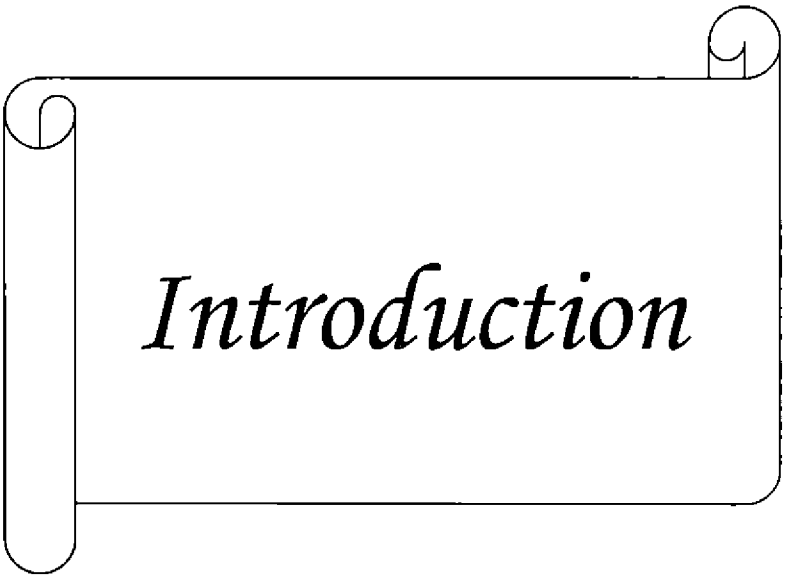

Introduction

1. INTRODUCTION

Ginger (*Zingiber officinale* Rosc.) is one of the earliest known oriental spices and has been valued for its medicinal properties since ancient times. It is being cultivated in most of the states in India such as Kerala, Meghalaya, Arunachal Pradesh and Mizoram. India stands first in terms of production (6.83 lakh tonnes) and second in terms of area (1.36 lakh hectares) under ginger cultivation in the world (GOI, 2013). Ginger is also a major foreign exchange earning crop, valued at Rs. 17 lakhs annually. It is cultivated in an area of 4505 ha in Kerala with a production of 22,064 tonnes and a productivity of 4.89 tonnes ha^{-1} respectively (GOK, 2013).

Insect pests constitute a major constraint in ginger cultivation. Nearly fifty species of insects infest ginger during the various stages of the crop, the most important among them being the shoot borer (*Conogethes punctiferalis* Guen.), several species of rhizome maggots, the leaf roller (*Udaspes folus* Cram.) and the rhizome scale (*Aspidiella hartii* Ckll.) (Nair, 1975).

The rhizome maggots are major pests of ginger and cause significant damage to the crop across the country. Losses of up to 31 per cent have been reported (Ghorpade *et al.*, 1983). Various species of dipteran maggots are known to infest ginger, such as, *Calobata indica* (Maxwell-Lefroy and Howlett, 1909), *Chalcidomyia atricornis* Mall., *Formosina flavipes* Mall. (Malloch, 1927), *Mimegralla coerulifrons* Macq. (Khaire *et al.*, 1972), *Celyphus* sp. (Nair, 1975), *Leia arsona* (Hutson, 1978), *Eumerus albifrons* Walk. (Sathiamma, 1979), *Phytosciara zingiberis*, *Psilosciara flammulinae* (Ogawa *et al.*, 1985), *Eumerus pulcherrimus* Bru. (CPCRI, 1986), *Gymnonerius* sp. (Koya, 1988) and *Bradysia* sp. (Lee *et al.*, 2001).

The rhizome maggot, *Mimegralla coeruleifrons* is the most important species of maggot infesting ginger in India. Apart from ginger, it is also known to attack turmeric, wild ginger, arrowroot (Koya, 1989), *Colacasia* sp. (CPCRI, 1986), *Curcuma aromatica* and *C. zeodaria* (CPCRI, 1979).

The adults of *M. coeruleifrons* lay eggs near the collar region of the plant. The maggots, upon emergence, feed initially on the shoots and cause drying and dead heart symptoms. Later, they bore into rhizomes and feed on the internal contents, leading to extensive rotting of the infested rhizomes. Several studies have indicated the constant association between the maggots and rot inducing fungi, though the exact nature of association is yet to be established (Ghorpade *et al.*, 1988).

Management of rhizome maggots in ginger is currently based on use of insecticides which are applied indiscriminately by the farmers. However, given the current ban on most of the recommended pesticides, there is an urgent need to formulate alternate management strategies. Biological control of the maggots using entomopathogenic organisms has, for long, been considered as worthy of exploration as the cool, moist subterranean habitat offers an ideal environment for microorganisms like fungi and nematodes.

Developing biocontrol strategies, however, calls for precise identification of the pest, studying its biology and bionomics and also, proper evaluation of the natural enemies of the pest. It is in this context that the present study was proposed, with the following objectives:-

1. to identify the major species of rhizome maggots infesting ginger,
2. to study the bioecology of major species of rhizome maggots on ginger, and,
3. to develop eco-friendly management measures against the rhizome maggots on ginger.

Review of literature

2. REVIEW OF LITERATURE

The available literature on biology, host range and management of ginger rhizome maggots on ginger are reviewed here.

2.1 Rhizome maggots on ginger

Several species of rhizome maggots infesting ginger have been reported from different parts of world and include *Calobata indica* (Maxwell-Lefroy and Howlett, 1909), *Chalcidomyia atricornis* Mall., *Formosina flavipes* Mall. (Malloch, 1927), *Mimegralla coerulifrons* Macq. (Khaire *et al.*, 1972), *Celyphus* sp. (Nair, 1975), *Leia arsona* (Hutson, 1978), *Eumerus albifrons* Walk. (Sathiamma, 1979), *Phytosciara zingiberis*, *Psilosciara flammulinae* (Ogawa *et al.*, 1985), *Eumerus pulcherrimus* Bru. (CPCRI, 1986), *Gymnonerius* sp. (Koya, 1988), and *Bradysia* sp. (Lee *et al.*, 2001).

Among the different maggots reported from ginger in India, those belonging to the family Micropezidae appear to be predominant and have been reported extensively. Lefroy (1909) was the first to report the incidence of *M. coeruleifrons* on ginger in India. Pillai (1921) reported that *Calobata* sp., along with an unidentified fly, infested ginger rhizomes in Kerala. Nair (1989) subsequently reported incidence of *C. atricornis*, *F. flavipes* and *Calobata* sp. from ginger in Kerala.

Hill (1983) reported that *M. coeruleifrons* as well as several other flies belonging to the family Chloropidae infested the rhizomes of ginger in Bangladesh. Infestation by *Calobata albimana* in Guntur was reported by Rao and Reddy (1990), while heavy incidence of *C. indica* was reported from Himachal Pradesh (RRS, 1996). The syrphid flies, *Eumerus marginatus* and *E. pulcherrimus* have also been reported as infesting ginger by different authors such as Trujillo (1964) and Kotikal and Kulkarni (1999).

Rhizome maggots are also known to attack several other plants such as turmeric and arrowroot. A study conducted in Kerala revealed that, apart from ginger, *M. coeruleifrons* also infested turmeric, wild arrowroot, *Colocasia* spp. and wild ginger (*Zingiber* sp.). *M. coeruleifrons* have also been reported from wild turmeric (*Curcuma aromatica*) and white turmeric (*C. zeodaria*) (CPCRI, 1979) as well as from *Kaemferia galanga* (Premkumar *et al.*, 1982). Koya (1988) recorded the maggots of *M. coeruleifrons* in fallen and decayed banana flowers. Kotikal and Kulkarni (2000c) observed the carryover of the pest in the form of diapausing pupae in decaying rhizomes in soil as well as in the seed rhizomes stored for next season.

2.2 Economic importance of ginger rhizome maggots

Infestation by rhizome maggots causes considerable yield loss in ginger. Jacob (1980) reported that attack by dipteran maggots such as *M. coeruleifrons* and *Eumerus* sp. caused a yield loss of ten per cent in ginger in Kerala. Similarly, Ghorpade *et al.* (1983) reported that the loss due to *M. coeruleifrons* infestation ranged from 15.63 to 32.26 per cent in turmeric and 17.86 to 44.12 per cent in case of ginger in Maharashtra.

A roving survey conducted in northern Karnataka during 1996 revealed the rhizome fly, *M. coeruleifrons* to be a major pest of turmeric in the region, causing more than ten per cent damage in field (Kotikal and Kulkarni, 2000a). According to Sontakke (2000), *M. coeruleifrons* caused 40 to 42 per cent loss in unprotected crop and 20 to 25 per cent loss in ginger fields treated with insecticides in Orissa.

Garg and Kashyap (2001) reported that the incidence of *Calobata indica* in ginger varied from 32.6 to 50.0 per cent in Sirmour district of Himachal Pradesh, with an average of 11.6 maggots per rhizome. Jacob *et al.* (2003) reported that serious outbreak of *C. indica* at Onattukara in Kerala resulted in severe yellowing of leaves, drying of shoots and rotting of rhizomes.

In one of the very few studies on economic impact of other species of rhizome maggots, Rao and Reddy (1990) reported that the incidence of *C. albimana* caused 90 per cent damage to turmeric in Andhra Pradesh. The damage appeared to be correlated with soil moisture, as maximum damage of 90 per cent was observed at high moisture regimes and minimum of 30 per cent at lower moisture regimes.

2.3 Biology of ginger rhizome maggot

Studies on the biology of rhizome maggots have mostly focussed on *M. coeruleifrons* and reports on the biology of other maggot species have been scant.

The bioecology of *M. coeruleifrons* in ginger was studied by Koya (1989), according to whom the life cycle of *M. coeruleifrons* consisted of egg, three larval, pupal and adult stages, which ranged from 3 to 4, 9 to 13 and 8 to 11 days respectively. The duration of first, second and third larval instars were reported as 3, 2 and 6 days respectively. The average length and width of eggs were 0.77 and 0.17 mm respectively. The three larval instars were 2.60, 5.25 and 10.22 mm long, while the pupa measured 7.78 × 1.62 mm in size. The adult male measured about 11.95 × 1.50 mm with a wing span of 16.60 mm and the adult female, about 13.65 × 1.75 mm with a wing span of 17.85 mm. The sex ratio of males and females in the field was about 1:1. The flies mated 4 to 7 times at 3 to 6 minutes interval between 11.00 a.m. and 2.00 p.m. on bright days. The mated females then oviposited in the soil up to a depth of one centimetre around the base of the plant.

Ghorpade *et al.* (1988), who studied the biology of *M. coeruleifrons* in turmeric, observed that an adult female fly laid about 76 to 150 eggs in soil in 2 to 3 days under laboratory conditions. The incubation period varied from 2 to 5 days and hatching ranged from 78 to 97 per cent. The average length and breadth of an egg was 0.81 mm and 0.22 mm respectively. The average larval period of first, second and third instars were 5.7, 4.8 and 4.75 days respectively. The mean length and breadth of first, second and third instar maggots were 0.63 mm × 0.15 mm, 4.5 mm × 1.0 mm and 9.6 mm × 1.7 mm respectively. The total larval period

varied from 13 to 25 days and pupal period from 5 to 15 days. The longevity of male and female flies ranged from 7 to 20 days and 9 to 24 days respectively. Copulation occurred during day time and each mating lasted for 40 to 45 seconds.

Studies conducted on the biology of *M. coeruleifrons* under laboratory conditions at Arabhavi, Karnataka, over four generations, revealed that the total life cycle of *M. coeruleifrons* occupied 28.30 to 38.00 days with an incubation period of 3.40 to 4.10 days. The average fecundity was 100 eggs with a hatching per cent of 87.07 to 89.87. The duration of first, second and third larval instars ranged from 3.7 to 4.9, 3.8 to 5.0 and 5.4 to 5.9 days respectively. The pupal period varied from 11.0 to 21.0 days. The mean adult longevity during August-September, September-October and October-December periods of 1996 as well as January-March of 1997 was 17.80 ± 3.37, 14.60 ± 2.49, 16.20 ±1.66 and 33.70 ± 1.90 days respectively (Kotikal and Kulkarni, 2000b).

Seasonal variation in biology of *M. coeruleifrons* has also been reported. Thus, Sontakke (2000) reported that fecundity of *M. coeruleifrons* was higher during August, 1998 (146.2 eggs), as compared to that of September, 1998 (84.2 eggs). The eggs also hatched earlier in the month of August than in September, with a hatching per cent of 73.5 and 83.4 respectively. The total larval period was about 16.6 days on ginger in August as against 21.3 days in September. The average pupal period was eight days while the average longevity of adult flies was 16 days, for both August and September of 1998.

Rao and Reddy (1990), who studied the biology of *C. albimana* reported an incubation period of 3 to 4 days, larval period of 23 to 25 days, pupal period of 10 to 15 days and adult longevity of 4 to 5 days, with a total duration of 36 to 44 days. However, Garg and Kashyap (2001) observed that the eggs hatched within 24 hours and that the total larval period ranged from 7 to 8 days, with fully grown maggots pupating within the rhizomes for 6 to 8 days.

2.3.1 Seasonal distribution of rhizome maggots

Dhoble (1975) as well as Jacob (1980) reported that the incidence of *M. coeruleifrons* and *Eumerus* spp. was observed in ginger from August onwards. Over forty maggots of *M. coeruleifrons* and around ten maggots of the lunate fly, *E. pulcherrimus* were observed in a single rhizome. Various stages of the pest were found from August until harvest, indicating presence of overlapping generations in field.

Ghorpade *et al.* (1988) reported that the activity of rhizome maggot, *M. coeruleifrons* started from first week of July in ginger and third week of July in turmeric fields. The flies remained active during the period from mid-August to mid-October. According to Sontakke (2000), abundance of rhizome maggots could be observed from the second fortnight of July with peak incidence occurring during the first week of September.

Studies conducted on seasonal incidence of *C. indica* in Himachal Pradesh revealed that the highest population of 43.8 maggots per rhizome occurred in September, followed by 36.7, 10.7, 9.6, 6.2 and 6.0 maggots per rhizome in October, November, August, December and July, respectively (Garg and Kashyap, 2001). Sontakke and Roul (2007) observed lesser incidence of *M. coeruleifrons* in ginger planted in January-February as compared to that planted in March-April, April-May and May-June.

2.3.2 Influence of weather on maggot population

The influence of weather on population of rhizome maggots have been brought out by several studies. Ghorpade *et al.* (1988) reported that the highest incidence of maggots occurred after the receipt of heavy but discontinuous showers. The abundance of flies was favoured by intermittent rains, cloudy weather, temperature ranging from 21 to 38^0 C and relative humidity of 55 to 80 per cent, prevalent during August-October in South India. The flies were first noticed in ginger fields, at around 45 days after planting, while they were observed much later in turmeric fields, at around 60 days after planting.

Rao and Reddy (1990) reported that initial incidence of rhizome maggots coincided with cessation of rains in September and that the pest incidence was highest from mid-October to February. Sontakke and Roul (2007) also had observed heavy incidence of rhizome maggot in ginger crop planted during monsoon.

2.3.3 Association of rhizome maggots with rhizome rot fungi

The rhizome rot disease, caused by the fungus *Pythium aphanidermatum* is a dreaded disease that most often occurs along with the rhizome maggot infestation, prompting investigation into the association between the two.

Alam (1962) had reported that maggots of *M. coeruleifrons* were mostly found in rhizomes infected with soft rot fungi such as *P. aphanidermatum* and bacteria such as *Erwinia caratovora* (Jones) Bergey *et al.*

Premkumar *et al.* (1982) similarly observed strong association between the rhizome maggots and rhizome rot disease in ginger. The disease and maggot infestation occurred together in 58 per cent of ginger rhizomes examined. *Pythium* spp., alone were observed in 42 per cent of samples while no sample contained maggots alone, suggesting that the maggot incidence was secondary in nature. Radke and Borle (1982) observed that the rotting of rhizomes occurred first in ginger and that adult flies preferred rotten rhizomes for oviposition.

Dohroo *et al.* (1987) reported that plants infected by wilt and rhizome rot complex were subsequently infested by rhizome maggots. Koya (1988), who studied the distribution of dipteran maggots in ginger growing areas of Kerala during 1984-85, recorded *E. pulcherrimus* and *M. coeruleifrons* in 33.60 and 26.40 per cent of samples respectively. However, rhizomes free of rot disease were free of maggot infestation as well, which indicated that dipteran maggots tended to infest rhizomes after disease had occurred.

Studies conducted under green house conditions to determine the status of rhizome maggot, *M. coeruleifrons* as a pest and its role in rhizome rot caused by

P. aphanidermatum showed that rhizome maggot was not a primary pest of ginger and had no role in the incidence of rot disease (Koya, 1990).

Infestation by dipteran maggots predisposing the rhizomes to invasion by *Pythium* spp., has also been reported (CPCRI, 1978). Ghorpade *et al.* (1988) observed that the feeding activity of maggots was responsible for the introduction of microorganisms such as *Fusarium* spp., *Pythium* spp., *Sclerotium* spp. and nematodes of the genera *Tylenchus, Helicotylenchus, Meloidogyne* and *Dorylaimida* into ginger rhizomes.

Rao *et al.* (1994) similarly reported that the association of soil borne fungi such as *Pythium* spp., *Fusarium* spp., *Macrophomina* spp. and *Rhizoctonia* spp. and *M. coeruleifrons* larvae led to rhizome rot. Kotikal and Kulkarni (2000c) also reported that infestation of maggots and pupae were higher in disease infected turmeric rhizomes. Balfas (2002) reported that *M. coeruleifrons* preferred diseased ginger plants for oviposition and development. The study also suggested that the adult fly could act a carrier of the fungus.

2.4 Natural enemies of rhizome maggots

Few natural enemies have been reported as attacking the rhizome maggots. One of the most important has been the pupal parasitoid *Trichopria* sp. (Hymenoptera:Diapriidae) attacking *M. coeruleifrons* in Kerala (Jacob, 1980). Ghorpade *et al.* (1982) studied the seasonal occurrence of the parasitoid *Trichopria* sp. in field collected pupae and found that the parasitism was 26.48 per cent in August, 1979. Parasitoid populations were reportedly favoured by temperatures ranging from 24 to 34^0 C and relative humidity above 65 per cent. The parasitoid was observed to be gregarious in nature, with 13 to 19 individuals emerging from a single pupa.

Koya *et al.* (1991) reported parasitisation of pupae of *M. coeruleifrons* by *Spalangia gemina* (Hymenoptera: Pteromalidae). They also observed that while twelve to twenty adults of *Trichopria* sp. emerged from a single pupa of *M. coeruleifrons,* only a single adult of *S. gemina* emerged from a parasitized pupa. Jacob (1980) as well as Kotikal and Kulkarni (2000b) observed predation of

adults of rhizome flies by dragonflies (*Cordulaia* spp.), robber flies (*Philodicus* sp. and *Heligmoneura* sp.) and spiders (*Araneus* sp., *Micaria* sp., *Thyene* sp. and *Pardosa* sp.) while maggots and pupae were devoured by earwig (*Euborellia stali* Dohrn.).

2.5 Management of rhizome maggots

Management of rhizome maggots have been attempted by several workers, though the carryover of pest in seed rhizomes, survival in alternate hosts and the association with the rhizome rot disease has made it a formidable challenge.

Kotikal and Kulkarni (1999) evaluated the efficacy of insecticides such as phorate @ 2.5 kg a.i. ha^{-1}, carbofuran @ 0.75 kg a.i. ha^{-1}, quinalphos @ 0.67 kg a.i. ha^{-1} as well as manures such as neem cake powder @ 250 kg ha^{-1}, pongamia cake powder @ 250 kg ha^{-1} and vermicompost @ 2.5 t ha^{-1}, for the management of *M. coeruleifrons* in turmeric in northern Karnataka. The lowest infestation of 8 per cent was recorded in plots treated with phorate, as compared to 26 per cent infestation in untreated plots. Reddy and Reddy (2000) reported that application of neem cake helped reduce the incidence by rhizome maggots in turmeric fields of Andhra Pradesh.

Six granular systemic insecticides such as phorate, dimethoate, and monocrotophos, all at 0.75 kg a.i. ha^{-1} as well as disulfoton, cyanamide 47470 and chlorfevinphos, all at 1.00 kg a.i. ha^{-1} were evaluated by Dhoble *et al.* (1978) in Maharastra against *M. coeruleifrons*. All the insecticides were significantly superior to the control in reducing the pest infestation, with phorate, recording a mean infestation of 1.88 per cent over two seasons, being the most effective. This was followed by disulfoton granules recording 4.38 per cent mean infestation. The application of chlorfevinphos showed highest incidence of 5.83 per cent of dead hearts. The application of phorate granules also had reduced the infestation of rhizomes by 2.59.

Dhoble *et al.* (1981) evaluated parathion, malathion and endrin at 0.03 and 0.05 per cent, diazinon at 0.03 per cent and carbaryl at 0.3 per cent concentrations as foliar sprays along with diazinon, chlordane and aldrin, all @ 0.75 kg a.i. per acre as soil application for the management of *M. coeruleifrons* in turmeric. Parathion at 0.05 per cent was found to be superior to all other treatments, with an average of 2.34 per cent infestation of rhizomes as against 23.28 per cent in control. Parathion at 0.03 per cent was the next superior treatment with 3.92 per cent infestation. Other treatments recorded values between 6.34 and 11.82 per cent infestation and were at par with each other.

Koya and Banerjee (1981) reported that aldicarb, followed by carbofuran and methyl parathion were the most effective treatments among the different insecticides evaluated for the management of *M. coeruleifrons*.

Kotikal and Kulkarni (2000c) treated seed rhizomes of turmeric with insecticides such as imidacloprid (0.5 g l^{-1}), quinalphos (2 ml l^{-1}), phosphamidon (0.5 ml l^{-1}), monocrotophos (1 ml l^{-1}), endosulfan (2 ml l^{-1}) and dimethoate (1.5 ml l^{-1}) to check the carryover of *M. coeruleifrons* through them. Soaking the seed rhizomes for eight hours in dimethoate as well as in phosphamidon was significantly superior to other treatments in checking emergence of adult flies. The highest germination of 98.33 per cent was recorded in case of rhizomes treated with dimethoate 30EC followed by rhizomes treated with monocrotophos 36SL which recorded 96.67 per cent germination. Both the treatments were at par with each other and were significantly superior to other insecticides as well as control. Among the different insecticides evaluated, endosulfan 35EC and quinalphos 20AF proved to be the least effective in checking maggot development in storage, with both recording mean fly emergence of 0.66, which, however, was superior to 5.66 recorded in control. Garg (2001) suggested treating seed rhizomes with chlorpyriphos before sowing and spraying with the same chemical one month after germination for the management of *C. indica*.

Studies were conducted by Jacob *et al.* (2003) in Kerala to control the rhizome rot caused by association of *C. indica* and *P. aphanidermatum.* Thirteen treatments, involving the combinations of three systemic insecticides *viz.* imidacloprid, carbofuran, and phorate and four fungicides *viz.* triademefon, benomyl, bitertanol and copper oxychloride along with an untreated check were applied @ three litre per sq.m. as soil drenching in farmers fields. Soil application of carbofuran along with copper oxychloride recorded the lowest disease incidence of 18.18 per cent 21 days after treatment. This was followed by phorate along with tridemefon which recorded disease incidence of 23.53 per cent. Both the treatments were also superior to other treatments, in terms of per cent reduction in disease over control, recording values of -70.13 and -61.34 respectively.

Sontakke and Roul (2007) conducted a study to elucidate the influence of different factors such as soil type, date of planting, varieties and application of chemicals on incidence of *M. coeruleifrons*. The study conducted in Orissa during 2002 and 2003 recorded the lowest pest incidence of 6.8 per cent in black soil as well as alluvial soil. Highest incidence of 17.4 per cent was recorded in case of sandy loam soil. Early planting in January to February recorded lowest infestation of 1.9 and 4.3 per cent of shoot and rhizome infestation respectively, as against the highest values of 27.8 and 40.4 per cent recorded during May-June planting. Among the six varieties evaluated, Rio-De-Janeiro recorded the lowest per cent shoot and rhizome infestation of 12.9 and 18.9 per cent, compared to 22.3 and 37.8 per cent shoot and rhizome infestation recorded in case of Suprabha. Rio-De-Janeiro was, however, on par with local cultivar (13.4%) and Suruchi (19.4%) in terms of shoot infestation. The highest rhizome infestation was recorded in case of Suruchi, which recorded 38.2 per cent.

Materials and methods

3. MATERIALS AND METHODS

The survey and identification of the major species of rhizome maggots on ginger, studies on the biology of the predominant species of rhizome maggot, documentation of natural enemies of rhizome maggots and evaluation of eco-friendly management measures against the rhizome maggots were carried out at the Department of Agricultural Entomology, College of Horticulture, Vellanikkara as described below.

3.1 Survey of rhizome maggots on ginger

Roving surveys were conducted in the ginger growing areas of Thrissur and Palakkad districts of Kerala. Two panchayats each, namely Perumatty and Pattenchery in Palakkad district as well as Vellanikkara and Madakkathara in Thrissur district were selected for the survey, based on the extent of ginger cultivation in the above panchayats.

The surveys were carried out at monthly intervals from August to October, 2013. Sixty infested plants, along with rhizomes were collected from each location during a visit and brought to the laboratory, where the rhizomes were cut open and maggots were counted. The rhizomes, along with the maggots were maintained under ambient conditions for emergence of adult flies, which were killed and preserved in 70 per cent alcohol. The preserved specimens were got identified at the University of Agricultural Sciences, Dharwar.

3.1.1 Relative abundance of rhizome maggot species

The relative abundance of ginger rhizome maggots was ascertained by counting the total number of maggots collected from each field as well as the number of flies of each species that emerged from the maggots.

The relative abundance was calculated as,

$$\text{Relative abundance} = \frac{\text{Number of maggots of each species from each location}}{\text{Total number of maggots from each location}} \times 100$$

3.2 Biology of ginger rhizome maggots

The bionomics of the most dominant ginger rhizome maggot, *Mimegralla* sp. nr *coeruleifrons* was studied in the laboratory during 2013-14 under ambient conditions. The mean temperature was 28.7°C and mean relative humidity was 82 per cent. The maggots collected from the surveyed fields, along with the infested rhizome pieces, were placed in plastic containers of 10 × 10 cm size and were covered with muslin cloth for emergence of adults.

The newly emerged adults were collected and released into aluminium mesh cages of 75 × 30 × 30 cm size and were provided with ten per cent honey solution as food. They were also provided with diseased ginger rhizome pieces in Petri dishes lined with wet tissue paper, for oviposition (Plate 1). The eggs were collected at 24 h interval and were used to raise the population for studying the biology as well as for recording biometric observations. All biometric observations (Plate 2) were recorded using Leica EZ4 HD stereo microscope equipped with LAS image analysing software.

3.2.1 Eggs

Upon commencement of oviposition, twenty numbers of 0-24 h old eggs were selected at random and the morphometric observations were recorded.

Plate 1. Rearing of *Mimegralla* sp. nr *coeruleifrons* in aluminium cages

A. Aluminium cage

Plate 2. Biometric observations of different life stages of *Mimegralla* sp. nr *coeruleifrons*

A. Egg

B. First instar larva

C. Second instar larva

Plate 2. Biometric observations of different life stages of *Mimegralla* sp. nr *coeruleifrons*

D. Third instar larva

E. Pupa

F. Adult

3.2.1.1 Incubation period

Twenty numbers of 0-24 h old eggs were collected by using a camel hair brush and were placed singly on a thin slice of ginger rhizome each in a Petri dish lined with cotton. The cotton was moistened periodically to prevent drying of the rhizome pieces. The eggs were observed daily for hatching and the incubation period was recorded.

3.2.2 Larvae

Newly hatched maggots were reared individually on single pieces of ginger rhizome in Petri dishes of 8 cm diameter lined with wet cotton and were observed at 24 h interval. Morphometric observations of 20, 0-24 h old maggots of each instar were recorded.

3.2.3 Pupa

Twenty numbers of 0-24 h old pupae were selected at random and the morphometric observations were recorded as described.

3.2.4 Adults

The adults of *Mimegralla* sp. nr *coeruleifrons,* upon emergence, were examined and their sex recorded, based on the presence or absence of ovipositor. The morphological characters as well as morphometric observations of twenty flies of each sex were recorded.

3.2.5 Adult longevity

Ten pairs of adults were released into aluminium mesh cages of 75 × 30 × 30 cm size @ one pair per cage and were provided with ten per cent honey solution as well as rotten ginger rhizome pieces for oviposition. The number of live male and female flies was recorded at 24 h interval.

3.2.6 Fecundity

Ten pair of adults were released into a single aluminium mesh cage of 75 × 30 × 30 cm size and were provided with ten per cent of honey solution as food. They were also provided with a piece of rotten ginger in a Petri plate lined with moist tissue paper for oviposition. The Petri plate, along with rhizome piece was retrieved at 24 h interval for collecting the eggs and were replaced with another Petri dish containing a rotten piece of ginger rhizome.

3.2.7 Statistical analysis

The duration of development of each stage of the ginger rhizome maggot *Mimegralla* sp. nr *coeruleifrons*, namely, egg, larva, pupa and adult was recorded and was expressed as mean days ± standard deviation (SD). Similarly the morphometric parameters of different stages of ginger rhizome maggots were measured in millimeters (mm) and expressed as mean ± standard deviation (SD).

3.3 Documentation of natural enemies

Ginger rhizomes infested with maggots were collected from different fields during the survey, brought to the laboratory and observed for the presence of natural enemies like predators, parasitoids and pathogens.

3.3.1 Predators

Rhizome maggot infested ginger fields surveyed at both Thrissur and Palakkad districts were carefully examined for the presence of predators, which were collected and recorded.

3.3.2 Parasitoids

Parasitoids that emerged from the different stages collected during field surveys were preserved in 70 per cent alcohol in small vials of five millilitre volume and were got identified at the Western Ghats Regional Centre of Zoological Survey of India, Kozhikode.

3.3.3 Pathogens

Diseased maggots obtained, if any, from the field were kept in humid chamber for further observations. Dead maggots with mycosis, if any, were surface sterilized with one per cent sodium hypochlorite solution for one minute and then washed three times with sterile distilled water. They were then transferred aseptically to Petri dishes of 8 cm diameter containing Potato Dextrose Agar Medium (Annexure I). The Petri dishes were incubated at room temperature (28 ± 2^0 C) and observed for development of fungal colonies.

3.4 Studies on management of ginger rhizome maggots

Two entomopathogenic fungi *viz. Metarhizium anisopliae* (Metschnikoff) Sorokin and *Beauveria bassiana* (Balsamo) Vuiilemin, along with two entomopathogenic nematodes *Steinernema carpocapsae* Weiser and *Heterorhabditis indica* Poinar and two insecticides namely, fipronil 5SC and chlorpyriphos 20EC were evaluated for their efficacy against ginger rhizome maggots. The evaluation involved contact bioassay studies in the laboratory followed by evaluation of effective treatments in pot culture studies.

M. anisopliae and *B. bassiana* used in the studies were obtained from the All India Coordinated Research Project on Biological Control of Crop Pests and Weeds, Vellanikkara. The spore count of the fungal bioagents was assessed using haemocytometer under microscope.

The culture of *Steinernema carpocapsae* was obtained from Banana Research Station (BRS), Kerala Agricultural University, Kannara and that of *Heterorhabditis indica* from Indian Cardamom Research Institute (ICRI), Myladumpara. They were multiplied on the larvae of greater wax moth, *Galleria mellonella* L. reared on artificial diet (Annexure II) as described by Singh (1994). The extraction of nematodes was carried out as per the procedure described by White (1927).

Commercial formulations of fipronil (Sargent 5SC, Bayer Crop Science, Mumbai) and chlorpyriphos (Mr. Bon 20EC, K. P. R. Fertilisers Ltd., Tata Nagar) were purchased locally.

3.4.1 Evaluation of contact toxicity of selected entomopathogens and insecticides in the laboratory

The laboratory studies were carried out in a completely randomized design with seven treatments (Table 1) and three replications with ten maggots per replication.

3.4.1.1 Petri plate bioassay

Petri plate bioassay was carried out by transferring 5 ml of the aqueous preparation of the entomopathogens or insecticides as the case may be, into the base of a Petri dish of 8 cm diameter. Ten second instar maggots were released into the Petri dish and were allowed to move freely in the Petri dish containing the relevant treatment. A small piece of ginger rhizome was placed at the centre of the Petri dish. The Petri dish was then covered and the maggots were observed for mortality at 24 h interval.

3.4.1.2 Rhizome dip assay

Rhizome dip assay involved dipping seventy day old rhizomes of ginger (variety Maran) for 30 min in one litre of distilled water taken in a trough and containing the entomopathogens or insecticides of required concentration as the case may be. The rhizomes were taken out at the end of thirty minutes and ten second instar maggots were released on to each of the treated rhizomes. The maggots were observed at 24 h interval for mortality. The number of maggots killed, as well as number of days taken to cause mortality was recorded for each treatment. Cadavers in treatments involving entomopathogens were used to isolate the pathogen concerned as per standard procedure.

Table 1. Treatments for evaluating contact toxicity of selected entomopathogens and insecticides against second instar maggots of *Mimegralla* sp. nr *coeruleifrons* in the laboratory

Treatment	Dose	Source/ Manufacturer
T_1 - *Metarhizium anisopliae*	1×10^9 spores ml^{-1}	AICRP on BCCP & W
T_2 - *Beauveria bassiana*	1×10^9 spores ml^{-1}	AICRP on BCCP & W
T_3 - *Steinernema carpocapsae*	400 IJs ml^{-1}	B R S, Kannara
T_4 - *Heterorhabditis indica*	400 IJs ml^{-1}	ICRI, Myladumpara
T_5 - Fipronil (5SC)	50 g a.i. ha^{-1}	Bayer Crop Science, Mumbai, India
T_6 – Chlorpyriphos (20EC)	300 g a.i. ha^{-1}	K. P. R. Fertilisers Ltd., Tata Nagar, India
T_7 - Distilled water (Control)		

IJs – Infective Juveniles

3.4.1.3 Statistical analysis

Statistical analysis of the data on contact toxicity was performed following standard procedures.

3.5 Pot culture experiments

The pot culture studies were carried out in a completely randomised design with three treatments and five replications using seventy day old potted ginger plants of variety Maran, maintained as per Package of Practices recommendations (KAU, 2011) (Plate 3). The treatments identified as effective in laboratory studies constituted the treatments for pot culture studies (Table 2). Second instar maggots of *Mimegralla* sp. nr *coeruleifrons* were released at the collar region of the potted plants of uniform growth @ ten maggots per pot. The pots were drenched with one litre of aqueous preparation of the relevant treatment, 48 h after the release of maggots. The number of plants showing infestation symptoms as well as the number of live larvae or pupae in each rhizome was recorded ten days after the application of the treatments.

Ginger rhizomes treated with fipronil 5SC was analysed 20 days after treatment at the All India Network Project on Pesticide Residues, College of Agriculture, Vellayani, Kerala Agricultural University, following the procedure given below.

Twenty five gram of ginger rhizome was weighed out from each replicate, blended with 50 ml acetonitrile (CH_3CN) and homogenized at 14000 rpm for two minutes. The homogenized sample was taken in a sample tube and shaken for one minute. Ten grams of sodium chloride (NaCl) was then centrifuged at 2500 rpm for five minutes. From this, 16 ml of supernatant was collected and transferred into 50 ml centrifuge tube containing 6 g anhydrous sodium sulphate (Na_2SO_4). The sample was mixed well using high speed vortex shaker for two minutes. From the supernatant, 12 ml was then transferred to a 15 ml centrifuge tube containing 0.2 g ± 0.01 g PSA sorbent (Primary Secondary Amine) and 1.2 ± 0.01 g of anhydrous magnesium sulphate ($MgSO_4$). Then the sample was shaken and

Plate 3. Pot culture experiments

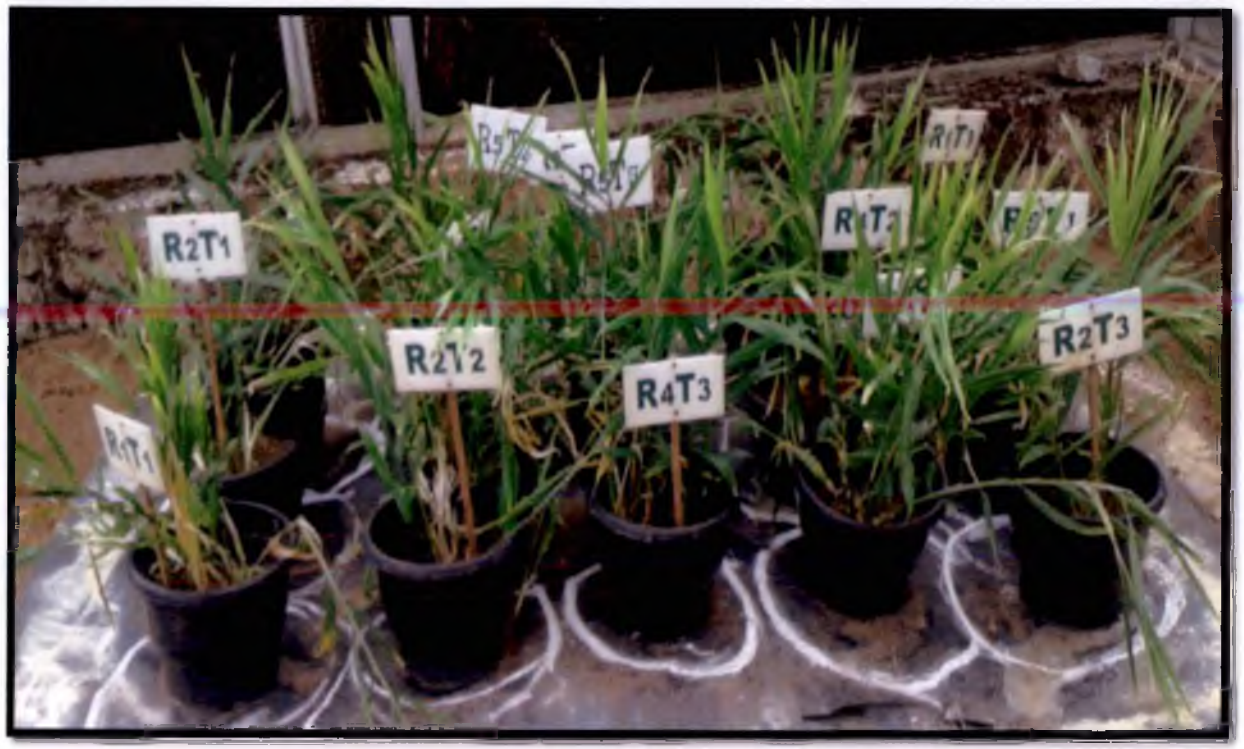


Table 2. Treatments for evaluating selected insecticides against second instar maggots of *Mimegralla* sp. nr *coeruleifrons* in pot culture experiment

Treatment	Dose	Source/ Manufacturer
T_1 - Fipronil (5SC)	50 g a.i. ha^{-1}	Bayer Crop Science, Mumbai, India
T_2 – Chlorpyriphos (20EC)	300 g a.i. ha^{-1}	K. P. R. Fertilisers Ltd. Tata Nagar, India
T_3 - Distilled water (Control)		

centrifuged for three minutes at 2500 rpm. From the supernatant, 5 ml was taken and evaporated in TurboVap at 45^0 C and reconstituted to 2 ml using methanol. The residue was quantified using a Water Acquity-UPLC + API 3200 (AB SCIEX) LC – MS/MS (Liquid Chromatography – Mass Spectrometry) fitted with Atlantis dC_{18}, 5 µm, 2.1 × 100 mm column. The mobile phase consisted of A, – 10 % methanol in water + 5 millimolar ammonium acetate + 0.1% H-COOH and B, – 10 % water in methanol + 5 millimolar ammonium acetate + 0.1 % H-COOH. Ten microlitres of the sample was injected and the flow rate was maintained at 0.75 ml/min. The retention time of fipronil was 3.03 min and limit of quantification was 0.05 mg kg^{-1}.

3.5.1 Statistical analysis

The data on pot culture experiment was analysed following standard procedures.

3.6 Interaction of *Mimegralla* sp. nr *coeruleifrons* with *Pythium aphanidermatum*

Interaction between the ginger rhizome maggot, *Mimegralla* sp. nr *coeruleifrons* and *Pythium aphanidermatum*, a fungus causing rhizome rot in ginger was studied under green house conditions, to ascertain the role of the maggots in rhizome rot infection. The study was carried out in a completely randomised design with four treatments on seventy day old ginger plants (variety Maran), grown in pots of 25 × 30 cm as per Package of Practices recommendations (KAU, 2011).

The culture of *P. aphanidermatum* was prepared by inoculating sterilised cowpea seeds with seven day old *P. aphanidermatum* culture @ three 8 mycelial disc per 100 seeds. The culture was incubated at room temperature (28 ± 2^0C) for seven days. The inoculum was applied to seventy day old potted ginger plant (variety Maran) @ 10g/plant.

The treatments were as follows:

T_1: Releasing second instar maggots of *Mimegralla* sp. nr *coeruleifrons* at the base of the plant @ 10 maggots per plant

T_2: Inoculation with *P. aphanidermatum* culture @ 10 g per plant

T_3: Releasing second instar maggots of *Mimegralla* sp. nr *coeruleifrons,* followed by inoculation with *P. aphanidermatum* @ 10 g per plant 48 h after release of maggots

T_4: Control (Distilled water)

Each treatment was replicated five times with one pot consisting one replication. Plants were observed at 24 h interval for yellowing of leaves. The plants were uprooted after 14 days and rhizomes were examined for rotting as well as tunnelling by maggots. The number of larvae in each rhizome was also recorded.

3.6.1 Statistical analysis

The data on interaction studies was analysed following standard procedures.


Results

4. RESULTS

The results of the study on "Bioecology and management of ginger rhizome maggots" carried out at the College of Horticulture, Kerala Agricultural University (Vellanikkara), during the period from August 2013 to December 2014 are presented here.

4.1 Survey of rhizome maggots on ginger

The results of the survey conducted in different locations of Thrissur and Palakkad districts during 2013-2014 to identify the major species of rhizome maggot infesting ginger are presented in Table 3.

4.1.1 Identification of ginger rhizome maggots

Three species of rhizome maggots were obtained in all the four locations surveyed (Plate 4). They were identified as *Mimegralla* sp. nr *coeruleifrons* (Diptera:Micropezidae), *Eumerus figurans* (Diptera:Syrphidae) and *Elassogaster* sp. (?) *linearis* (Diptera:Platystomatidae).

4.1.1.1 Description of species

4.1.1.1.1 *Mimegralla* sp. nr *coeruleifrons*

Mimegralla sp. nr *coeruleifrons*, commonly known as stilt legged flies belong to the family Micropezidae (Subfamily Taeniapterinae). It is an Oriental species with a widespread distribution throughout Indo-China and Malay archipelago. It is a frequent fly in the tropics and a number of larvae have been found breeding in rhizomes and roots of plants. One or more species of this genus have been recorded as a pest of ginger in many parts of India, including Kerala.

4.1.1.1.2 *Eumerus figurans*

The rhizome maggot, *E. figurans* belonging to the family Syrphidae (Subfamily Eristalinae), commonly known as hover flies. They are an Oriental, Papuan and Pacific species, is fairly widespread and is distributed from Sri Lanka

Table 3. Occurrence and seasonal abundance of rhizome maggots species on ginger

Month and year	Location	No. of maggots collected from each location	Number of maggots of each species collected			Seasonal abundance of rhizome maggots species		
			Mimegralla sp. nr *coeruleifrons*	*Eumerus figurans*	*Elassogaster* sp. (?) *linearis*	*Mimegralla* sp. nr *coeruleifrons*	*E. figurans*	*Elassogaster* sp. (?) *linearis*
August 2013	Vellanikkara	438	428	10	0	97.71	2.28	0
	Madakkathara	30	26	3	1	86.66	10.00	3.33
	Perumatty	8	8	0	0	100.00	0	0
	Pattencheri	42	30	9	3	71.42	21.42	7.14
September 2013	Vellanikkara	380	370	9	1	97.36	2.36	0.26
	Madakkathara	44	44	0	0	100.00	0	0
	Perumatty	181	174	5	2	96.13	2.76	1.10
	Pattencheri	173	172	0	1	99.42	0	0.57
October 2013	Vellanikkara	160	150	7	3	93.75	4.37	1.87
	Madakkathara	88	85	2	1	96.59	2.27	1.13
	Perumatty	129	120	6	3	93.02	4.65	2.32
	Pattencheri	150	145	5	0	98.66	2.00	0

Plate 4. Different species of ginger rhizome maggots

A. *Mimegralla* sp. nr *coeruleifrons*

B. *Eumerus figurans*

C. *Elassogaster* sp. (?) *linearis*

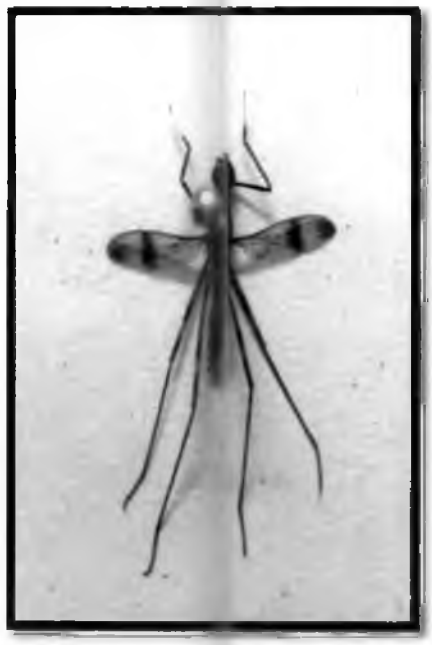
Plate 4. Different species of ginger rhizome maggots

A. *Mimegralla* sp. nr *coeruleifrons*

B. *Eumerus figurans*

C. *Elassogaster* sp. (?) *linearis*

Plate 4. Different species of ginger rhizome maggots



A. *Mimegralla* sp. nr *coeruleifrons*

B. *Eumerus figurans*

C. *Elassogaster* sp. (?) *linearis*

through the Malay archipelago as well as across the Pacific to Hawaii. *E. marginatus* Grimshaw, 1902 is a junior synonym and was recorded as a minor pest of ginger in Hawaii. This species is new to south India.

4.1.1.1.3 *Elassogaster* sp. (?) *linearis*

Elassogaster sp. (?) *linearis*, commonly known as signal flies, belong to the family Platystomatidae, subfamily Platystomatinae and is an Oriental, Papuan and Pacific species. It is widely distributed from Sri Lanka to Taiwan and the Philippines, as well as from the tropical Pacific Ocean islands through the Moluccas and New Guinea to New Britain. *Elassogaster* sp. (?) *linearis* has been recorded as a secondary pest of taro roots (*Colocasia esculenta*) in Australia and larvae have been also found in rotting asparagus crowns. However, the taxonomic identity of the collected population need be confirmed. This species is new to India.

4.1.2 Occurrence of ginger rhizome maggots

Infestation by ginger rhizome maggots was observed in all locations surveyed, *viz.* Vellanikkara and Madakkathara panchayaths of Thrissur district as well as Pattencheri and Perumatty panchayaths of Palakkad district during August, September and October months of 2013.

The highest population of 778 maggots was recorded during September 2013, followed by October and August months with 527 and 518 maggots respectively.

The highest population of 438 maggots in August 2013, was recorded at Vellanikkara and was followed by 42, 30 and 8 maggots recorded at Pattencheri, Madakkathara and Perumatty respectively. During September also, highest maggot population of 380 maggots was recorded at Vellanikkara, followed by 181 maggots at Perumatty, 173 maggots at Pattencheri and 44 maggots at Madakkathara. A similar trend was observed during October 2013 as well, with

160, 150, 129 and 88 maggots being recorded at Vellanikkara, Pattencheri, Perumatty and Madakkathara respectively.

4.1.3 Seasonal abundance of rhizome maggot species

The different species of ginger rhizome maggots collected from the locations surveyed during the period from August, 2013 to October, 2013 and their relative abundance is presented in Table 3.

The rhizome maggots collected from four locations belonged to three different species, namely, *Mimegralla* sp. nr *coeruleifrons* (Macquart, 1843), *Eumerus figurans* (Walker, 1859) and *Elassogaster* sp. (?) *linearis* (Walker, 1849). The three species varied in their abundance at each of the locations surveyed.

The micropezid fly *Mimegralla* sp. nr *coeruleifrons* was the most abundant species in all the four locations surveyed. It constituted cent per cent of the eight maggots collected at Perumatty and accounted for 97.71, 86.66 and 71.42 per cent of flies collected at Vellanikkara, Madakkathara and Pattencheri respectively during August 2013. *Mimegralla* sp. nr *coeruleifrons* dominated the number of maggots collected in September 2013 as well, recording 100, 99.42, 97.36 and 96.13 per cent at Madakkathara, Pattencheri, Vellanikkara and Perumatty. Similarly, it again was the most abundant species in October 2013, forming 98.66 per cent of the 145 maggots collected from Pattencheri, 96.59 per cent of the 85 maggots from Madakkathara as well as 93.75 and 93.02 per cent of the 150 and the 120 maggots collected from Vellanikkara and Perumatty respectively.

The population of *E. figurans* (Diptera:Syrphidae) ranged from zero to 21.42 per cent in different locations surveyed. The highest value of 21.42 per cent during August, 2013 was recorded at Pattencheri, followed by 10.00 and 2.28 per cent at Madakkathara and Vellanikkara respectively. No maggots of *E. figurans* were obtained from ginger fields in Perumatty during August.

During September, 2.76 per cent of maggots collected from Perumatty belonged to *E. figurans* while the corresponding figure for Vellanikkara was 2.36 per cent. *E. figurans* was not encountered at Madakkathara as well as at Pattencheri during the period. The highest population of *E. figurans* during October was recorded at Perumatty (4.65%) followed by 4.37, 2.27 and 2.00 per cent at Vellanikkara, Madakkathara and Pattencheri respectively.

Maggots of *Elassogaster* sp. (?) *linearis* constituted 7.14 and 3.33 per cent of total maggots collected at Pattencheri and Madakkathara and were not encountered at either Vellanikkara or Perumatty during August. In September, it recorded consistently lower values of 1.10, 0.57 and 0.26 per cent at Perumatty, Pattencheri and Vellanikkara respectively, with none being present in the samples from Madakkathara. Values of 2.32, 1.87 and 1.13 per cent were recorded at Perumatty, Vellanikkara and Madakkathara respectively during October with none being observed in samples collected from Pattencheri.

4.1.4 Relative abundance of rhizome maggot species with respect to location

The relative abundance of ginger rhizome maggots in different locations surveyed is presented in Table 4.

Mimegralla sp. nr *coeruleifrons* was found to be the most abundant species in all the four locations surveyed, based on its proportion among the total number of maggots collected. It accounted for 1755 or 96.26 per cent of the 1823 maggots collected from the four locations surveyed from August to October, 2013. *Mimegralla* sp. nr *coeruleifrons* also was the most abundant species in each of the locations surveyed, accounting for 948 or 96.93 per cent of the 978 maggots collected at Vellanikkara, 155 or 95.67 per cent of the 162 maggots collected at Madakkathara, 302 or 94.96 per cent of the 318 maggots collected at Perumatty and 350 or 95.89 per cent of the 365 maggots collected at Pattencheri.

Table 4. Relative abundance of ginger rhizome maggot species in selected locations of Thrissur and Palakkad districts

Locations	Total no. of maggots collected	Number of each species of rhizome maggots			Per cent abundance of each species of rhizome maggots		
		Mimegralla sp. nr *coeruleifrons*	*E. figurans*	*Elassogaster* sp. (?) *linearis*	*Mimegralla* sp. nr *coeruleifrons*	*E. figurans*	*Elassogaster* sp. (?) *linearis*
Vellanikkara	978	948	26	4	96.93	2.65	0.40
Madakkathara	162	155	5	2	95.67	3.08	1.23
Perumatty	318	302	11	5	94.96	3.45	1.57
Pattencheri	365	350	12	4	95.89	3.28	1.09
Total	1823	1755	54	15	96.26	2.96	0.82

In comparison, *E. figurans* accounted for only 54 or 2.96 per cent out of the 1823 maggots collected. The relative proportion of the maggots of *E. figurans* among the four locations of Vellanikkara, Madakkathara, Perumatty and Pattencheri was 2.65, 3.08, 3.45 and 3.28 per cent respectively.

The lowest values for relative abundance was registered in case of *Elassogaster* sp. (?) *linearis.* It accounted for 15 or 0.82 per cent of the 1823 maggots collected. The relative proportion of *Elassogaster* sp. (?) *linearis* among the four locations of Vellanikkara, Madakkathara, Perumatty and Pattencheri was 0.40, 1.23, 1.57 and 1.09 per cent respectively.

4.2 Biology of ginger rhizome maggots

The biology of *Mimegralla* sp. nr *coeruleifrons* (Plate 5), the predominant fly among the three species of ginger rhizome maggots encountered, was studied at the Dept. of Entomology, College of Horticulture, Vellanikkara under ambient conditions. The results of the study are presented in Table 5. The morphometric values of different life stages of *Mimegralla* sp. nr *coeruleifrons* are presented in Table 6.

4.2.1 Egg stage

Eggs of *Mimegralla* sp. nr *coeruleifrons* were small, white and the chorion was sculptured with parallel longitudinal stripes. The posterior end of the eggs was rounded and the anterior end, pointed. The incubation period ranged from 3.31 to 4.19 days with an average of 3.75 ± 0.44. On an average, an individual egg measured 0.74 ± 0.02 mm in length and 0.20 ± 0.03 mm in width. The length ranged from 0.72 to 0.76 mm while the width ranged from 0.17 mm to 0.23 mm. Eclosion occurred through longitudinal split of chorion which extended from anterior end up to three fourth of the egg. The head came first followed by a wriggling movement of body which helped the remaining portion to come out during eclosion. Hatching generally occurred during forenoon.

Plate 5. Life cycle of *Mimegralla* sp. nr *coeruleifrons*

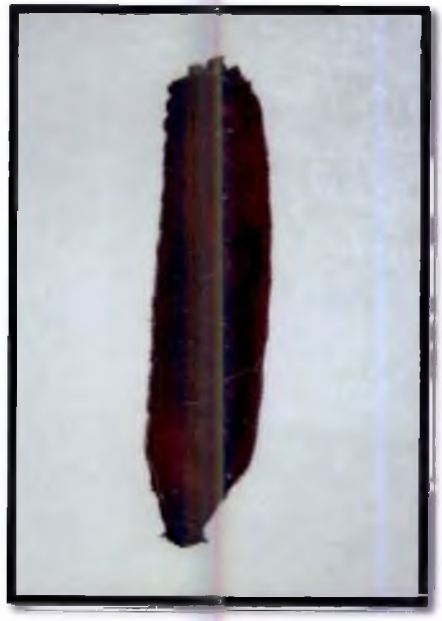
A. Egg

B. First instar larva

C. Second instar larva

D. Third instar larva

Plate 5. Life cycle of *Mimegralla* sp. nr *coeruleifrons*



E. Pupa

F. Adult male

G. Adult female

Table 5. Biology of ginger rhizome maggot, *Mimegralla* sp. nr *coeruleifrons* under laboratory conditions

Sl. No.	Parameters	Duration * in days (Mean ± SD)	Range (days)
1	Incubation period	3.75 ± 0.44	3.31 – 4.19
2	First instar larva	2.25 ± 0.44	1.81 - 2.69
3	Second instar larva	3.15 ± 0.36	2.79 – 3.51
4	Third instar larva	6.70 ± 0.73	5.97 – 7.43
5	Total larval period	12.10 ± 0.30	11.80- 12.40
6	Pupal period	8.80 ± 1.85	6.95 – 10.65
7	Life cycle	24.65 ± 1.84	22.81 - 26.50
8	Adult male	43.90 ± 18.77	25.13 – 62.67
9	Adult female	51.00 ± 20.79	30.21 – 72.00
10	Fecundity (numbers)	55.40 ± 17.64	38.00 – 73.00

* Mean of 20 observations

Table 6. Measurement of different stages of *Mimegralla* sp. nr *coeruleifrons*

Sl. No.	Stage	Mean length* in mm (Mean ± SD)	Range (mm)	Mean width* in mm (Mean ± SD)	Range (mm)
1	Egg	0.74 ± 0.02	0.72 - 0.76	0.20 ± 0.03	0.017 - 0.23
2	First instar larva	0.63 ± 0.05	0.58 - 0.68	0.16 ± 0.01	0.15 - 0.17
3	Second instar larva	4.20 ± 0.08	4.12 – 4.28	0.90 ± 0.08	0.82 - 0.98
4	Third instar larva	8.11 ± 0.06	8.05 - 8.17	1.68 ± 0.04	1.64 - 1.72
5	Pupa	6.53 ± 0.62	5.91 - 7.15	1.65 ± 0.20	1.45 - 1.85
6	Adult female	13.56 ± 1.10	12.50 - 14.66	2.18 ± 0.77	1.41 - 3.00
7	Adult male	11.27 ± 1.40	9.87 - 12.67	1.30 ± 0.33	0.95 - 1.63

* Mean of 20 observations

4.2.2 Maggots

4.2.2.1 First instar

The maggot on emergence, was tiny, apodous, translucent and colourless with a cylindrical body that lacked distinct segmentation. The body was narrow at the anterior end and widened towards posterior end. The larvae were active immediately after hatching. The duration of first instar ranged from 1.81 to 2.69 days, with an average of 2.25 ± 0.44, and they measured 0.63 ± 0.05 mm in length and 0.16 ± 0.01 mm in width. The length and width ranged from 0.58 to 0.68 and 0.15 to 0.17 mm respectively.

4.2.2.2 Second instar

The second instar larva had white, cylindrical tapering body with twelve visible segments. A pair of reddish brown spiracles on the blunt end of last abdominal segment as well as two semicircular flaps or oral lobes anterior to the mouth orifice on the first body segment were characteristic of the stage. Spinulose areas, which helped in locomotion occupied the anterior part on the ventral side of each abdominal segment. The duration of the second instar larvae ranged from 2.79 to 3.51 days, with an average of 3.15 ± 0.36. On an average, the second instar maggot measured 4.20 ± 0.08 mm in length and 0.90 ± 0.08 mm in width at the broadest part. The length ranged from 4.12 to 4.28 mm while the width varied from 0.82 to 0.98 mm.

4.2.2.3 Third instar

The fully grown third instar maggot was creamy white and similar in appearance to second instar maggot. The cephalic mouth hooks and pair of spiracles on the last abdominal segment were thicker, darker and bigger. Spinulose areas on ventral surface of each abdominal segment were fleshy, blunt and directed backwards. Pair of dark brown to black, fan shaped spiracles was present on the first thoracic segment. The duration of larval period ranged from 5.97 to 7.43 days on an average of 6.70 ± 0.73. The third instar maggots measured

8.11 ± 0.06 mm in mean length and 1.68 ± 0.04 mm in mean width. The third instar ranged from 8.05 to 8.17 mm in length and 1.64 to 1.72 mm in width.

The total larval period lasted, on an average, 12.10 ± 0.30 days with a range from 11.80 to 12.40 days.

4.2.3 Pupa

The full-grown maggots pupated in the larval tunnels in ginger rhizomes. The puparium was dark brown and elongated, with posterior spiracles similar to those of larvae, though more sclerotized. The colour of pupae changed gradually from brown to black towards emergence. The adult emerged by rupturing the puparium along a circular suture near the thoracic segments, detaching the anterior part while the posterior end of pupae usually remains loosely attached to its body. The pupal period ranged from 7.0 to 10.65 days with an average of 8.80 ± 1.85. The mean length and width of pupa was 6.53 ± 0.62 and 1.65 ± 0.20 mm respectively. The length ranged from to 5.91 to 7.15 mm while the width varied from 1.45 mm to 1.85 mm.

4.2.4 Adults

The adults of *Mimegralla* sp. nr *coeruleifrons* were fairly large, slender flies with stilt like legs. The antenna was short with a sub-basal arista. The abdomen, thorax and legs were brownish black. The tarsi of fore legs were white. The wings were transparent with well defined cross-bands. Males were smaller than females. The males were identified with presence of extremely conspicuous, prong like digitate claspers. The last abdominal segments of female were modified into a short ovipositor. The male lived for an average of 43.90 ± 18.77 days and the female, for an average of 51.00 ± 20.79 days. The longevity of male and female flies ranged from 25.13 to 62.67 days and 30.21 to 72.0 days respectively. The adult male fly measured 11.27 ± 1.40 mm in mean length and 1.30 ± 0.33 mm in mean width. The length ranged from 9.87 to 12.67 mm while the width ranged from 0.95 to 1.63 mm. The adult female fly measured 13.56 ± 1.10 mm in mean

length and 2.18 ± 0.77 mm in mean width. The length ranged from 12.50 to 14.66 mm while the width ranged from 1.41 to 3.00 mm.

The life cycle ranged from 22.81 to 26.50 days with an average of 24.65 ± 1.84.

4.2.5 Oviposition

The female flies became receptive to mating by the tenth day after emergence and oviposition occurred 2 to 3 days after mating. The females were normally observed to oviposit on diseased rhizomes. However, laying eggs on the tissue paper beneath rhizome was also common. Eggs were laid singly and in most cases in batches of 4 to 7.

4.2.6 Fecundity

Mated female fly laid 38 to 73 eggs with an average of 55.40 ± 17.64 eggs during the oviposition period which varied from 1 to 3 days.

4.2.7 Sex ratio

The sex ratio of female and male flies was 1:1.

4.3 Documentation of natural enemies

The rhizome maggot infested ginger fields were surveyed for documenting the natural enemies like predators, parasitoids and pathogens.

4.3.1 Predator

An unidentified species of spider (Plate 6) was observed to be feeding on the adults of *Mimegralla* sp. nr *coeruleifrons*. The spider remained on the leaf surface and preyed on the adult flies that landed on the leaf surface.

Plate 6. Predator of *Mimegralla* sp. nr *coeruleifrons*

A. Spider

4.3.2 Parasitoid

A parasitoid, *Trichopria malabarensis* (Hymenoptera: Diapriidae) was found to infest the pupae in the field (Plate 7). The parasitoid was observed to be gregarious in habit with 4 to 5 parasitoids emerging from each parasitized pupa.

The female wasps had shining black body except for the petiole which was brownish black. The compound eyes and ocelli were silvery with brown tinge. Legs were reddish brown with black apical tarsi. Wings were hyaline with dark brown veins and marginal fringes. Pubescence on antennae and body was dull white in colour. The females were bigger than males, with broader abdomen. Bristles were present all over the body but concentrated more on the last abdominal segment. Antenna was 12 segmented with the scape insertion on frontal shelf level with vertex. Scape was a little thickened towards the distal end and club was densely hairy. The fore tibia had single, small, outwardly directed spine. The femora were distinctly spindle shaped and tibiae apically swollen. Forewing was densely hairy with a bare area towards the median. The marginal fringe of hairs was well developed. The gaster was petiolated and petiole was cylindrical with dense, whitish hairs. Petiole was invested with long dense scales medially, and had, with longitudinal striations distally.

The male parasitoid has shiny black body, except for petiole which was brownish black in colour. The eyes and ocelli were silvery with brown tinge. The antennae were inserted on prominent frontal shelves or projections. The moniliform antennae were 14 segmented, with the flagellar segments in male having fine apressed white hairs. The thorax was oval in shape with short pronotum with silvery white woolly hairs on sides. All femora were distinctly spindle shaped and tibiae apically swollen.

Plate 7. Parasitoid of *Mimegralla* sp. nr *coeruleifrons*

A. *Trichopria malabarensis*

(Female)

B. *Trichopria malabarensis*

(Male)

C. Parasitised pupa

4.3.3 Pathogens from ginger rhizome maggots

No pathogens were found to be infecting any stage of *Mimegralla* sp. nr *coeruleifrons* during the survey.

4.4 Studies on management of ginger rhizome maggots

Two species of entomopathogenic fungi, two species of entomopathogenic nematodes and two insecticides were evaluated for their efficacy against rhizome maggots, as already described under materials and methods. The treatments found to be promising in the laboratory experiments were further evaluated in a pot culture experiment.

4.4.1 Evaluation of contact toxicity of selected entomopathogens and insecticides in the laboratory

The results of the Petri plate bioassay (Table 7) and rhizome dip assay (Table 8) of the four selected entomopathogens as well as two insecticides against ginger rhizome maggot *Mimegralla* sp. nr *coeruleifrons* are presented below.

4.4.1.1 Petri plate bioassay

Among the different treatments, the insecticide chlorpyriphos 20EC applied @ 300 g a.i. ha^{-1} recorded cent per cent mortality within 24 h after treatment. This was followed by fipronil 5SC @ 50 g a.i. ha^{-1} which recorded an average mortality of 90 per cent.

Among the different entomopathogens, *Heterorhabditis indica,* applied @ 400 IJs ml^{-1} recorded mean mortality of 16.66 per cent, followed by *Metarhizium anisopliae* at 3.33 per cent. Both *Beauveria bassiana* and *Steinernema carpocapsae* failed to record any mortality of the treated maggots.

Table 7. Mortality of second instar maggots of *Mimegralla* sp. nr *coeruleifrons* using selected entomopathogens and insecticides through Petri plate bioassay

Treatments	Dose	Total number of maggots	Mortality (No.)	Mortality (%)
T_1 – *Metarhizium anisopliae*	1×10^9 spores ml^{-1}	30	1	3.33
T_2 – *Beauveria bassiana*	1×10^9 spores ml^{-1}	30	0	0
T_3 – *Steinernema carpocapsae*	400 IJs ml^{-1}	30	0	0
T_4 – *Heterorhabditis indica*	400 IJs ml^{-1}	30	5	16.66
T_5 – Fipronil (5SC)	50 g a.i. ha^{-1}	30	20	90.00
T_6 – Chlorpyriphos (20EC)	300 g a.i. ha^{-1}	30	30	100
T_7 – Control (Distilled water)		30	0	0

IJs- Infective Juveniles

Table 8. Mortality of second instar maggots of *Mimegralla* sp. nr *coeruleifrons* using selected entomopathogens and insecticides through rhizome dip assay

Treatments	Dose	Total number of maggots	Mortality (No.)	Mortality (%)
T_1 – *Metarhizium anisopliae*	1×10^9 spores ml^{-1}	30	0	0
T_2 – *Beauveria bassiana*	1×10^9 spores ml^{-1}	30	0	0
T_3 – *Steinernema carpocapsae*	400 IJs ml^{-1}	30	0	0
T_4 – *Heterorhabditis indica*	400 IJs ml^{-1}	30	0	0
T_5 – Fipronil (5SC)	50 g a.i. ha^{-1}	30	20	66.66
T_6 – Chlorpyriphos (20EC)	300 g a.i. ha^{-1}	30	30	100
T_7 – Control (Distilled water)		30	0	0

IJs- Infective Juveniles

4.4.1.2 Rhizome dip assay

Among the different treatments, the insecticide chlorpyriphos 20EC applied @ 300 g a.i. ha^{-1} recorded cent per cent mortality within 24 h after treatment. This was followed by fipronil 5SC applied @ 50 g a.i. ha^{-1}, which recorded an average mortality of 66.66 per cent. The selected entomopathogens failed to record any mortality of the treated maggots.

The two insecticides also varied in time required to effect the kill of treated larvae. While all the maggots treated with chlorpyriphos were killed in 24 h, maggots treated with fipronil required up to six days to bring about maximum mortality (Table 9).

4.5 Pot culture experiments

Two treatments, namely chlorpyriphos and fipronil which were identified as superior in the laboratory experiments were evaluated for their efficacy against ginger rhizome maggots in a pot culture experiment. The results are presented in Table 10.

The pots drenched with chlorpyriphos 20EC @ 300 g a.i. ha^{-1} recorded cent per cent mortality while those drenched with fipronil 5SC @ 50 g a.i. ha^{-1} recorded 78 per cent mortality. Control pots treated with distilled water showed no mortality.

Result of the residue analysis in ginger rhizomes treated with fipronil analysed at twenty days after exposure are furnished in Table 11. The rhizomes treated with fipronil recorded a value of 0.052 mg kg^{-1}, which was marginally above the minimum detectable limit of 0.05 mg kg^{-1} of rhizome.

Table 9. Differential response of chlorpyriphos and fipronil in rhizome dip assay against second instar maggots of *Mimegralla* sp. nr *coeruleifrons*

Treatments	Dose	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Total mortality (No.)	Mortality (%)
Fipronil (5SC)	50 g a.i. ha^{-1}	4	4	1	2	6	3	0	20	66.66
Chlorpyriphos (20EC)	300 g a.i. ha^{-1}	30	-	-	-	-	-	-	30	100.00

Table 10. Mortality of second instar maggots of *Mimegralla* sp. nr *coeruleifrons* in pot culture experiment

Treatments	Dose	Total number of maggots	Plants showing foliar symptoms	Mortality (No.)	Mortality (%)
T_1 – Fipronil (5SC)	50 g a.i. ha^{-1}	50	1	39	78
T_2 – Chlorpyriphos (20EC)	300 g a.i. ha^{-1}	50	0	50	100
T_3 – Control (Distilled water)		50	5	0	0

Table 11. Residue analysis of ginger rhizomes treated with fipronil

Treatment	Dose	Residue at 10 DAT ($mg\ kg^{-1}$)	LOQ ($mg\ kg^{-1}$)
Fipronil	500 g a.i. ha^{-1}	0.052	0.05
Untreated control	-	BLQ	0.05

DAT - Days After Treatment

BLQ – Below Limit of Quantification

LOQ – Limit of Quantification

4.6 Interaction of *Mimegralla* sp. nr *coeruleifrons* with *Pythium aphanidermatum*

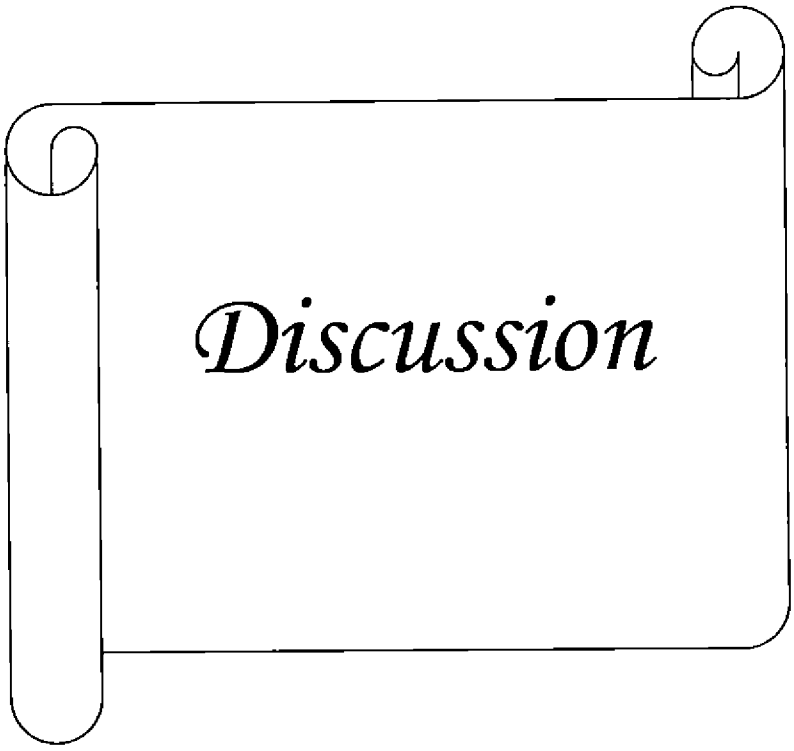
Results of the study on the interaction of *Mimegralla* sp. nr *coeruleifrons* with *Pythium aphanidermatum* are presented in Table 12.

All the plants inoculated with the *P. aphanidermatum* alone as well as the plants treated with *P. aphanidermatum* along with maggots of *Mimegralla* sp. nr *coeruleifrons* showed disease symptoms such as yellowing of leaves and rotting of rhizomes. None of the plants inoculated with second instar maggots of *Mimegralla* sp. nr *coeruleifrons* alone recorded disease symptoms, though tunnelling by maggots was observed.

A total of 35 maggots, constituting 70 per cent of the 50 maggots released in the pots treated with both *P. aphanidermatum* and *Mimegralla* sp. nr *coeruleifons*, were recovered as late third instar or pupae 14 days after treatment, whereas only 21 maggots or 42 per cent of the 50 maggots released in pots treated with *Mimegralla* sp. nr *coeruleifrons* alone were recovered after 14 days.

Table 12. Interaction of *Mimegralla* sp. nr *coeruleifrons* with *Pythium aphanidermatum*

Treatments	No. of plants with foliar yellowing	Per cent disease incidence	Total no. of maggots inoculated	No. of maggots recovered	Per cent of maggots recovered
T_1: Releasing second instar maggots of *Mimegralla* sp. nr *coeruleifrons* @ 10 maggots per plant	0	0	50	21	42
T_2: Inoculation with *P. aphanidermatum* culture @ 10 g per plant	5	100	0	0	0
T_3: Releasing second instar maggots of *Mimegralla* sp. nr *coeruleifrons*, @ 10 maggots per plant + inoculation with *P. aphanidermatum* @ 10 g per plant	5	100	50	35	70
T_4: Control (Distilled water)	0	0	0	0	0


Discussion

5. DISCUSSION

A study entitled "Bioecology and management of ginger rhizome maggots" was conducted at College of Horticulture, Vellanikkara. The study involved identification of major species of ginger rhizome maggots, biology of the predominant species of rhizome maggots, documentation of the natural enemies and evaluation of eco-friendly management measures against the predominant species. The results of the study are discussed below.

5.1 Survey of rhizome maggots on ginger

5.1.1 Identification of ginger rhizome maggots

5.1.1.1 *Mimegralla* sp. nr coeruleifrons

The maggots collected from the four locations during the survey belonged to three species, namely, *Mimegralla* sp. nr *coeruleifrons* (Diptera:Micropezidae), *Eumerus figurans* (Diptera:Syrphidae) and *Elassogaster* sp. (?) *linearis* (Diptera:Platystomatidae), in the order of their relative abundance. Among the three, the taxonomic identity of two species remains to be confirmed. This uncertainity, *inter alia*, can place a certain degree of ambiguity throughout the discussion, especially with regard to *Mimegralla* sp. nr *coeruleifrons* as to whether it is same as *Mimegralla coeruleifrons* reported in earlier studies. *M. coeruleifrons* has not been reported from south India previously (Ghorpade, personal communication) and the possibility of the rhizome maggot identified as *Mimegralla* sp. nr *coeruleifrons* being synonymous with *M. coeruleifrons* reported earlier cannot be ruled out. *Mimegralla* sp. nr *coeruleifrons* has been reported as infesting ginger by a number of authors. Ghorpade *et al.* (1988) reported *M. coeruleifrons* as infesting ginger and turmeric in Maharashtra while Sontakke (2000) had reported the same species from ginger in Orissa. Koya (1989) and Jacob (1980) also reported the fly from infested ginger rhizomes in Kerala.

5.1.1.2 *Eumerus figurans*

Several syrphid flies such as *Eumerus marginatus* and *E. pulcherrimus* have been reported as infesting ginger and turmeric in India (Trujillo, 1964; CPCRI, 1986). They are often seen in later stages of the crop and are fewer in number, as compared to *Mimegralla* sp. nr *coeruleifrons*. However, the present species that has been identified as *E. figurans* has not been reported so far and could constitute a new report from Kerala.

5.1.1.3 *Elassogaster* sp. (?) *linearis*

Elassogaster sp. (?) *linearis* has been reported as a secondary pest of taro roots in Australia (McAlpine, 2001) and has also been reported from Sri Lanka. It has not been reported from India till date and could be a new report.

5.1.2 Occurrence and seasonal abundance of ginger rhizome maggots

Infestation of ginger rhizome maggots was recorded from all locations surveyed, *viz.* Vellanikkara and Madakathara panchayaths of Thrissur district as well as Pattencheri and Perumatty panchayaths of Palakkad district, throughout the survey period, indicating the widespread nature of the rhizome maggots both in time and space.

The highest population of 778 maggots per 60 plants was recorded in September, 2013 followed by 528 and 518 maggots in October and August 2013 respectively, confirming the temporal variation in population of rhizome maggots. The population of 778 maggots during September was 47.30 per cent higher than the next highest value of 528 maggots in October and coincided with finger formation stage of the crop planted in June.

Variation in population of rhizome maggots during different periods of the year has been documented by several authors. Ghorpade *et al.* (1983), for instance, had conducted detailed study on the rhizome maggot incidence on both ginger and turmeric in Maharashtra. They recorded peak population of 15.5 maggots per 25 m^2 area during the second fortnight of September (1970-80) as

against 12.5 in August (1970-80) and opined that the cloudy weather with intermittent rains along with high temperature and relative humidity prevalent during September appeared to favour the build up of *M. coeruleifrons*. No flies were encountered in ginger fields from December onwards, which coincided with cessation of rainfalls, though maggots and pupae were observed in rhizomes right up to harvest. The authors, based on the above observations suggested that the build up of *M. coeruleifrons* population was closely correlated with prevalent weather condition.

The findings of the present study also support the above conclusion that weather parameters could be more significant in regulating rhizome maggot populations than the stage of crop. The near identical but lower populations in both August and October of 2013, supports the above observation. However, studies on the rhizome maggot population in relation to the crop stages in ginger are needed for confirming the same.

The variation observed in the total population of rhizome maggots between different months was also observed in each of the location surveyed. The maggot population at Vellanikkara, which consistently recorded highest maggot populations throughout the survey period, registered a decline from 438 in August 2013 to 380 in September 2013 and 160 during October, 2013.

The maggot population at Madakkathara, on the other hand, registered an increasing trend, with population increasing from 30 in August to 44 in September and 88 in October. The maggot population at Perumatty in August 2013 was the lowest for any location with just eight maggots being collected from sixty plants. The number of maggots collected during September and October months of 2013 were much higher, at 181 and 129 maggots respectively. This again follows the general trend of populations peaking in September month. The very low number of maggots could presumably be due to plant protection measures adopted by farmer, though the same could not be confirmed as most ginger farmers are lease holders and could not be contacted.

The maggot population at Pattencheri varied from 42 in August to 173 in September and 150 in October, 2013. Here again, peak population was recorded in September, as in case of Perumatty.

A comparison between the populations at different locations during the period reveals a similar pattern for the two panchayaths in Palakkad district while the populations at Vellanikkara and Madakkathara in Thrissur showed opposite tendencies. Given the proximity of the two locations, an explanation for the above observation could possibly lie in the differences in varieties as well as agronomic practices, the documentation of which was beyond the scope of the present study. However, at Perumatty and Pattencheri, the populations tended to follow the overall pattern with maximum populations being recorded in September.

5.1.3 Relative abundance of rhizome maggot species with respect to location

Mimegralla sp. nr *coeruleifrons* constituted 96.26 per cent of the total number of maggots collected and its relative proportion among the maggot population was 96.93, 95.89, 95.67 and 94.96 per cent at Vellanikkara, Pattencheri, Madakkathara, and Perumatty respectively. This confirms that *Mimegralla* sp. nr *coeruleifrons* was the dominant species of rhizome maggots in the two districts surveyed.

Mimegralla coeruleifrons has been consistently reported as infesting ginger and turmeric across south India by various authors *viz.* Kotikal and Kulkarni (2000a), Ghorpade *et al.* (1983), Sontakke (2000) and Jacob (1980).

Eumerus figurans accounted for 2.96 per cent of the total rhizome maggots collected from the four locations. The relative proportion of the fly was low compared to that of *Mimegralla* sp. nr *coeruleifrons* but was nearly uniform across the locations studied, recording 3.45, 3.28, 3.08 and 2.65 per cent at Perumatty, Pattencheri, Madakkathara and Vellanikkara respectively. Nair (1975) had reported infestation by *E. albifrons* in ginger in Kerala. Ghorpade *et al.* (1988) had reported that *Eumerus* spp. coexisted with *M. coeruleifrons* in ginger

rhizomes and that occasionally up to ten maggots of the former could be observed in a single rhizome along with up to 40 maggots of the latter, implying that they were less numerous compared to *M. coeruleifrons*. Members of the genus '*Eumerus*' have been known to be pest of narcissus bulb, snowdrops, onion and secondary pest of potato, carrot and cabbages (Hill, 1987). The present study confirm that several species under the genus '*Eumerus*' attack ginger rhizomes in field, though the extent of damage they cause need be ascertained, given their low numbers.

The lowest number of maggots recorded in the survey was that of *Elassogaster* sp. *linearis,* accounting for just 1.4 per cent of the total maggots collected. *Elassogaster* sp. *linearis* infestation appeared to be infrequent and the maggots were often not encountered during field visits. Considering that it could be a new species, its biology, ecology and host range remain to be studied.

5.2 Biology of ginger rhizome maggots

5.2.1 Egg stage

The incubation period of eggs varied from 3.31 to 4.19 days, with an average of 3.75 ± 0.44 days. These values are in close conformity with those reported by earlier reports. The mean incubation period in the present study, which is in agreement with the findings of Ghorpade *et al.* (1988) who reported an incubation period of 2 to 5 days. However, Sontakke (2000) had reported a lower incubation period of 2.5 days in studies conducted at Sambalpur in Orissa. This variation could possibly be due to the differences in weather parameters the details of which were not available.

Eggs recorded a mean length of 0.74 ± 0.02 mm and mean width of 0.20 ± 0.03 mm. Koya (1989) had reported the mean length of eggs to be 0.77 mm, with a range of 0.75 to 0.80 mm and mean width of 0.17 mm with a range of 0.16 to 0.18 eggs of *Mimegralla coeruleifrons*. Ghorpade *et al.* (1988), similarly, had reported average length of eggs to be 0.81 mm and average width to be 0.22 mm.

The values recorded in the present study are in agreement with the above observations.

5.2.2 Maggots

5.2.2.1 First instar

The mean duration of first instar maggots was 2.25 ± 0.44 days with a range of 1.81 to 2.69 days. Koya (1989) had reported the average duration of first instar as 3 days. Ghorpade *et al.* (1988), however, had reported a longer duration of 5 to 7 days for the first instar under conditions of 22 to 28^{0}C and relative humidity of 65 to 87 per cent, which were lower than those recorded during the present study. The findings of the present investigation broadly agree with that of the former, which were carried out under similar conditions.

The mean length of 0.63 ± 0.05 mm and mean width of 0.16 ± 0.01 mm recorded in case of first instar larvae is in accordance with mean length of 0.63 mm and mean width of 0.15 mm, reported by Ghorpade *et al.* (1988), though is lower than the mean length of 2.60 mm reported by Koya (1989).

5.2.2.2 Second instar

The duration of the second instar larvae ranged from 2.79 to 3.51 days with an average of 3.15 ± 0.36 days. This is at variance with the findings of Ghorpade *et al.* (1988), who recorded mean duration of 2.0 days only for *M. coeruleifrons*. The wide variation could be due to the difference in ambient conditions.

The mean length and width of second instar maggots was 4.20 ± 0.08 mm and 0.90 ± 0.08 mm respectively are again in conformity with the dimensions of 4.5 × 1.0 mm reported by Ghorpade *et al.* (1988) and is only marginally lower than the 5.2 mm length reported by Koya (1989) for the second instar maggots of *M. coeruleifrons*.

5.3.2.3 Third instar

The duration of third instar larva varied from 5.97 to 7.43 days with an average of 6.70 ± 0.73 days. Ghorpade *et al.* (1988) had reported the average duration of third instar as 4.7 days. Koya (1989) also had recorded duration of third instar maggots to be ranging from 4 to 8 days. The findings of the present study are in line with the earlier reports.

The mean length recorded for third instar was 8.11 ± 0.06 mm with a range of 8.05 to 8.17 mm and mean width recorded was 1.68 ± 0.04 mm with a range of 1.64 to 1.72 mm. The observations are marginally lower than the mean length of 9.6 mm and mean width of 1.7 mm reported by Ghorpade *et al.* (1988) and mean length of 10 mm reported by Koya (1989) for *M. coeruleifrons*, and could be ascribed to variations in the conditions under which the studies were conducted.

5.2.3 Pupa

The average duration of pupa varied from 6.95 to 10.65 days with an average of 8.80 ± 1.85 days, and agrees with 8 to 11 days recorded by Koya (1989).

The mean length of 6.53 ± 0.62 mm and mean width of 1.65 ± 0.20 mm for pupae recorded in the present study is more or less in agreement with the dimensions of 8.0 × 1.7 mm reported by Ghorpade *et al.* (1988) as well as values of 7.78 × 1.61 mm, reported by Koya (1989) for the corresponding stage of *M. coeruleifrons*.

5.2.4 Adult

The average longevity of the adult male and female flies was 43.90 ± 18.77 days and 51.00 ± 20.79 days respectively. The recorded values were much higher than the values reported previously. Ghorpade *et al.* (1988), for instance, had recorded the average longevity of male and female flies on ginger as 8.8 and 10.6 days respectively in Maharashtra, though higher values of up to 17.1 and

21.3 days were recorded on turmeric. Kotikal and Kulkarni (2000b) also had reported the longevity of males and females as 10.50 ± 3.35 and 17.20 ± 2.66 days respectively. Sontakke (2000) reported average longevity of *M. coeruleifrons* adults as ranging from 13.8 to 20.4 days. Koya (1989) had reported that longevity of the fly increased when reared on banana flowers. While the greater longevity of female flies compared to that of males is in conformity with the findings of earlier studies, the considerably higher values for both sexes in the present study is indicative of the potential longevity of the pest and require further investigations.

The female flies, with 13.56 ± 1.10 mm in length and 2.18 ± 0.77 mm in width, were larger than males, which had an average length of 11.27 ± 1.40 mm and average width of 1.30 ± 0.33 mm. The morphometric data of the adult flies is in closely conformity with the findings of Ghorpade *et al.* (1988) who reported that the length of females and males varied from 13 to 16 mm and 12 to 14 mm respectively. Koya (1989) also had reported mean values of 11.95 × 1.50 mm and 13.65 × 1.75 mm for the male and female flies respectively. The female flies were larger than males, across all the reports.

5.2.5 Oviposition

The female flies recorded a preoviposition period of 13 days and an average oviposition period of three days. The females, in most cases, also exhibited a tendency to lay their eggs on or near diseased rhizomes. Ghorpade *et al.* (1988) had reported similar observations on the oviposition period of the female fly as well as on their tendency to oviposit near diseased rhizomes, confirming the findings of the present study.

5.2.6 Fecundity

The average fecundity recorded in the present study was 55.40 ± 17.64 eggs, within a range of 38 to 73 eggs, which is lower than the values of 83.8 to 110.6 reported by Kotikal and Kulkarni (2000b), under the temperature range of 19.80 to 32.56^0 C and relative humidity of 60.33 to 78.56 per cent, as well as the mean fecundity of 130 eggs reported by Ghorpade *et al.* (1988) under conditions

of 25.6^0 C mean temperature and 76 per cent mean relative humidity. The lower fecundity recorded in the present study could be due to variations in the ambient conditions under which the experiments were carried out.

5.2.7 Sex ratio

The sex ratio of female and male flies was 1:1. Koya (1989) as well as Ghorpade *et al.* (1988) also had reported similar sex ratio for *M. coeruleifrons*.

5.3 Documentation of natural enemies

The results of the survey for documentation of natural enemies yielded a spider (*Araneus* sp.) as well as a pupal parasitoid, *Trichopria malabarensis* and are in conformity with earlier studies on natural enemies of *Mimegralla coeruleifrons*. Kotikal and Kulkarni (2000a) had reported eight predators and two parasitoids as attacking rhizome maggots, including four spiders *viz. Araneus* sp., *Micaria* sp., *Thyene* sp., *Pardosa* sp. Taxonomic identification of the spider species could not be carried out during the present study, as only a single specimen was obtained.

The pupal parasitoid obtained from infected pupae collected from field was identified as *T. malabarensis* Rajmohana and Narendran, which was reported for the first time by Rajmohana (2006). The diapriid wasps of genus *Trichopria* are well known pupal parasitoids of dipteran flies. They constitute a widespread and diverse group of parasitoids, with the members exhibiting considerable variation in size, colour and pubescence. *T. malabarensis* have been reported as pupal parasitoids of *M. coeruleifrons* by several authors including Kotikal and Kulkarni (2000b). Parasitisation of up to 37 per cent in field was reported by Ghorpade *et al.* (1988).

The present investigation did not come across any rhizome maggots infected by entomopathogenic organisms in the field. Hardly any microbial pathogen has been reported as infesting *M. coeruleifrons*. Given the moist subterranean environment inhabited by the maggots which are ideally suited for

entomopathogenic fungi as well as nematodes, the absence of microbial pathogens calls for more detailed investigations.

4.4 Laboratory experiments

4.4.1 Evaluation of contact toxicity of selected entomopathogens and selected insecticides in the laboratory

4.4.1.1 Petri plate bioassay

Evaluation of entomopathogens as well as selected insecticides revealed chlorpyiphos to be most effective treatment, with 100 per cent mortality followed by fipronil, which caused 90 per cent mortality of the treated maggots. Among the biocontrol agents, the entomopathogenic nematodes *Heterorhabditis indica* caused a mortality of 16.66 per cent, followed by the green muscardine fungus *Metarhizium anisopliae*, with a mortality of 3.33 per cent. No mortality was recorded in treatments involving *Beauveria bassiana, Steinernema carpocapsae* and the absolute control.

Chlorpyriphos is a very popular organophosphorous insecticide with broad spectrum of activity and is recommended for soil drenching against soil borne pests such as root grubs and termites.

Fipronil, a phenyl pyrazole compound introduced in 1993 is a contact and stomach poison with delayed action. It is highly selective to insects and is considered safer to higher organisms than conventional insecticides (Hainzl and Casida, 1991). The mortality of 90 per cent at the recommended dose was indicative of its potential value in management of rhizome maggots.

Among the entomopathogens, *H. indica* and *M. anisopliae* recorded 16.66 and 3.33 per cent mortality respectively. The mortality induced by the pathogens was far below the mortality induced by either of the insecticides.

The entomopathogenic nematodes as well as the green muscardine fungus *M. anisopliae* are known to be very effective against soil borne organisms at doses

lower than those employed in the present study. For instance, both *H. indica* and *S. carpocapsae* have been reported to cause 100 per cent moratlity of much larger and hardier grubs of cashew stem borer *Plocaederus ferrugineus* L., at a much lower dose of 100 IJs/ml (Poojari, 2014).

Metarhizium anisopliae, similarly, has been found effective against a number of soil borne insects and has been recommended for use against pests such as the rhinoceros beetle, *Oryctes rhinoceros* (KAU, 2011). The low moratlity values recorded under laboratory condition, therefore calls for investigations into the interactions between the pest and the natural enemies. A comparison with previous studies is not possible as there are hardly any reports on evaluation of entomopathogens against *M. coeruleifrons.*

4.4.1.2 Rhizome dip assay

The results of the rhizome dip assay recorded 100 and 66.66 percent per cent mortality in maggots treated with chlorpyriphos and fipronil. The experiment confirmed the superiority of chlorpyriphos over other treatments including fipronil, which proved to be the next best treatment. All the four entomopathogens as well as absolute control recorded zero mortality in rhizome dip assay.

The results of rhizome dip assay are in broad agreement with the results of Petri plate bioassay. While the insecticides have been promising, the biocontrol agents have been ineffective. As already stated, biocontrol of rhizome maggots, including the herbivore-natural enemy interaction have hardly been studied, to effect a comparison.

The failure of natural enemies in causing mortality of any significance to treated rhizome maggot population, on the other hand, have also to be read along with the fact that few instances of successful use of entomopathogens against dipteran flies have been reported till date, in spite of the fact that the nature of the microenvironment in which the maggots are invariably found are conducive to most entomopathogens, especially entomopathogenic fungi and nematodes.

Among the two insecticides found to be effective, chlorpyriphos induced mortality in 24 h whereas fipronil was slower in action, with mortality occurring over six days. This is in conformity with the known fact fipronil is a delayed action insecticide.

5.5 Pot culture experiments

Only the two insecticides *viz.* chlorpyriphos and fipronil were evaluated in the pot culture studies. The results closely follow the findings of the rhizome dip treatment with chlorpyriphos @ 300 g a.i. ha^{-1} recording cent per cent mortality while fipronil recorded 78 per cent mortality. Control pots which received distilled water recorded no mortality. The pot culture studies thus confirmed the relative superiority of chlorpyriphos in managing rhizome maggots.

Sontakke (2006) had reported that treatment of rhizome with chlorpyriphos (0.1%) followed by drenching at 50 days after planting caused a significant reduction in maggot infestation in the field. Soil drenching with chlorpyriphos resulted in 8.5 and 10.2 per cent shoot and rhizome infestation respectively. Treating seed rhizomes with chlorpyriphos (0.1%) followed by drenching with the same 50 days after planting was the most effective treatment, with 2.5 and 5.2 per cent shoot and rhizome infestation respectively. All the treatments were significantly superior to the control, which recorded 14.6 and 29.4 per cent shoot and rhizome damage respectively.

The identical values of results between rhizome dip treatment and pot culture experiment also points towards using the possibility rhizome dip treatment as a quick and easier method for evaluating insecticides against rhizome maggots.

Analysis of fipronil residues in treated ginger rhizomes showed that the residue levels were marginally above the detectable limit, twenty days after treatment. Considering that seventy day old rhizomes were used, the possibility of fipronil residues in the harvested produce when applied at the recommended dose appear to the minimal, though not confirmed in the present study. Fipronil is described as an insecticide with moderate persistence in plants and soil but poor

uptake by plants (EPA, 2005). Saini *et al.* (2014) reported that half life period of fipronil in soil was 8.2 days and that it was safe enough to be used at recommended doses since the insecticide dissipated to very low levels in 90 days.

5.6 Interaction of *Mimegralla* sp. nr *coeruleifrons* with *Pythium aphanidermatum*

Plants treated with *Pythium aphanidermatum* alone as well as those treated with both *P. aphanidermatum* and maggots of *Mimegralla* sp. nr *coeruleifrons* recorded cent per cent and 80 per cent of disease incidence respectively. None of the plants inoculated with second instar maggots of *Mimegralla* sp. nr *coeruleifrons* alone showed disease symptoms.

The interaction between *M. coeruleifrons* and the rhizome rot fungi in ginger has been reported by several authors. Koya (1990) had reported that rhizome maggots had no role in the incidence of disease and therefore infestation by maggots was secondary in nature. Ginger plants inoculated with *M. coeruleifrons* alone were reported as devoid of rot disease, whereas plants treated with *P. aphanidermatum* alone and *P. aphanidermatum* along with *M. coeruleifrons* recorded 80 and 60 per cent disease incidence respectively. Similarly Premkumar *et al.* (1982) also observed strong association between the rhizome maggots and rhizome rot disease in ginger. Rhizome rot and maggot infestation occurred together in 58 per cent of the ginger rhizomes evaluated. *Pythium* spp., alone was observed in 42 per cent of samples while no sample contained maggots alone, suggesting that, the maggot incidence was secondary in nature. The results of the present study are in conformity with the above reports and suggest that the maggots have little role in causing rhizome rot in ginger and that they could be secondary in nature.

The higher recovery of 70 per cent maggots from plants treated with *P. aphanidermatum* and *Mimegralla* sp. nr *coeruleifons* as against 42 per cent in *Mimegralla* sp. nr *coeruleifons* alone also corraborate the above conclusion. However, the fact that maggots could establish in healthy rhizomes independent

of fungal pathogen is indicative of the potential of the insect as a pest of ginger. Facultative pathogen like *Pythium* spp. are known to cause secondary infestation in a number of plants and hence the injury by maggots predisposing the plants to cause disease at a late stage also cannot be ruled out, as observed by Ghorpade *et al.* (1988). Further studies involving yield loss assessments are called for to determine the pest status of rhizome maggots.


Summary

6. SUMMARY

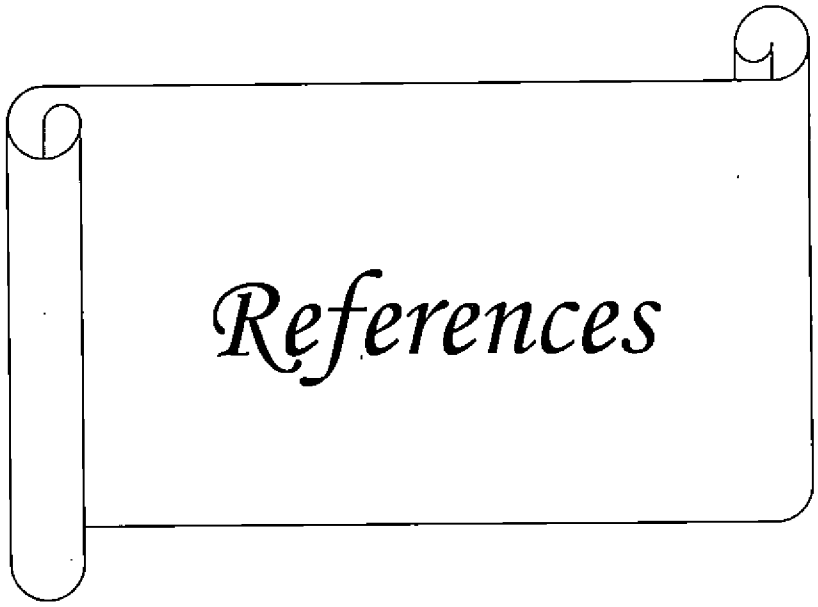
A study entitled "Bioecology and management of ginger rhizome maggots" was carried out at the College of Horticulture, Kerala Agricultural University (Vellanikkara) during the period from August 2013 to December 2014. The objectives of the experiment were to identify of the major species of rhizome maggots on ginger, to study the bioecology of major species of rhizome maggots on ginger and to develop eco-friendly management measures against the rhizome maggots. The salient findings of the investigations are listed below.

- Surveys conducted in ginger fields in Vellanikkara and Madakkathara panchayaths of Thrissur district as well as Perumatty and Pattencheri panchayaths of Palakkad district from August 2013 to October 2013 revealed that the highest population of 778 rhizome maggots was recorded during September 2013, followed by October and August months with 527 and 518 maggots respectively.
- Three species of rhizome maggots were obtained in all the four locations surveyed, namely, *Mimegralla* sp. nr *coeruleifrons*, *Eumerus figurans* and *Elassogaster* sp. (?) *linearis*.
- *Mimegralla* sp. nr *coeruleifrons* was the most abundant species in all the four locations surveyed during the surveyed period and constituted 96.26 per cent of the total number of maggots collected.
- The population of *Eumerus figurans* accounted for 2.96 per cent of the rhizome maggots collected. The species has not been reported so far and constitute a new report from Kerala.
- *Elassogaster* sp. (?) *linearis* was the least numerous of the three species of rhizome maggots collected from each locations. This species has not been reported previously and could be a new species of rhizome maggots in ginger.

- The study on the biology of *Mimegralla* sp. *nr coeruleifrons* showed that the mean incubation period was 3.75 ± 0.44 days. An egg measured 0.74 ± 0.02 mm in mean length and 0.20 ± 0.03 mm in mean width.
- The average duration of first instar maggots was 2.25 ± 0.44 days, and they measured 0.63 ± 0.05 mm in mean length and 0.16 ± 0.01 mm in mean width.
- The duration of the second instar larvae lasted for an average of 3.15 ± 0.36 days. The second instar maggots, on an average, measured 4.20 ± 0.08 mm in length and 0.90 ± 0.086 mm in width.
- The mean duration of third instar larva was 6.70 ± 0.73 days and the maggots measured 8.11 ± 0.06 mm in mean length and 1.68 ± 0.04 mm in mean width.
- The total larval duration varied from 11.80 to 12.40 days on an average of 12.10 ± 0.30 days.
- The pupal stage lasted for an average duration of 8.80 ± 1.85 days. The individual pupa measured 6.53 ± 0.62 mm in mean length and 1.65 ± 0.20 mm in mean width.
- The life cycle ranged from 22.81 to 26.50 days with an average of 24.65 ± 1.84 days.
- The longevity of a male fly was 43.90 ± 18.77 days and that of the female fly was 51.00 ± 20.79 days. The adult male fly measured 11.27 ± 1.40 mm in mean length and 1.30 ± 0.33 mm in mean width, while the female fly measured 13.56 ± 1.10 mm in mean length and 2.18 ± 0.77 mm in mean width.
- Mated female flies laid an average of 55.4 ± 17.64 eggs during the oviposition period which varied from 1 to 3 days. The sex ratio of female and male flies was 1:1.
- An unidentified spider predator and a gregarious pupal parasitoid, *Trichopria malabarensis* (Hymenoptera: Diapriidae) were documented as natural enemies of rhizome maggots in the field. No pathogens of rhizome

- Laboratory evaluation through Petri plate bioassay showed that chlorpyriphos (20EC) @ 300 g a.i. ha^{-1} was the most effective treatment, recording cent per cent mortality within 24 h. Fipronil (5SC) @ 50 g a.i. ha^{-1} proved to be the next best treatment, recording an average mortality of 90 per cent.
- Among the entomopathogens evaluated in the laboratory, *Heterorhabditis indica* applied at the rate of 400 IJs ml^{-1} recorded the highest mortality of 16.66 per cent, followed by *Metarhizium anisopliae* at 3.33 per cent. Both *Beauveria bassiana* and *Steinernema carpocapsae* fail to record any mortality of the treated maggots.
- Rhizome dip assay confirmed that chlorpyriphos 20EC (300 g a.i. ha^{-1}) was the most effective treatment, bringing about 100 per cent mortality in 24 h, followed by fipronil 5SC (50 g a.i. ha^{-1}), which recorded 66.66 per cent mortality in six days. All the four entomopathogens failed to induce any mortality in the treated maggots.
- Pot culture studies revealed that drenching with chlorpyriphos @ 300 g a.i. ha^{-1} was the most effective treatment for managing *Mimegralla* sp. nr *coeruleifrons* recording cent per cent mortality while fipronil recorded 78 per cent mortality.
- Rhizomes of the plant treated with fipronil 5SC (50 g a.i. ha^{-1}), recorded residue level of 0.052 mg kg^{-1}, twenty days after treatment which was marginally above the minimum detectable limit of 0.05 mg kg^{-1} of rhizome.
- Studies on the interaction between the maggots of *Mimegralla* sp. nr *coeruleifrons* with *Pythium aphanidermatum*, which causes rhizome rot in ginger indicated that infestation by the maggots could be secondary in nature.
- The plants inoculated with *P. aphanidermatum* alone, as well as the plants inoculated with *P. aphanidermatum* along with the maggots of *Mimegralla*

sp. nr *coeruleifrons* showed rhizome rot symptoms while infestation by maggots alone failed to produce any such symptoms. The establishment of maggots, at 70 per cent was also greater in rhizomes inoculated with the fungus, as against 42 per cent in rhizomes treated with maggots alone.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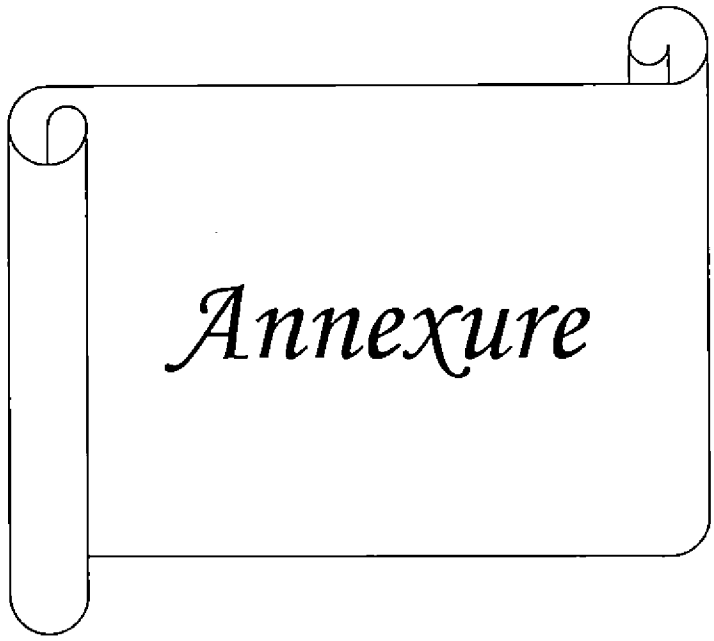

Annexure

Annexure I

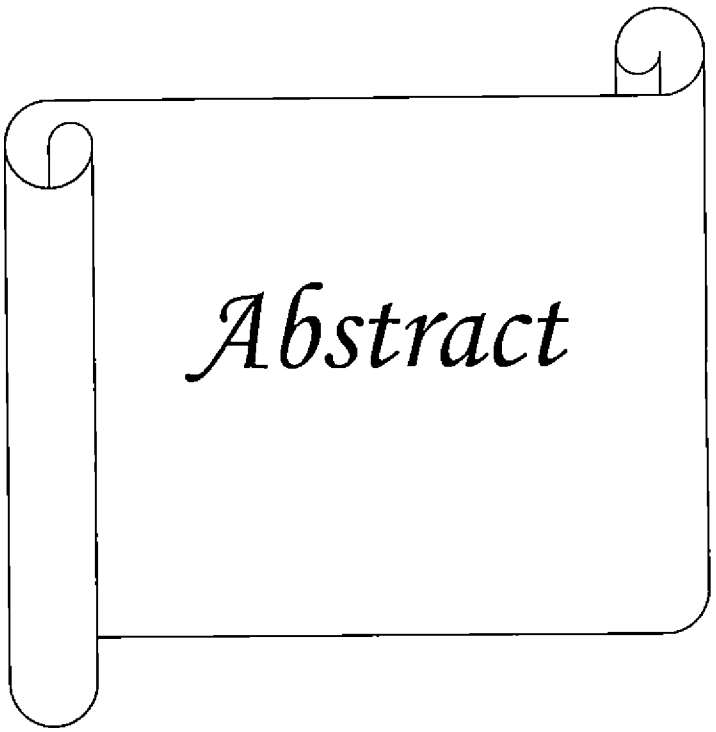
Composition of PDA medium

Potato	–	200 g
Dextrose	–	20 g
Agar	–	20 g
Distilled water	–	1L

Annexure II

Diet of Greater wax moth, *Galleria mellonella* L.

Wheat flour	-	100 g
Wheat bran	-	100 g
Glycerin	-	175 ml
Milk powder	-	100 g
Honey	-	175 ml
Yeast	-	50 g
Corn meal	-	200 g


Abstract

BIOECOLOGY AND MANAGEMENT OF GINGER RHIZOME MAGGOTS

By

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ABSTRACT OF THE THESIS

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ABSTRACT

A study entitled "Bioecology and management of ginger rhizome maggots" was carried out at College of Horticulture, Vellanikkara during 2013-2014, with the objective to identify the major species of rhizome maggots on ginger; to study the bioecology of major species of rhizome maggots and to evaluate eco-friendly management measures against the rhizome maggots.

Surveys were conducted in farmers' fields at Vellanikkara and Madakathara panchayats of Thrissur district as well as Pattencheri and Perumatty panchayats of Palakkad district during August, September and October months of 2013, for identification of the major species of ginger rhizome maggots. Three species of rhizome maggots were obtained in all the four locations surveyed which were identified as *Mimegralla* sp. nr *coeruleifrons* (Macquart, 1843), *Eumerus figurans* (Walker, 1859) and *Elassogaster* sp. nr *linearis* (Walker, 1849). This is the first report of the incidence of *E. figurans* in India, *Elassogaster* sp. nr *linearis*, is recorded for the first time as a ginger rhizome maggot.

Mimegralla sp. nr *coeruleifrons* was the most abundant species in all the locations surveyed and constituted 96.26 per cent of the total number of maggots collected. *E. figurans* accounted for 2.96 per cent of the overall population, followed by *Elassogaster* sp. *linearis*, forming 0.82 per cent of the maggots collected.

Studies on the biology of *Mimegralla* sp. nr *coeruleifrons* showed the average incubation period was about 3.75 days, while the mean duration of first, second and third instars was 2.25, 3.15 and 6.70 days respectively. The mean pupal period lasted for 8.80 days. The longevity of adult male and female fly were 43.90 and 51.00 days respectively, with a sex ratio of 1:1.

The morphometric observations of the different life stages of *Mimegralla* sp. nr *coeruleifrons* showed that eggs, on an average, measured 0.75

mm in length and 0.20 mm in width. The size of the first, second, and the third instar maggots averaged 0.63 × 0.16 mm, 4.2 × 0.90 mm and 8.1 × 1.68 mm in length and width respectively, while the pupae recorded a mean length of 5.36 mm and mean width of 1.65 mm. The adult male and female flies measured 11.2 × 1.30 mm and 13.56 × 2.18 mm respectively. The average fecundity of an adult female fly was 55.4 eggs during an oviposition period of 1 to 3 days.

Attempts at documentation of natural enemies revealed that *Trichopria malabarensis* Rajmohana and Narendran sp. nov. (Hymenoptera:Diapriidae), a gregarious pupal parasitoid, was the most important natural enemy of *Mimegralla* sp. nr *coeruleifrons* in the field. An unidentified spider belonging to the family Araneidae was observed to feed on the adult flies in the field. No pathogens were isolated from maggots collected from the surveyed locations.

Two entomopathogenic fungi *viz. Metarhizium anisopliae* (Metschnikoff) Sorokin and *Beauveria bassiana* (Balsamo) Vuillemin, along with two entomopathogenic nematodes *Steinernema carpocapsae* Weiser and *Heterorhabditis indica* Poinar and two insecticides, namely, fipronil and chlorpyriphos were evaluated in the laboratory for their efficacy in managing rhizome maggots. Petri plate bioassay as well as rhizome dip bioassay revealed that chlorpyriphos (20EC) @ 300 g a.i. ha^{-1} to be the most effective treatment, recording cent per cent mortality within 24 h after treatment. Fipronil 5SC @ 50 g a.i. ha^{-1} recorded an average mortality values of 90 and 66.66 per cent in Petri plate and rhizome dip assays respectively. Among the entomopathogenic organisms, the nematode *H. indica* recorded 16.66 per cent mortality while the fungus *M. anisopliae* recorded 3.33 per cent mortality in the Petri plate bioassay. Both *B. bassiana* and *S. carpocapsae* failed to induce mortality in the treated maggots. The entomopathogens failed to record any mortality in the rhizome dip study.

The pot culture studies confirmed the above findings with chlorpyriphos and fipronil recording cent per cent and 78 per cent mortality respectively.

Analysis of the ginger rhizomes, twenty days after exposure to fipronil, recorded a value of 0.052 mg kg^{-1}, marginally above the detectable limit of 0.05 mg kg^{-1} of rhizome.

Studies on the interaction between the maggots of *Mimegralla* sp. nr *coeruleifrons* with *Pythium aphanidermatum*, which causes rhizome rot in ginger indicated that infection by the fungus could be independent of maggot. While all the plants inoculated with *P. aphanidermatum* alone, as well as the plants inoculated with *P. aphanidermatum* along with the maggots of *Mimegralla* sp. nr *coeruleifrons* showed rhizome rot symptoms, infestation by maggots alone, failed to produce any such symptoms. The establishment of maggots, at 70 per cent was also greater in rhizomes inoculated with the fungus, as against 42 per cent in rhizomes treated with maggots alone.