ECOLOGICAL MANAGEMENT OF COCONUT ROOT GRUB, *Leucopholis coneophora* Burm.

by

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(2017-11-023)

THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"ECOLOGICAL MANAGEMENT OF COCONUT ROOT GRUB *Leucopholis coneophora* Burm."** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

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LIST OF ABBREVIATIONS AND SYMBOLS USED

%	Per cent
@	At the rate of
a.i.	Active ingredient
CD	Critical Difference
CRD	Completely Randomized Design
cm	Centimeter
DAT	Days after treatment
EC	Emulsifiable concentrate
EPF	Entomopathogenic fungi
EPN	Entomopathogenic nematodes
et al	And others
g	Gram
G	Granules
ha^{-1}	Per hectare
IJs	Infective Juveniles
ie.,	In Other Words
KAU	Kerala Agricultural University
kg	Kilogram
L	Litre

m	Meter
mg	Milligram
mL	Millilitre
mm	Millimeter
NSKE	Neem Seed Kernal Extract
PDA	Potato Dextrose Agar
PDB	Potato Dextrose Broath
ppm	Parts per million
rpm	Rotations per minute
SC	Suspension Concentrate
SD	Standard Deviation
SL	Soluble Liquid
sp	Species
viz.,	Namely
WDG	Water Dispersible Granules
WG	Wettable Granules

Introduction

1. INTRODUCTION

Coconut (*Cocos nucifera*) is an important horticulture crop that provides oil, food, beverage, fiber, medicine and a variety of raw materials for the production of diverse products of commercial importance (Smith, 1984). It is widely called the "tree of life" for its important role in the livelihoods of small and marginal farmers as a direct source of income, nutrition and various resources (Warner *et al.*, 2007). In India, it is cultivated in 20.96 lakh ha with an average productivity of 11350 nuts ha^{-1}. Kerala, Tamil Nadu, Karnataka and Andhra Pradesh contribute the major share in area and production (CDB, 2019).

The importance of coconut in the socio-economic status of Keralites needs no emphasis, and it occupies a predominant role in all the culinary operations, religious rites, commercial and industrial enterprises. Majority of the area in the coastal regions is of sandy and sandy loam soils, where coconut and coconut-based homesteads are the major farming systems.

Root grub, *Leucopholis coneophora* Burm. is a subterranean pest of coconut and its intercrops grown in the coastal belts of peninsular India. It was first reported as a pest of coconut by Nirula *et al.* (1952). The grub tunnels into the bole and collar regions of the seedlings and severe infestation lead to death of the seedlings. In adult palms, they feed on roots impairing the conduction of water and nutrients and thus lead to yellowing of fronds and complete yield loss. Crop loss to the tune of 30 to 80 per cent was noticed due to the pest in the endemic pockets (Veeresh, 1981). The pest has an annual life cycle and adult emergence coincides with the onset of the monsoon (Abraham and Kurian, 1970; Abraham and Mohandas, 1988a). Besides coconut, it feeds on rhizomatous and tuberous intercrops raised in coconut gardens *viz.*, banana, fodder grass, colocasia, cassava, elephant foot yam and sweet potato. Taking into account the severe damage caused by the pest and its wide distribution in the country, white grubs have been declared as a national pest.

Several tactics have been adopted for the management of white grubs including cultural, mechanical, biological, chemical and integrated methods suggested by various workers (Sahayaraj and Borgio, 2009; Srikanth and Singaravelu, 2011). Application of imidacloprid, phorate and chlorpyriphos to soil against the grubs is a widely followed method that provides considerable control (Prakash *et al.*, 2011). However, many of these insecticides have negative effect on the soil micro arthropods and earthworms (Adarsha *et al.*, 2015a).

Application of chemical insecticides in the soil for managing white grubs may result in residue problems and soil, water as well as environmental pollution. This may adversely affect beneficial microflora and fauna in the soil. Disturbances caused by pollutants in the soil result in both qualitative and quantitative changes in fauna, which affect soil functioning (Cortet *et al.*, 1999). Hence, there is a strong need for the development of alternative strategies using naturally available resources. *viz.*, botanicals and biocontrol agents for managing white grubs, which are eco-friendly and economically feasible. In this background, the study, "Ecological management of coconut root grub, *L. coneophora*" was undertaken with an objective to test the efficacy of botanical insecticides and biocontrol agents against the pest.

Review of Literature

2. REVIEW OF LITERATURE

A literature search was undertaken to review the information pertaining to root grub pest of crops particularly on coconut. The relevant information is presented in the following pages under different headings.

2.1 BIOLOGY OF *Leucopholis coneophora*

A brief description of the adult, grub and pupal stages of *L. coneophora* was given by Nirula *et al.* (1952). Nirula and Menon (1957) observed that the insect had an annual life cycle and emerges in masses with the onset of the south-west monsoon during May-June. They remained active for about eight weeks. On mating, the eggs were laid in loose moist soil and hatched in 20 days. Nirula (1958) reported that eggs were creamy white, translucent, smooth when freshly laid and the size increased during embryonic development with the absorption of moisture. During hatching, the colour became dirty white whereas just emerged grubs were white with a light brown head. Early instar grubs fed on organic matter and roots of grasses. Sekhar (1958) furnished a detailed morphological description of the adult of *L. coneophora*. He reported that final instar grubs had more duration than the first instar and within 20-33 days third instar grubs entered into the pre-pupal stage. Pupal period ranged from 28 days in the field and 26 to 33 days in the laboratory. Abraham and Mohandas (1988a) conducted a cage experiment to study the biology of coconut root grub *L. coneophora*. They found that the total larval period was 270 and 260 days and the pupal period was 25.7 and 25.3 days for females and males respectively. The incubation period averaged 23 days.

2.2 ADULT EMERGENCE AND FACTORS AFFECTING ADULT EMERGENCE

Adults of coconut root grub emerged from the soil at dusk for mating and returned to the soil within 25-30 minutes. Adults were not found on feeding the vegetation (Abraham and Mohandas, 1988a).

Prathibha *et al.* (2013) studied the behaviour and adult emergence pattern of *L. coneophora* for a period of four years. In Kerala, adult emergence commenced with a summer shower in April. Delayed emergence was observed with delay in the summer shower. Emergence, after a gap in May, resumed with the onset of the monsoon. When the soil temperature exceeded 34.5°C, the beetles did not emerge during dry spells in between the rainy days. An illuminance of 124.37 ± 75.5 lux at evening triggered the emergence of adult beetles and remained active till 2 ± 0.4 lux. Maximum swarming occurred at 32.6 ± 15.1 lux. Emergence of female beetles and mating started at 12.04 ± 8.1 lux (Prathibha *et al.*, 2018).

Kalleshwaraswamy *et al.* (2015) observed the adult emergence pattern of *Leucopholis lepidophora* Blanchard., major insect pest infesting arecanut in India. The emergence was noticed between June and October during the two years of study. The maximum emergence of adult beetles took place between 1900 and 2000 h. No adult beetles emerged when rain occurred between 1800 and 2100 h. Male beetles emerged first compared to female beetles. The sex ratio varied over time (female: male; 1:1.18 and 1:1.46 in 2013 and 2014 respectively).

2.3 NATURAL ENEMIES OF WHITE GRUBS

2.3.1 Predators

Kalea and Kulshreshtha (1961) reported that larvae of *Lachnosterna consanguinea* (Blanch.) exposed during pre-sowing ploughing of sugarcane were removed by predatory birds like crow (*Corvus splendens* L.) and common mynah (*Acridotheres tristis* L.). The same was observed by Yadava *et al.* (1973) on *Holotrichia* spp., a pest of groundnut.

Parasharya *et al.* (1994) identified 14 species of birds that are predaceous to white grub, *Holotrichia* spp. Myna, *A. tristis* and *A. ginginianus* (Latham), crow *C. splendens*. *C. macrorhynchos* (Sykes) drongo, *Dicrurus adsimilis* (Hodgson) and cattle egret, *Bubulcus ibis* L. were the important predatory birds. A

reduction of 45 to 65 per cent in the grub population was achieved through birds with three subsequent ploughings. Different extraneous factors affect the number of birds attracted to the plough, and it was not consistent with the density of grubs exposed. Timing of ploughing, proximity to the breeding sites and presence of insectivorous birds in the surroundings, widen the chances of bird predation. Compared to chemical methods, control by birds is an economically cheaper and environmentally safe approach for root grub management.

Common crow (*C. splendens*) and jungle crow (*C. macrorhynchos*), kingfisher (*Alcedo atthis* L.), brahmini kite (*Haliastur indus* L.) and common egret (*Ardea alba* L.) were found to be predaceous on the beetles during adult emergence period. Except for egret, all other birds were found roosting on the coconut fronds watching beetle emergence (Prathibha, 2015).

A terrestrial crab species, which could feed on an average of three third instar larva of *L. coneophora* per day, was identified by Prathibha (2015). It was also found predating on *L. lepidophora* in Sringeri, Karnataka. Feeding studies of this species indicated that they could not search out the grubs inside the soil.

2.3.2 Parasitoids

The grubs of *L. consanguinea*, a pest of sugarcane were parasitized by a scoliid, *Scolia aureipennis* Lep. during September and the rate of parasitization was only about five per cent (Kalea and Kulshreshtha, 1961).

Samoedi (1995) reported that *Campsomeris* spp. (Hymenoptera: Scoliidae) parasitizes on *Leucopholis* sp. nr. armata Sharp (Coleoptera: Scarabaeiidae), a pest of sugarcane in south Kalimantan. The population and incidence of parasitoids were sporadic and very scarce throughout the study period.

Hairy flower wasps (Scoliidae) and thynnids or flower wasps (Tiphiidae) parasitize the scarab grubs found in pastures. Scarab grub infested pastures were frequently visited by the male wasps in searching for the female

wasps and after mating, the female wasp locates the third instar grubs by burrowing into the soil and paralyzes them by stinging. A single egg was laid by the thynnid wasps on each grub. The grubs were taken deeper into the ground and kept in an earthen cell before parasitization by the scoliids (Goodyer and Nicholoas, 2007).

2.3.3 Entomopathogenic Fungi (EPF)

2.3.3.1 Cordyceps spp.

Cordyceps is a genus of ascomycete fungi and the natural incidence of *Cordyceps* (DMRO-526) had been found in coconut root grub (Kumar and Aparna, 2014).

Evans *et al.* (1999) identified a *Cordyceps* species infecting sugarcane white grubs in East Africa. Similar pathogens of scarabid hosts in the Neotropics and Asia were compared with the fungus *Cordyceps barnesii.*

A hypocrealean coleopteran pathogen, which is morphologically similar to *Cordyceps barnesii* was reported by Luangsa-Ard *et al.* (2010) during the collections from KhaoYai National Park and Kaeng Krachan National Park in Thailand and was identified and placed in the genus *Ophiocordyceps.*

2.3.3.2 Green muscardine fungus, Metarhizium spp.

Metarhizium anisopliae strains MaWG from larvae of *Leucopholis irrorata* and MaOR from *Oryctes rhinoceros* L. caused 73 and 30 per cent larval mortality respectively in *L. irrorata* (Braza, 1990).

The 1st, 2nd and 3rd instar grubs and prepupae of *L. burmeisteri* and *L. coneophora* were susceptible to the natural infection of *Metarhizium* spp. in the endemic areas of Kerala (Padmanabhan and Daniel, 2003). Sreekumar (2007) isolated *Metarhizium* spp. from coconut root grub *L. coneophora.*

Maximum reduction in the grub population (56.5 %), plant mortality (75-80 %) and tuber damage (63.7 %) in potato was reported, when *Metarhizium anisopliae* at 5 x 10^{11} conidia ha^{-1} along with chlorpyriphos 20 EC at 200 g a.i. ha^{-1} was given (Bhagath *et al.*, 2003).

In field experiment, maximum mycosis was recorded with the use of *M. anisopliae* @ 2 x 10^{12} conidia ha^{-1} (44.44 %) with lowest percentage of tuber infestation (6.91 %) in potato. When *M. anisopliae* and *B. bassiana* applied at 8 x 10^5 conidia mL^{-1} against third instar larvae of *H. consanguinea*, LT_{50} recorded was 4.88 and 6.73 days respectively (Kulye and Pokharkar, 2009).

Lowest plant mortality (21.83 %) and 61.58 per cent decrease in grub population were induced by the *M. anisopliae* (5.0 x 10^{13} spores g^{-1}) treatment against soybean white grub, *Holotrichia longipennis* in field conditions. It was followed by *B. bassiana* (5 x 10^{13} spores g^{-1}) where, decrease in grub population and plant mortality was 54.75 per cent, and 25.18 per cent respectively. The highest percentage of increase in yield (113.41 %) was also recorded with *M. anisopliae* (Pandey, 2010).

According to Kesarasing *et al.* (2010), *M. anisopliae* (Ma-1) at 1 x 10^{13} conidia ha^{-1} resulted in 91.95 per cent reduction in grub population (60 DAT) of *Holotrichia serrata* (F), in sugarcane, which was found next best to chlorpyriphos. *M. anisopliae,* when applied at 1 x 10^{13} conidia ha^{-1} gave the highest cane yield and it was on par with chlorpyriphos at 3 L a.i. ha^{-1}. Similarly, 77.10 per cent reduction in grub population was obtained in field application of *M. anisopliae* (Ma-1) against arecanut white grub, *L. lepidophora* at 2 x 10^{13} conidia ha^{-1} and was next best to chlorpyriphos drenching at 1 L a.i. ha^1 (96.80 %). Application of *M. anisopliae* against sugarcane white grub, *H. serrata* at 4 x 10^9 conidia ha^{-1} reduced the grub population by 92 per cent on 60^{th} DAT and recorded the 2^{nd} highest cane yield (100.6 t ha^{-1}) after chlorpyriphos (110.5 t ha^{-1}) (Manisegaran *et al.*, 2011).

Prabhu *et al.* (2011) reported that *M. anisopliae* with 2 x 10^8 conidia g^{-1} at the rate of 20 g $palm^{-1}$ recorded 31.38 per cent mortality of arecanut root grub *L. lepidophora*.

An additive or synergistic effect of the combined application of *M. anisopliae* with entomopathogenic nematodes was reported by Ansari *et al.* (2004). Combinations of nematodes, *Heterorhabditis megidis* and *Steinernema glaseri* with *M. anisopliae* generated a strong synergistic effect only at higher concentrations (2 x 10^{12} and 2 x 10^{13} conidia ha^{-1} against third instar grubs of welsh chafer *Hoplia philanthus*).

***2.3.3.3 White muscardine fungus, Beauveria* spp.**

Ranganathaiah *et al.* (1973) found the entomopathogenic fungi *Beauveria brongniartii* infecting larvae of *H. serrata* from arecanut fields and reported that the larvae ceased feeding and died within 7-10 days upon infection. It persisted in the soil for a long period and was found to attack all stages of the beetle except the egg.

A survey conducted by Jayaramaiah and Veeresh (1983) for the fungal pathogens of white grubs revealed the natural incidence of *B. brongniartii, B. bassiana* and *M. anisopliae*.

Enkerli *et al.* (2003) demonstrated the long-term persistence of the applied *B. brongniartii* strains in the fields while working on the biological control of *M. melolontha*. In addition to the applied strains, indigenous populations or isolates that might have arisen from mutations or interactions among the applied strains and indigenous isolates were also present at some sites.

In green gram, the highest yield (6.83 q ha^{-1}), lowest grub population (1.60 per pit) and lowest plant mortality (1.66 %) were exhibited by the application of *B. bassiana* at 5 x 10^{13} conidia mL^{-1} in combination with imidacloprid 200 SL at 48 g a.i. ha^{-1} (Bhattacharyya *et al.*, 2008).

Cowpea was found to be the best solid substrate for the sporulation and virulence of *Beauveria brongniarti* (Metschinikoff) isolates on sugarcane white grub. The conidia produced from this media resulted in high virulence against third instar larvae with LC_{50} value of 1.30×10^9 conidia mL^{-1} (Chelvi *et al.*, 2010).

B. brongniartii isolates were infective to adults and larvae of two endemic scarab pests, *Schizonycha affinis* Boheman and *Hypopholis sommeri* Burmeister (Coleoptera: Melolonthinae). Significant variation in virulence was observed between the adults and larvae of *S. affinis* (50.1-95 % mortality), and adult *Tenebrio molitor* (Coleoptera: Tenebrionidae) (39-74 % mortality) as a surrogate test insect (Goble *et al.*, 2015).

Application of 25 kg farmyard manure (FYM) along with a combination of *B. bassiana* at 25 kg ha^{-1} and *M. anisopliae* at 25 kg ha^{-1} recorded lowest number of grubs per square meter at 14, 28, 45 and 60 DAT. Chlorpyriphos treatment recorded the highest cane yield of 93.45 t ha^{-1} and the combination recorded 89.62 t ha^{-1} which is on par with chlorpyriphos (Tippannavar *et al.*, 1993).

In the laboratory, when *Holotrichia* spp. was treated, *B. bassiana* achieved 100 per cent mortality and *M. anisopliae* achieved 93.91 per cent on 20^{th} DAT. In field experiments also, *B. bassiana* was found to be most effective compared to other entomopathogenic fungi (Mohi-ud-din *et al.*, 2006).

Morales-Rodriguez and Peck (2009) found that the synergistic combinations of *B. bassiana* and *M. anisopliae* with neonicotinoids were discernible in the laboratory and greenhouse experiments, but not in the field, when tested on *Popillia japonica* Newman. and *Amphimallon majale* Razoumowsky.

2.3.4 Entomopathogenic Nematodes (EPNs)

Askari (2009) reported that EPNs belonging to the genera *Heterorhabditis* and *Steinernema* were potential biocontrol agents of insect pests of crops. *Xenorhabdus* and *Photorhabdus* were the bacteria which forms a symbiotic association with EPNs. Short life cycle, wide host range and survival under environmental extremities were the peculiarities of these nematodes.

Toepfer *et al.* (2010) pointed out that for a pest, whose most damaging stages are below ground, soil-dwelling entomopathogenic nematodes could be exploited as a potential candidate in the biological control programme.

The invasions of the larvae of army worm *Pseudaletia unipunctata* by the infective stage of the EPNs are quite different. The highest number of insects was invaded by *S. carpocapsae* and reported the highest penetration rate, followed by *H. bacteriophora* (Rosa *et al.,* 2002).

Laboratory, greenhouse and field experiments on the larvae of the Asiatic garden beetle, *Maladera castanea* (Arrow), in turf grass revealed that *H. bacteriophora* and *S. glaseri* were ineffective against third instars and *S. scarabaei* provided good control. *H. bacteriophora and S. scarabaei* gave 12-33 per cent and 71-86 per cent control respectively when applied at the rate of 2.5 x 10^9 IJ ha^{-1}. But, *S. scarabaei* and imidacloprid combinations failed to provide higher control of third instars compared with *S. scarabaei* alone (Koppenhofer and Fuzy, 2003).

There was no significant difference in the efficacy of *S. scarabaei* on the second and third instars of *P. japonica* or *Anomala orientalis* or between small and large third instars in *A. orientalis*. Efficacy of *H. bacteriophora* decreased from early first instar to the third instar and from small third instars to large third instars in *A. orientalis,* but did not differ significantly between *P. japonica* larval stages. Koppenhofer and Fuzy (2004) concluded that the efficacy of EPNs against

different developmental stages of white grub varies with white grub and nematode species, and no generalization could be made.

Bhatnagar *et al.* (2004) reported that out of six EPN species or strains tested, *H. bacteriophora* was found to be most effective as a pathogen of white grub, *Maladera insanabilis* Brenske. with an LD_{50} of 14090 IJs per 100 g soil per grub. Compared to other nematodes tested, it also showed a higher rate of invasion and more production of IJs per cadaver of the infected host (69480 per grub; 607.30 IJs per mg host body weight).

A survey conducted by Banu *et al.* (2005) throughout the districts of Kerala, revealed that EPNs were found to occur more in sandy loam soil (13.8 %) than in sandy soil (10 %). *Steinernema* spp. and *H. indica* were isolated from the coconut root grub *L. coneophora*.

Sankaranarayanan *et al.* (2006) reported that, out of the four EPNs evaluated in the laboratory against pupae and adult beetles of *H. serrate*, *S. glaseri* recorded lowest LD_{50} value (113 IJs per pupa) followed by *H. indica* (127.0 IJs per pupa). *S. glaseri* recorded lowest LT_{50} value (24.9 h) followed by *H. indica* (27.3 h) at 1000 IJs per pupa.

Morris and Grewal (2011) obtained 55-95 per cent mortality of *P. japonica* adults under laboratory conditions when 20 strains of *Heterorhabditis* and *Steinernema* were applied at a rate of 10, 000 infective juveniles per 10 beetles. *H. georgiana* (D61), three strains of *Steinernema* spp. (R54, R45 and FC48) and two strains of *S. carpocapsae* (A11 and D 60) were the most virulent strains which caused 50 per cent beetle mortality in less than five days.

Laboratory and field experiments conducted by Koppenhofer and Fuzy (2008) showed that imidacloprid-nematode combinations were more effective against second instars than third instars of *A. orientalis* and *P. japonica*. This combination was found superior to the full rate application of neonicotinoid alone. Most consistent synergism was performed by *H. bacteriophora*-imidacloprid

combinations but did not cause significantly higher mortality than *H. zealandica*-imidacloprid combinations.

Koppenhofer and Kaya (1998) stated that the application of imidacloprid could be a better synergist for entomopathogenic nematodes than clothianidin and did not affect the number of nematode progeny emerging from each cadaver and pathogenicity or infectivity of the nematode progeny in the combined application.

Imidacloprid and clothianidin with *H. bacteriophora* combinations were discernible in all the laboratory, greenhouse and field trials for *A. majale* (Morales-Rodriguez and Peck, 2009).

2.4 MANAGEMENT USING BOTANICALS

Pot experiments were conducted by Padmanaban *et al.* (1997a) for testing the effect of plant products and oil cakes against the second and third-instar larvae of *Leucopholis burmeisteri*. Fresh leaves, dry leaves and dried leaf powder of *Vitex negundo* L. were evaluated against second-instar larvae in the first experiment and oil cakes of karanj (*Pongamia pinnata*), neem (*Azadirachta indica*) and mahua (*Madhuca indica*) at the rate of 8.5, 19.0, 34.53 g pot^{-1} basis were tried against third-instar larvae in the second experiment. Dried leaf powder of *Vitex* and karanj oil cake were found to be the most effective treatment after 30 days of application in the first and second experiment respectively.

Neem, karanj and mahua cakes were applied at rates equivalent to 1000, 1500, 2000 and 2500 kg ha^{-1} to pots containing two year old arecanut seedlings grown in sterile soil with 10 third instar *L. burmeisteri* grubs. Similarly, in pots containing second instar grubs, 250 mL of vitoxyl (2 %), nimbecidine (2 %) achook (2 %), and 85 g of fresh, dried and powdered leaves of *V. negundo* were applied and grub mortality was recorded 30 days after treatment. Results revealed that among the oil cakes, karanj gave the highest mortality and dry leaf powder of *V. negundo* followed by achook among the plant and plant products (Padmanaban *et al.*, 1997b).

Theurkar (2014) evaluated the efficacy of two biopesticides *Thevetia peruviana* (Pers) and *Datura innoxia* (Mills) against *H. serrata*. Mortality of 50 per cent has occurred at 48 and 96 hours after treatment with *T. peruviana* at the concentration of 0.020 per cent and 0.25 per cent respectively. Both plant extract concentrations were effective against adults and they laid the lowest numbers of eggs. More reduction in the infestation of scarab species was observed with *T. peruviana* leaves than *D. innoxia* seeds.

Meshram and Homkar (2011) suggested an integrated management of the white grub by adopting early sowing and application of biopesticide cakes instead of toxic pesticide application in the teak nursery. The efficacy of bio pesticides and the effects of different dates of sowing of teak seeds were studied on white grubs in teak nursery. Bio pesticides used were neem, mahua, karanj and jatropha. The population of grubs and percent of damaged seedlings differ significantly. Seedlings sown in March followed by April recorded maximum number of healthy seedlings. Among the biopesticides most effective one was neem at 5 kg bed^{-1} (size 10 m x 1 m), followed by jatropha cake.

Mohan and Padmanaban (2013) observed that the application of bio pesticides and distillery effluent affected the entire larval growth of the rhinoceros beetle (*Oryctes rhinoceros* L.) irrespective of the experimental concentrations. The LC_{50}/96 hours value for the larvae were 14.9 per cent for distillery effluent, 24.5 per cent for neem oil and 29.5 per cent for neem cake powder.

According to Suhasini *et al.* (2017), under semi field conditions, the grub mortality rate of *O. rhinoceros* was found to be the highest with the application of neem cake at 200 g per kg of feed and in *Annona squamosa* at 200 g per kg of feed.

2.5 CHEMICAL MANAGEMENT

A series of three field tests were carried out by Kumar and Daniel (1981) on *L. burmeisteri*. Significant control of the larvae was given by application of 5

% granules of dimethoate at 30 kg ha^{-1}, pongamia oil cake at 2000 kg ha^{-1}, 5 % dusts of chlordane at 90 and 120 kg ha^{-1} and of HCH (BHC) at 120 kg ha^{-1} and 1.5 % dust of quinalphos at 90 and 120 kg ha^{-1} twice in May and November.

Yearlong control of white grub, *L. irrorata* was given by furrow application of lindane granules at 0.25 kg of a.i. ha^{-1} during sowing of rice in rice - maize cropping system. Cost involved in the management is affordable to the small -scale farmers (Litsinger *et al.,* 1983).

Efficacy of controlled-release chemical compounds like chlorpyriphos and carbosulfan on white grub and root bug was tested by Estioko and Gipanago (1987). The effect was compared with known broad-spectrum activities of phorate, carbofuran, and gamma BHC. Controlled-release chlorpyrifos suppressed pest build-up in the 8^{th} month at 2 kg a.i. ha^{-1}, whereas, for phorate, carbofuran and gamma BHC to attain the same preventive result, higher rates were needed.

Prevention of root weevil and white grub infestations in the container grown nursery crops were attained by the pre-plant potting mix incorporation of Talstar 0.2 G (bifenthrin). Irrespective of the medium composition, bifenthrin has a half-life of at least 3 years. Cowles (2003) concluded that more than 95 per cent larval mortality can be expected up to three years following treatment of media with 10 ppm bifenthrin and more than 99.9 per cent with 20 ppm bifenthrin.

Shivanna *et al.* (2014) assessed new molecules and botanicals against arecanut root grub *L. lepidophora* by conducting multi-location trial in farmer's field of Shimoga district of Karnataka. Significantly lower number of grubs per palm was recorded five days after drenching of fipronil 0.75 ml L^{-1} + imidacloprid 0.75 ml L^{-1}. The treatment rynaxypyr 18.5 SC 0.16 ml L^{-1} also gave the lowest number of grubs per palm.

Several experiments conducted on root grubs indicate that for any chemicals to be effective against grubs, method and time of application were very important. The chemical insecticides which showed superiority over control as

well as to chlordane 75 EC at 2.72 kg a.i. acre^{-1}, disulphoton 5 G at 0.75 kg a.i. acre^{-1} and heptachlor at 1.81 kg a.i. acre^{-1} were phorate 10 G at 1.00 kg a.i. acre^{-1}, carbofuran 5 G at 0.30 kg a.i. acre^{-1} and pyridyl phosphate 20 EC at 0.48 kg a.i. acre^{-1}. Carbofuran was more effective than phorate and pyridyl phosphate (Veeresh, 1974).

Veeresh (1977) made some observations that to obtain good control of grubs and maximum benefit from insecticides, application should be in three to four weeks after the first summer rains and before sowing since at this stage, the eggs and first instar grubs confined to about 5 cm depth. Soil drenching either with aldrin 30 EC @ 2 L 400 L^{-1} of water or chlordane 20 EC @ 2 L acre^{-1} achieved prominent control. Uniform incorporation of insecticide and enough moisture in the infested field should be ensured before application.

According to Prasad and Thakur (1959), satisfactory results were not obtained when heavy doses of contact insecticides like aldrin, dieldrin, endrin, DDT and BHC were applied around the base of sugarcane clumps in September.

Tashrio and Firori (1969) concluded that initially recommended doses of chloradane and dieldrin, 24.4 kg and 5.6 kg respectively per hectare against European chafer could be reduced to 4.5 kg and 1.1 kg if applied when the pest was at first instar instead of the third instar.

Long-term field experiment conducted by Abraham and Kurian (1970) at Kayamkulam, Kerala, India, showed that the soil treatment twice a year with 5 % aldrin at 120 kg, 5 % BHC at 120 kg, 3 % heptachlor at 120 kg or 10 % chlordane at 60 kg ha^{-1} controlled the larvae of *L. coneophora*. and *Anomala marginipennis* Arr. on coconut.

Abraham and Mohandas (1988b) evaluated the efficacy of chlorinated hydrocarbons like HCH, heptachlor, aldrin and chlordane against the immature stages of larvae of the scarabaeid *L. coneophora* in the laboratory. Two most active compounds against 2nd and 3rd instar larvae were aldrin and heptachlor. But,

HCH and heptachlor were the most promising compounds on a projected cost-performance basis. Root grub could best be controlled with heptachlor applied at 1.4 kg a.i. ha^{-1} in June or with HCH applied twice at 5 kg a.i. ha^{-1} in June and September.

Fenemore and Perrott (1970) assessed the impact of seventeen insecticides of low residue hazard for contact activity against grass grub, *Costelytra zealandica* White. adults. Insecticides were applied at the time of adult emergence and the appearance of eggs, patterns of development of pupae and adults were determined in four successive years by soil sampling on four sites. Three field trials were conducted using these insecticides, one with dilute spraying and two with ultra-low volume. Insecticides Dursban and Bayer 77488 at the rate of 200 µg cm^{-2} achieved complete mortality with a single exposure and failure of treatments to exert any effect is associated with the behaviour of adult beetles, especially females.

Channakeshavamurthy *et al.* (2010) recorded the effect of new chemicals and other products for the management of *L. lepidophora*. Maximum mortality (96.12 % and 95.14 %) was given by imidacloprid 17.8 SL at 6 mL $palm^{-1}$, at two locations. The next best was chlorpyriphos 20 EC at 12 ml $palm^{-1}$ with 93.71 per cent and 93.10 per cent, followed by carbofuran 3 G at 25 g $palm^{-1}$ (90.06 %) and phorate 10 G at 25 g $palm^{-1}$ (88.69 %).

White grubs, *H. serrata* and *H. reynaudi* Blanchard are serious pests in south-central India. Seed dressings of groundnut using chlorpyrifos and imidacloprid were effective against *H. serrata* at rates as low as 0.6 and 3.5 g a.i. kg^{-1}, respectively whereas that of *H. reynaudi* is 1.2 and 3.5 g a.i. kg^{-1} of chlorpyrifos and imidacloprid, respectively. Analysis of insecticide residue indicated that rates up to 5.0 g a.i. kg^{-1} produced residues in soil and groundnut seedlings markedly below the relevant MRL at 20 days after sowing. Under the southern Indian rainy-season environment, no residues at harvest stage were detected (Anitha *et al.*, 2005).

Prathibha *et al.* (2017) assessed the impact of newer and safer insecticides against white grubs, *Leucopholis* spp., subterranean pests of arecanut grown in south India. Effective insecticides identified were imidacloprid (LC_{50} at 120 h = 16.849 ppm on 3rd instar larvae), chlorpyriphos (LC_{50} = 14.242) and bifenthrin (LC_{50} = 12.797 ppm). They also reported that bifenthrin would be an ideal alternative insecticide to chlorpyriphos for the management of white grubs in the palm garden, which might be due to its high lipophilic property, contact toxicity and therefore safe and long persisting.

Subhaharan *et al.* (2001) screened four insecticides, carbosulfan, tefluthrin, chlorpyriphos and phorate (standard insecticide) against *L. lepidophora*. The order of toxicity observed in laboratory bioassay studies was carbosulfan, tefluthrin, chlorpyriphos and phorate. In the case of second instar grubs, carbosulfan was 4.2 times more toxic as compared to phorate followed by tefluthrin (2.8) and chlorpyriphos (1.9). On relative toxicity, carbosulfan was 13 times more toxic than phorate followed by tefluthrin (12.5) and chlorpyriphos (2.7). Field trials conducted in arecanut gardens at Sringeri, Karnataka, for two years resulted in a mean reduction in the grub population to a tune of 80.6 and 66 per cent respectively. During the years of study, greater than 60 per cent reduction in the grub population was given by chlorpyriphos at 8 mL $palm^{-1}$ and carbosulfan 10 g $palm^{-1}$.

Efficacy of newer molecules of insecticides against white grub, *L. lepidophora* infesting sugarcane in western Maharashtra was carried out by Mane and Mohite (2015). Most effective treatment for control of white grub was found to be imidacloprid 40 % + fipronil 40 % 80 WG at 400 mL ha^{-1}, followed by clothianidin 50 WDG at 250 g ha^{-1}, flubendiamide 480 SC at 400 mL ha^{-1} and rynaxypyr 0.4 G at 125 g ha^{-1}.

The results of the field experiment conducted by Adarsha *et al.* (2015b) against arecanut white grub, *L. lepidophora*, revealed that 60 days after treatment, chlorantraniliprole 18.5 SC at 658 mL ha^{-1} was effective in reducing the early

instar root grub population at both the locations (89.29 and 87.01 % respectively). After 105 days of treatment, a significant reduction in larval population was given by imidacloprid 17.8 SL at 1 L ha^{-1} (88.88 %) followed by fipronil 5 SC 2.5 L ha^{-1} and chlorantraniliprole 18.5 SC at 658 mL ha^{-1} (86.66 %). Imidacloprid 17.8 SL at 1 L ha^{-1}, chloropyriphos 20 EC at 10 L ha^{-1} and fipronil 5 SC at 2.5 L ha^{-1} resulted in 100 per cent reduction in larval population.

Materials and Methods

3. MATERIALS AND METHODS

The study entitled "Ecological management of coconut root grub, *Leucopholis coneophora* Burm." was carried out in the Department of Agricultural Entomology, College of Agriculture, Vellayani, Thiruvananthapuram and College of Agriculture, Padannakkad, Kasaragod, during the year 2017-19. Laboratory and pot culture experiments were conducted to evaluate the efficacy of biocontrol agents *viz.*, entomopathogenic fungi (EPF), entomopathogenic nematodes (EPN), botanicals and chemical insecticides against the coconut root grub, *L. coneophora*. The materials used and the methods adopted are detailed hereunder.

3.1 REARING OF COCONUT ROOT GRUB

Root grubs were reared under laboratory conditions (temperature 25-30^{0}C and relative humidity 80-90 %) using the method developed by Abraham (1983). Field collected adult beetles were used for this purpose. Hand collection as well as collection using sweep net was done during emergence period (May-June). Test insects in the ratio 4:1 (male:female) were transferred to plastic jars (10 x 15 cm), half-filled with moist soil. Rearing was carried out in a wooden cage of 100 x 50 x 50 cm (Plate 1). Plastic basin (36 x 15 cm) half filled with sterile moist soil passed through a 20 mesh sieve was provided for oviposition. Cashew leaf twigs were provided as feed for the adults and they were replaced as and when it dries. Eggs laid were collected daily by passing the soil through a 20 mesh sieve. The eggs were kept in Petri dishes in batches of five and were covered with sterilized moistened soil. Sterile water was sprinkled over the soil frequently to avoid desiccation of eggs. The dishes were observed daily in order to understand the hatching pattern. Soon after hatching, the grubs were transferred to plastic jar planted with sprouted groundnut. When the grubs were sufficiently grown-up for handling (3-4 days old), they were collected and used for various experiments.

Higher instar grubs were obtained by growing first instar grubs under laboratory conditions with potato as feed. For getting second instar grubs, the first

Plate 1: Rearing cage

instar grubs were transferred to the plastic basin (36 x 15 cm) filled with 15 kg of sterilized moist soil. Thoroughly washed and the surface sterilized potatoes were given as food. Periodical renewal of food and moistening of soil were done to maintain ambient growth conditions.

3.1.1 Biometric Observations of Developmental Stages of *L. coneophora*

The egg and larval stages obtained from rearing and those collected from the coconut palm basin were used for biometric observations. Micrometry was used for the head capsule width measurement.

3.2 SCREENING OF ENTOMOPATHOGENIC FUNGI AGAINST *L. coneophora*

3.2.1 Maintenance of Fungal Cultures

Metarhizium anisopliae and *Beauveria bassiana* cultures maintained in the Biocontrol laboratory for crop pest management, Department of Agricultural Entomology, College of Agriculture, Vellayani were utilized for the study. *Metarhizium anisopliae* isolate Ma 4 and *B. bassiana* isolate Bb 5, were originally obtained from the National Bureau of Agricultural Insect Resources, Bengaluru. The cultures of *M. anisopliae* and *B. bassiana*, were revived by passing through the grubs of *Odoiporus longicollis* (Oliver) and pure cultures were maintained in Potato Dextrose Agar (PDA) slants and mass multiplied in Potato Dextrose Broth (PDB).

3.2.2 Preparation of Conidial Suspension

Conidial suspensions were prepared from 14 day old cultures of *M. anisopliae* and *B. bassiana* by adding 10 mL of sterile water containing 0.05 % Triton X-100 into the culture broth in 250 mL conical flasks. Each of the mixtures was blended in a mixer-grinder for 20 seconds aseptically to obtain homogenous suspensions. The suspensions were filtered through double layered muslin cloth and collected in sterile containers. The required conidial concentration was

obtained by centrifugation at 4000 rpm for 4 minutes. The conidial concentration is then adjusted to 1 x 10^8, 1 x 10^9 and 1 x 10^{10} spores mL^{-1} using a Neubauer haemocytometer.

3.2.3 Evaluation Against *L. coneophora* Grubs

Efficacy of spore suspension of *M. anisopliae* and *B. bassiana* was tested under laboratory conditions on first and third instar grubs obtained from laboratory culture (Para 3.1). The experiment was conducted using plastic basins (36 x 15 cm), filled with 15 kg of sterile moist soil. Clean, healthy and surface-sterilized potato tubers at 100 g $basin^{-1}$ were provided as feed. The moisture level (just wet) was maintained by sprinkling sterile water. Three grubs each were released into the basins carrying soil.

The treatments were applied one week after the release of grubs. Since the quantity of pesticide solution required for drenching the coconut basin is 40 L as per Package of Practices Recommendations (KAU, 2016), the same quantity was taken as standard and quantity required for the experiment was worked out by proportionately reducing the area of coconut basin (3.14 x 1.8 x 1.8 m) to the experimental unit (3.14 x 1.8 x 1.8 cm), where the depth of soil was taken as 15 cm in both conditions. Spore suspension (400 mL) prepared as mentioned in para 3.2.2 was drenched through small wells to reach the treatment up to the bottom of the basin. The experiment was laid out in completely randomized design (CRD) with three replications, a chemical check (chlorpyriphos 20 % EC @ 225 g a.i. ha^{-1}) and untreated control. The two fungi at three different doses *viz.*, 1 x 10^8, 1 x 10^9 and 1 x 10^{10} spores mL^{-1} were evaluated. Mortality of grubs was observed at the weekly intervals, up to 30 days after treatment.

The lower concentration of EPF (1 x 10^8 spores mL^{-1}) was sprayed on the freshly laid eggs to know its infectivity and sterile water was taken as control.

3.3 SCREENING OF ENTOMOPATHOGENIC NEMATODES AGAINST *L. coneophora* GRUBS

Efficacy of *Steinernema carpocapsae* (Weiser) Wouts and *Heterorhabditis bateriophora* Poinar were tested against the first and third instar grubs. Nematode cultures maintained at Banana Research Station, Kannara was used. The experiment was conducted using the same methodology as mentioned in para 3.2.3. Nematode suspension (400 mL) was drenched through small wells to reach the treatment up to the bottom of the basin. The treatments were given one week after the release of grubs. The experiment was laid out in completely randomized design (CRD) with three replications, a chemical check and untreated control. The nematodes were evaluated at three different doses *viz.*, 100, 500 and 1000 IJ mL^{-1}. Mortality of grubs was recorded at daily intervals up to 10 days after treatment.

3.4 SCREENING OF BOTANICAL INSECTICIDES AGAINST *L. coneophora* GRUBS

The efficacy of botanical insecticides such as neem (*Azadirachta indica*), gliricidia (*Gliricidia maculata*), hill glory bower (*Clerodendron infortunatum*), and siam weed (*Chromolaena odorata*) was tested against the first and third instar grubs. The experiment was conducted using the methodology mentioned in para 3.2.3. The treatments were given one week after the release of grubs. Finely chopped leaves and tender plant parts at 25 g kg^{-1} of soil were applied in each treatment. The experiment was laid out in completely randomized design (CRD) with three replications, a chemical check and untreated control. Mortality of grubs was observed at 15, 20 and 30 days after treatment.

3.5 SCREENING OF CHEMICAL INSECTICIDES AGAINST *L. coneophora* GRUBS

The efficacy of chemical insecticides was tested using the methodology mentioned in para 3.2.3. The treatments were given one week after the release of grubs. The experiment was laid out in completely randomized design (CRD) with

four replications, a chemical check and untreated control. Mortality of grubs was recorded at daily intervals up to 10 days after treatment. The chemical insecticides evaluated under laboratory conditions were indicated in Table 1.

Table 1. Chemical insecticides evaluated under laboratory conditions

Sl. No.	Insecticides	Trade name	Dosage (g a.i. ha^{-1})
1	Chlorantraniliprole 0.4 % G	Ferterra	75
2	Fipronil 0.3 % G	Regent	75
3	Spinosad 45 % SC	Tracer	73
4	Chlorpyriphos 20 % EC (chemical check)	Dursban	225

3.5.1 Method of Application of Treatments

Granular insecticides such as chlorantraniliprole 0.4 % G (1.02 g 15 kg^{-1} of soil) and fipronil 0.3 % G (1.36 g 15 kg^{-1} of soil) were incorporated into the soil by thorough mixing and liquid formulations such as spinosad 45 % SC (0.32 mL L^{-1}) and chlorpyriphos 20 % EC (2.25 mL L^{-1}) were drenched (400 mL $basin^{-1}$) into the soil.

3.6 POT CULTURE EXPERIMENT FOR EVALUATION OF PROMISING TREATMENTS

The effect of promising treatments in the laboratory experiment was tested in the pot culture experiment. Earthen pots of the dimension (28 x 24 cm) were used for the experiment (Plate 2). The pots were filled with sterilized soil, and the bottom hole for drainage was covered with a rectangular piece of nylon net to avoid the escape of grubs. Fodder grass variety CO-3 was used as the test crop since its roots were fed by the grubs. Irrigation was given at frequent intervals.

Plate 2: Pot culture experiment

The crop was allowed for proper root development and grubs were released on this after the establishment of the crop. Treatments were given one week after the release of the grubs. The experiment was laid out in completely randomized design (CRD). Observation on mortality was recorded by destructive sampling.

3.7 IDENTIFICATION OF NATURAL ENEMIES

Parasitized cadavers were collected from the field, kept in sterile containers and examined for parasitoid emergence. Observation for predators of adult beetles was done mostly during adult emergence and for grubs during ploughing and other intercultural operations in the coconut garden. Cadavers which were suspected to be infected were brought to the laboratory for isolation of causal organisms.

3.7.1 Isolation of EPF

Field collected cadavers were brought to the laboratory and kept in a sterile humid chamber for sporulation. The cadavers were surface sterilized using mercuric chloride (0.1 % aqueous solution) and washed subsequently with sterile distilled water for three times. It is then placed on PDA plates and sub cultured subsequently to obtain pure cultures.

Results

4. RESULTS

The results of the study entitled "Ecological management of coconut root grub, *Leucopholis coneophora* Burm." carried out during the period 2017-19 is detailed below.

4.1. BIOLOGY OF *L. coneophora*

4.1.1 Egg

The freshly laid egg was white in colour with a yellow tinge, oval or elliptical in shape. The colour of the egg changed to dirty white as the development progressed (Plate 3). Prolonged exposure to moisture stress in the soil caused shrinking and shriveling of eggs. Freshly laid eggs measured a mean length of 4.44 mm (range 4.0 to 4.8 mm), mean width of 2.85 mm (range 2.7 to 3.0 mm) and mean weight of 0.019 g (range 0.017 to 0.026 g). Just before hatching the size increased to 5.83 mm (range 5.63 to 6.01 mm) in length, 4.53 mm (range 4.30 to 4.91 mm) in width and 0.07 g in weight (range 0.063 to 0.079 g). The incubation period of eggs was found to be 23 days.

4.1.2 Grub

The grubs immediately after hatching were semi-transparent and became bluish white within two days. The head capsule and other appendages became brown (Plate 3). On hatching, the grubs were 14.28 mm (range 12 to 15.5 mm) long and 0.053 g (range 0.041 to 0.061 g) in weight. The mean head capsule width was 3.20 mm (range 3.11 to 3.32 mm). The duration of first instar grubs varied from 33 to 45 days with a mean of 40.1 days.

The second instar grubs were cream coloured and more sclerotized. The grubs were 24.75 mm (range 22.2 to 28.7 mm) long and 0.528 g (range 0.378 to 0.693 g) in weight. The mean head capsule width was 4.65 mm (range 4.12 to 5.17 mm). The duration of second instar grubs varied from 43 to 56 days with a mean of 50.2 days.

A). Eggs

B). First instar grubs

C). Second instar grub

D). Third instar grub

E). Pupae

F). Adult beetle

Plate 3. Life stages of *Leucopholis coneophora*

The anterior part of third instar grubs was creamy white coloured with a yellowish tinge and posterior part of the abdomen with grey or slate colour. The head capsule is dark brown in colour and well sclerotized. Just before prepupation, the grubs were 52.02 mm (range 43.9 to 58.1 mm) long and 5.26 g (range 4.11 to 6.57 g) in weight. The mean head capsule width was 7.67 mm (range 7.31 to 8.03 mm). The duration of the third instar grubs varied from 155 to 175 days.

4.1.3 Pupa

Pupation was observed in the earthen pupal chamber. The exarate pupa was initially light brown in colour and later changed to dark brown as the development progressed (Plate 3). The average length, width and weight of pupae were 35 mm, 16.3 mm and 4.63 g respectively. The pupal period was 25.5 days.

4.1.4 Adult

Adult beetles were greyish white initially and later turned to deep greyish brown (Plate 3). The male measured 27.1 mm in length (range 26.3 to 28.4 mm), 1.74 g (range 1.41 to 2.0 g) in weight and the female measured 30 mm (range 27.1 to 31.88 mm) in length and 3.58 g (range 2.8 to 4.1 g) in weight. The longevity of the male beetle was 41.99 days and that of the female beetle was 42.40 days

4.2 EFFECT OF ENTOMOPATHOGENIC FUNGI ON *L. coneophora*

4.2.1 First Instar Grubs

The first instar grubs treated with spore suspensions of *M. anisopliae* and *B. bassiana* @ 1 x 10^8, 1 x 10^9 and 1 x 10^{10} spores mL^{-1} did not exhibit any symptoms of mycosis (Plate 4). Mortality of grubs treated with spore suspension is expressed in Table 2.

M. anisopliae @ 1 x 10^{10} spores mL^{-1} (66.66 %) resulted in highest mortality at seven days after treatment (DAT). The treatments *M. anisopliae* @ 1

x 10^9 spores mL^{-1} (55.55 %) and *B. bassiana* @ 1 x 10^{10} spores mL^{-1} (51.84 %) were statistically on par. *M. anisopliae* @ 1 x 10^8 spores mL^{-1} resulted 37.03 per cent mortality, which is on par with *B. bassiana* @ 1 x 10^9 spores mL^{-1} (33.33 %), followed by *B. bassiana* @ 1 x 10^8 spores mL^{-1} (22.22 %). The chemical check, chlorpyriphos 20 % EC @ 225 g a.i. ha^{-1} resulted in 100 per cent mortality. No mortality was observed in untreated control.

At 14 DAT, *M. anisopliae* @ 1 x 10^{10} spores mL^{-1}(100 %) exhibited highest mortality of grubs, which was found to be statistically on par with the chemical check chlorpyriphos 20 % EC @ 225 g a.i. ha^{-1} (100 %), followed by *M. anisopliae* @ 1 x 10^9 spores mL^{-1} (77.77 %), *B. bassiana* @ 1 x 10^{10} spores mL^{-1} (81.47 %) and *B. bassiana* @ 1 x 10^9 spores mL^{-1} (70.36 %). The treatments, *M. anisopliae* @ 1 x 10^8 spores mL^{-1} (51.84 %) and *B. bassiana* @ 1 x 10^8 spores mL^{-1} (40.17 %) were found to be statistically on par. No mortality was observed in untreated control.

At 21 DAT, both the fungi exhibited similar results. Mortality of grubs treated with 1 x 10^{10} spores mL^{-1} of *M. anisopliae* and *B. bassiana* were 100 per cent, which was on par with chemical check chlorpyriphos 20 % EC @ 225 g a.i. ha^{-1} (100 %). Mortality obtained with 1 x 10^9 spores mL^{-1} of both the fungi were statistically on par (81.47 % with both *M. anisopliae* and *B. bassiana*). When the spore concentration was 1 x 10^8 spores mL^{-1}, the effect of both fungi was similar and resulted a mortality of 59.25 per cent with *M. anisopliae* and 40.17 per cent with *B. bassiana*.

By 28^{th} day the mortality increased to 92.58 per cent in *M. anisopliae* @ 1 x 10^9 spores mL^{-1} and 85.17 per cent in *B. bassiana* @ 1 x 10^9 spores mL^{-1}. The mortality noted with 1 x 10^8 spores mL^{-1} was 62.95 per cent in *M. anisopliae* and 51.84 per cent in *B. bassiana* and were statistically on par. No mortality was observed in untreated control.

4.2.2 Third Instar Grubs

Table 2. Effect of entomopathogenic fungi on 1st instar grubs of *Leucopholis coneophora*

Treatment	*Percentage mortality			
	7 DAT	14 DAT	21 DAT	28 DAT
M.anisopliae 1 x 10^8 spores mL^{-1}	37.03 $(37.44)^d$	51.84 $(46.06)^d$	59.25 $(50.36)^c$	62.95 $(52.74)^d$
M.anisopliae 1 x 10^9 spores mL^{-1}	55.55 $(48.24)^c$	77.77 $(62.37)^{bc}$	81.47 $(65.25)^b$	92.58 $(76.69)^b$
M.anisopliae 1 x 10^{10} spores mL^{-1}	66.66 $(54.92)^b$	100 $(89.04)^a$	100 $(89.04)^a$	100 $(89.04)^a$
B.bassiana 1 x 10^8 spores mL^{-1}	22.22 $(28.12)^e$	40.17 $(39.62)^d$	48.14 $(43.93)^c$	51.84 $(46.06)^d$
B.bassiana 1 x 10^9 spores mL^{-1}	33.33 $(35.26)^d$	70.36 $(57.11)^c$	81.47 $(64.75)^b$	85.17 $(67.63)^c$
B.bassiana 1 x 10^{10} spores mL^{-1}	51.84 $(46.06)^c$	81.47 $(64.75)^b$	100 $(89.04)^a$	100 $(89.04)^a$
Chlorpyriphos 20% EC – 225 g a.i ha^{-1} (Chemical check)	100 $(89.04)^a$	100 $(89.04)^a$	100 $(89.04)^a$	100 $(89.04)^a$
Untreated Control	0 $(0.95)^f$	0 $(0.95)^e$	0 $(0.95)^d$	0 $(0.95)^e$
CD (0.05)	(6.604)	(7.039)	(7.134)	(8.980)

* Mean of 3 replications DAT – Days after treatment

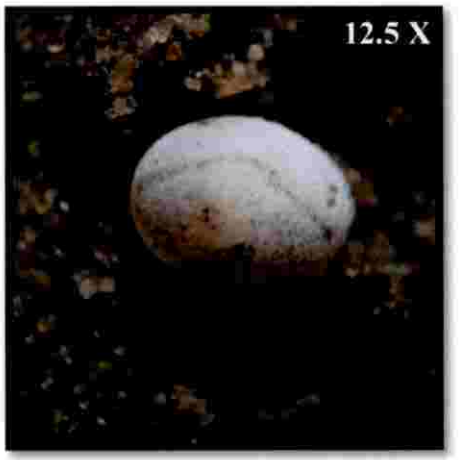
Figures in parenthesis are angular transformed values

A). *Metarhizium anisopliae* treated 1st instar grubs (7 DAT)

B). *Azadirachta indica* treated 3rd instar grub (30 DAT)

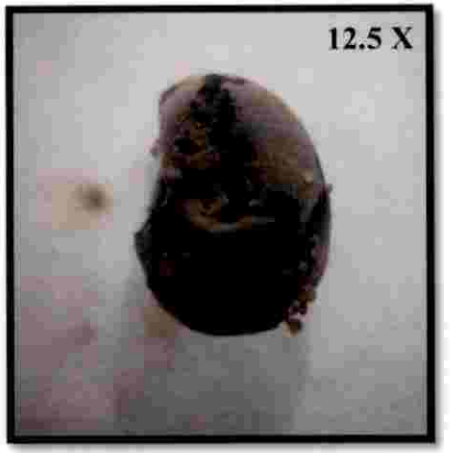
C). Fipronil treated 3rd instar grubs (14 DAT)

Plate 4. Physical appearance of cadavers in different treatments



A). Healthy egg

B). *B. bassiana* treated egg (7 DAT)



C). *M. anisopliae* treated egg (7 DAT)

Plate 5. Symptoms of mycosis in eggs of *Leucopholis coneophora*

No mortality was observed in third instar grubs treated with the entomopathogenic fungi, *M. anisopliae* and *B. bassiana* at all tested concentrations (1 x 10^8, 1 x 10^9 and 1 x 10^{10} spores mL^{-1}).

4.2.3 Eggs

All the eggs treated with both the fungi caused infection in the eggs. The *M. anisopliae* infected eggs turned blackish grey in colour and shrinked, whereas *B. bassiana* treated eggs became light brown in colour and later darkened (Plate 5).

4.3 EFFECT OF ENTOMOPATHOGENIC NEMATODES ON *L. coneophora* GRUBS

Steinernemae carpocapsae and *Heterorhabditis bacteriophora* tested at 100, 500 and 1000 IJ mL^{-1} concentrations failed to cause infection in both first and third instar grubs.

4.4 EFFECT OF BOTANICAL INSECTICIDES ON *L. coneophora* GRUBS

The efficacy of botanical insecticides was evaluated against the first and third instar grubs of *L. coneophora* under laboratory conditions.

4.4.1 First Instar Grubs

Mortality of treated first instar grubs observed at fortnightly interval is indicated in Table 3.

Among the treatments, incorporation of *Azadirachta indica* @ 25 g kg^{-1} of soil (25.92 %) was superior resulting on 15 DAT, followed by *Clerodendrone infortunatum* @ 25 g kg^{-1} of soil (11.11 %), which were significantly different also. *Gliricidia maculata* @ 25 g kg^{-1} of soil and *Chromolaena odorata* @ 25 g kg^{-1} of soil failed to produce mortality, which were statistically on par with the untreated control. The chemical check chlorpyriphos 20 % EC @ 225 g a.i. ha^{-1} resulted in 100 per cent mortality.

The results obtained on the 20th day after treatment showed a similar trend. By 20th day the mortality increased to 33.33 per cent in *A. indica* @ 25 g kg^{-1} of soil and 18.51 per cent in *C. infortunatum* @ 25 g kg^{-1} of soil. No mortality was recorded in the treatments *G. maculata* @ 25 g kg^{-1} of soil and *C. odorata* @ 25 g kg^{-1} of soil and was on par with untreated control.

After thirty days of treatment a similar trend was observed. Recorded mortality with the treatments *A. indica* @ 25 g kg^{-1} of soil and *C. infortunatum* @ 25 g kg^{-1} of soil were increased to 48.14 per cent and 37.03 %per cent respectively and were significantly different. The treatments, *G. maculata* @ 25 g kg^{-1} of soil and *C. odorata* @ 25 g kg^{-1} of soil resulted in no mortality and were statistically on par with untreated control.

4.4.2 Third Instar Grubs

The efficacy of botanical insecticides evaluated against the third instar grubs under laboratory conditions is shown in Table 4. The grubs treated with *A. indica* @ 25 g kg^{-1} of soil turned soft muddy brown to grey in colour on 15 DAT (Plate 4).

On the 15th day after treatment, significantly higher mortality was recorded in *A. indica* @ 25 g kg^{-1} of soil (25.92 %) followed by *C. infortunatum* @ 25 g kg^{-1} of soil (7.40 %), which were significantly different also. *G. maculata* @ 25 g kg^{-1} of soil and *C. odorata* @ 25 g kg^{-1} of soil failed to produce mortality, which were statistically on par with control. The chemical check chlorpyriphos 20 % EC @ 225 g a.i. ha^{-1} resulted in 100 per cent mortality.

By 20th day the mortality increased to 29.62 per cent in *A. indica* @ 25 g kg^{-1} of soil and 11.11 per cent in *C. infortunatum* @ 25 g kg^{-1} of soil .No mortality was recorded in the treatments *G. maculata* @ 25 g kg^{-1} of soil and *C. odorata* @ 25 g kg^{-1} of soil and was on par with untreated control.

Table 3. Effect of botanicals on 1st instar grubs of *Leucopholis coneophora*

Treatments	*Percentage mortality		
	15 DAT	20 DAT	30 DAT
Azadirachta indica (25 g kg^{-1} of soil)	25.92 (29.99)^{b}	33.33 (35.06)^{b}	48.14 (35.26)^{b}
Gliricidia maculata (25 g kg^{-1} of soil)	0.00 (0.95)^{d}	0.00 (0.95)^{d}	0.00 (0.95)^{d}
Clerodendron infortunatum (25 g kg^{-1} of soil)	11.11 (22.35)^{c}	18.51 (25.23)^{c}	37.03 (37.44)^{c}
Chromolaena odorata (25 g kg^{-1} of soil)	0.00 (0.95)^{d}	0.00 (0.95)^{d}	0.00 (0.95)^{d}
Chlorpyriphos 20% EC - 225 g a.i ha^{-1} (Chemical check)	100.00 (89.04)^{a}	100.00 (89.04)^{a}	100.00 (89.04)^{a}
Untreated control	0.00 (0.95)^{d}	0.00 (0.95)^{d}	0.00 (0.95)^{d}
CD (0.05)	(7.55)	(6.15)	(3.83)

* Mean of 3 replications DAT – Days after treatment

Figures in parenthesis are angular transformed values

Table 4. Effect of botanicals on 3rd instar grubs of *Leucopholis coneophora*

Treatments	*Percentage mortality		
	15 DAT	20 DAT	30 DAT
Azadirachta indica (25 g kg^{-1} of soil)	25.92 $(30.50)^b$	29.62 $(32.88)^b$	33.33 $(35.26)^b$
Gliricidia maculata (25 g kg^{-1} of soil)	0.00 $(0.95)^d$	0.00 $(0.95)^d$	0.00 $(0.95)^d$
Clerodendron infortunatum (25 g kg^{-1} of soil)	7.40 $(13.29)^c$	11.11 $(16.18)^c$	14.81 $(19.06)^c$
Chromolaena odorata (25 g kg^{-1} of soil)	0.00 $(0.95)^d$	0.00 $(0.95)^d$	0.00 $(0.95)^d$
Chlorpyriphos 20% EC - 225 g a.i ha^{-1} (Chemical check)	100.00 $(89.04)^a$	100.00 $(89.04)^a$	100.00 $(89.04)^a$
Untreated control	0.00 $(0.95)^d$	0.00 $(0.95)^d$	0.00 $(0.95)^d$
CD (0.05)	(8.324)	(10.512)	(11.392)

* Mean of 3 replications DAT – Days after treatment

Figures in parenthesis are angular transformed values

After thirty days of treatment, the trend observed was more or less the same. Recorded mortality with the treatments *A. indica* @ 25 g kg^{-1} of soil and *C. infortunatum* @ 25 g kg^{-1} of soil increased to 33.33 per cent and 14.81 per cent respectively. The treatments, *G. maculata* @ 25 g kg^{-1} of soil and *C. odorata* @ 25 g kg^{-1} of soil resulted in no mortality and were statistically on par with control.

4.5 EFFECT OF CHEMICAL INSECTICIDES ON *L. coneophora* GRUBS

The efficacy of chemical insecticides was evaluated against the first and third instar grubs of *L. coneophora* under laboratory conditions.

4.5.1 First Instar Grubs

The mortality of first instar grubs treated with insecticides is presented in Table 5.

The treatments fipronil 0.3 % G @ 75 g a.i. ha^{-1}(22.22 %), chlorantraniliprole 0.4 % G @ 75 g a.i. ha^{-1} (19.44 %) and spinosad 45 % SC @ 73 g a.i. ha^{-1} (16.66 %) were found to be statistically on par with chemical check chlorpyriphos 20 % EC @ 225 g a.i. ha^{-1} (24.99 %) on one day after treatment. All the treatments were found to be significantly different from the control.

The treatment fipronil 0.3 % G @ 75 g a.i. ha^{-1} (38.88 %) was superior among all the treatments and resulted in highest mortality on two DAT, followed by chlorantraniliprole 0.4 % G @ 75 g a.i. ha^{-1} (30.55 %) and spinosad 45 % SC @ 73 g a.i. ha^{-1} (22.22 %). A mortality of 55.55 per cent was imparted by the chemical check chlorpyriphos 20 % EC @ 225 g a.i. ha^{-1}. No mortality was observed in untreated control.

At three DAT, Fipronil 0.3 % G @ 75 g a.i. ha^{-1} (41.44 %), chlorantraniliprole 0.4 % G @ 75 g a.i. ha^{-1} (41.66 %) and spinosad 45 % SC @ 73 g a.i. ha^{-1} (27.77) were on par with each other. The chemical check chlorpyriphos 20 % EC @ 225 g a.i. ha^{-1} resulted in 94.44 per cent mortality. No mortality was observed in untreated control.

Highest mortality on the fourth day after treatment was observed in the treatment fipronil 0.3 % G @ 75 g a.i. ha^{-1}(61.10 %) and was statistically superior from all other treatments. This was followed by the treatment chlorantraniliprole 0.4 % G @ 75 g a.i. ha^{-1} (52.77%) and spinosad 45 % SC @ 73 g a.i. ha^{-1} (36.10 %) and was significantly different also. Chemical check chlorpyriphos 20 % EC @ 225 g a.i. ha^{-1} resulted in absolute mortality of grubs. No mortality was observed in untreated control.

On five DAT, highest mortality was sighted in fipronil 0.3 % G @ 75 g a.i. ha^{-1} (80.54 %). The recorded mortality in the treatments, chlorantraniliprole 0.4 % G @ 75 g a.i. ha^{-1} and spinosad 45 % SC @ 73 g a.i. ha^{-1} were increased to 61.10 per cent and 47.21 per cent respectively and were statistically on par. No mortality was observed in untreated control.

By six DAT the mortality increased to 88.88 per cent in fipronil 0.3 % G @ 75 g a.i. ha^{-1} and was superior among all the treatments. The treatments chlorantraniliprole 0.4 % G @ 75 g a.i. ha^{-1} and (66.66 %) spinosad 45 % SC @ 73 g a.i. ha^{-1} (52.77 %) were statistically on par.

After seven days of treatment, a similar trend was observed. The treatment fipronil 0.3 % G @ 75 g a.i. ha^{-1} (91.66 %) recorded highest mortality followed by, chlorantraniliprole 0.4 % G @ 75 g a.i. ha^{-1} (69.43 %) and spinosad 45 % SC @ 73 g a.i. ha^{-1} (52.77 %) and was significantly different from untreated control. No mortality was observed in untreated control.

By eight days after treatment the mortality increased to 94.44 per cent in fipronil 0.3 % G @ 75 g a.i. ha^{-1}, 72.21 per cent in chlorantraniliprole 0.4 % G @ 75 g a.i. ha^{-1} and 55.55 per cent in spinosad 45 % SC @ 73 g a.i. ha^{-1}. All the treatments were found to be significantly different from untreated control. No mortality was observed in untreated control.

On nine DAT, fipronil 0.3 % G @ 75 g a.i. ha^{-1} resulted in 97.22 per cent mortality which is on par with the chemical check chlorpyriphos 20 % EC @ 225

g a.i. ha^{-1} (100 %), followed by chlorantraniliprole 0.4 % G @ 75 g a.i. ha^{-1} (74.99 %) and spinosad 45 % SC @ 73 g a.i. ha^{-1} (55.55 %). The treatments were found to be significantly different from untreated control. No mortality was observed in untreated control.

After ten days of treatment, a similar trend was observed. Mortality obtained in fipronil 0.3 % G @ 75 g a.i. ha^{-1} remained 97.22 per cent and showed superiority over all other treatments, followed by chlorantraniliprole 0.4 % G @ 75 g a.i. ha^{-1} (74.99 %) and spinosad 45 % SC @ 73 g a.i. ha^{-1} (55.55 %). The treatments were found to be significantly different from untreated control. No mortality was observed in untreated control.

4.5.2 Third Instar Grubs

The mortality of third instar grubs treated with insecticides is indicated in Table 6.

On first day after treatment all the treatments were found to be non-significant. The chemical check chlorpyriphos 20 % EC @ 225 g a.i. ha^{-1} (5.55 %) was the only treatment in which mortality was obtained.

Chlorantraniliprole 0.4 % G @ 75 g a.i. ha^{-1} (11.11 %) was superior among all the treatments and resulted in highest mortality on 2nd DAT. Spinosad 45 % SC @ 73 g a.i. ha^{-1} showed a mortality of 2.77 per cent, whereas no mortality was observed in fipronil 0.3 % G @ 75 g a.i. ha^{-1} and untreated control and were statistically on par. The chemical check, chlorpyriphos 20 % EC @ 225 g a.i. ha^{-1} brought about 41.66 per cent mortality.

On three DAT, fipronil 0.3 % G 75 g a.i. ha^{-1} (27.77 %) recorded highest mortality. The treatments spinosad 45 % SC @ 73 g a.i. ha^{-1} (11.11 %) and chlorantraniliprole 0.4 % G @ 75 g a.i. ha^{-1} (11.11 %) were statistically on par and significantly different from untreated control. The mortality in the chemical check, chlorpyriphos 20 % EC @ 225 g a.i. ha^{-1} increased to 88.88 per cent.

The results obtained on the fourth day after treatment showed a similar trend. Highest mortality was observed in the treatment fipronil 0.3 % G @ 75 g a.i. ha^{-1} (33.33 %) and was statistically superior from all other treatments. This was followed by the treatment chlorantraniliprole 0.4 % G @ 75 g a.i. ha^{-1} (19.44 %) and spinosad 45 % SC @ 73 g a.i. ha^{-1} (13.88 %) and was significantly different also. Absolute mortality was obtained in the chemical check chlorpyriphos 20 % EC @ 225 g a.i. ha^{-1}. No mortality was observed in untreated control.

After five days of treatment similar trend was observed. Mortality of grubs increased to 33.33 per cent in fipronil 0.3 % G @ 75 g a.i. ha^{-1}, 24.99 per cent in chlorantraniliprole 0.4 % G @ 75 g a.i. ha^{-1} and 16.66 per cent in spinosad 45 % SC @ 73 g a.i. ha^{-1} and were significantly different also. No mortality was observed in untreated control.

On six DAT, similar trend as that on third DAT was observed. Fipronil 0.3 % G @ 75 g a.i. ha^{-1} (36.10 %) resulted in highest mortality and was significant. The treatments chlorantraniliprole 0.4 % G @ 75 g a.i. ha^{-1} (24.99 %) and spinosad 45 % SC @ 73g a.i. ha^{-1} (19.44 %) were statistically on par and significantly different from untreated control.

After seven days of treatment, a similar trend was observed. The recorded mortality in fipronil 0.3 % G @ 75 g a.i. ha^{-1} increased to 38.88 per cent. The treatments chlorantraniliprole 0.4 % G @ 75 g a.i. ha^{-1} (24.99 %) and spinosad 45 % SC @ 73 g a.i. ha^{-1} (19.44 %) were statistically on par and significantly different from untreated control.

Observations on 8^{th}, 9^{th} and 10^{th} DAT followed a similar trend. At 9^{th} and 10^{th} DAT, fipronil 0.3 % G @ 75 g a.i. ha^{-1} (41.66 %) recorded highest mortality. The treatments chlorantraniliprole 0.4 % G @ 75 g a.i. ha^{-1} (27.77 %) and spinosad 45 % SC @ 73 g a.i. ha^{-1} (19.44 %) were statistically on par and significantly different from untreated control.

Table 5. Effect of chemical insectcides on 1st instar grubs of *Leucopholis coneophora*

Treatments	*Percentage mortality									
	1 DAT	2 DAT	3 DAT	4 DAT	5 DAT	6 DAT	7 DAT	8 DAT	9 DAT	10 DAT
Chlorantraniliprole 0.4% G 75 g a.i ha^{-1}	19.44 (25.96)^{a}	30.55 (33.47)^{bc}	41.66 (39.98)^{b}	52.77 (46.59)^{c}	61.10 (51.64)^{c}	66.66 (54.87)^{c}	69.43 (56.66)^{c}	72.21 (58.30)^{c}	74.99 (60.08)^{b}	74.99 (60.08)^{b}
Fipronil 0.3% G 75 g a.i ha^{-1}	22.22 (27.74)^{a}	38.88 (38.53)^{b}	44.44 (41.76)^{b}	61.10 (51.45)^{b}	80.54 (64.03)^{b}	88.88 (72.98)^{b}	91.66 (75.15)^{b}	94.44 (79.78)^{b}	97.22 (84.41)^{a}	97.22 (84.41)^{a}
Spinosad 45% SC 73 g a.i ha^{-1}	16.66 (23.79)^{a}	22.22 (27.74)^{c}	27.77 (31.69)^{b}	36.10 (36.89)^{d}	47.21 43.36)^{c}	52.77 (46.63)^{c}	52.77 (46.63)^{c}	55.55 (48.26)^{d}	55.55 (48.26)^{c}	55.55 (48.26)^{c}
Chlorpyriphos 20% EC 225 g a.i ha^{-1} (Chemical check)	24.99 (29.90)^{a}	55.55 (48.22)^{a}	94.44 (79.78)^{a}	100 (89.04)^{a}	100 (89.04)^{a}	100 (89.04)^{a}	100 (89.04)^{a}	100 (89.04)^{a}	100 (89.04)^{a}	100 (89.04)^{a}
Untreated Control	0 (0.95)^{b}	0 (0.95)^{d}	0 (0.95)^{c}	0 (0.95)^{e}	0 (0.95)^{d}	0 (0.95)^{d}	0 (0.95)^{d}	0 (0.95)^{e}	0 (0.95)^{d}	0 (0.95)^{d}
CD (0.05)	(6.672	(6.628)	(10.233)	(3.999)	(9.229)	(10.806)	(9.210)	(5.632)	(8.360)	(8.360)

* Mean of 4 replications DAT – Days after treatment Figures in parenthesis are angular transformed values

Table 6. Effect of chemical insectcides on 3rd instar grubs of *Leucopholis coneophora*

Treatment	*Percentage mortality									
	1 DAT	2 DAT	3 DAT	4 DAT	5 DAT	6 DAT	7 DAT	8 DAT	9 DAT	10 DAT
Chlorantraniliprole 0.4% G 75 g a.i ha^{-1}	0 (0.95)	11.11 $(19.47)^{b}$	11.11 $(19.47)^{c}$	19.44 $(25.96)^{c}$	24.99 $(29.90)^{c}$	24.99 $(29.90)^{c}$	24.99 $(29.90)^{c}$	24.99 $(29.90)^{c}$	27.77 $(31.69)^{c}$	27.77 $(31.69)^{c}$
Fipronil 0.3% G 75 g a.i ha^{-1}	0 (0.95)	0 $(0.95)^{c}$	27.77 $(31.69)^{b}$	33.33 $(35.26)^{b}$	33.33 $(35.26)^{b}$	36.10 $(36.89)^{b}$	38.88 $(38.53)^{b}$	41.66 $(40.12)^{b}$	41.66 $(40.12)^{b}$	41.66 $(40.12)^{b}$
Spinosad 45% SC 73 g a.i ha^{-1}	0 (0.95)	2.77 $(5.58)^{c}$	11.11 $(19.47)^{c}$	13.88 $(21.63)^{d}$	16.66 $(23.79)^{d}$	19.44 $(25.96)^{c}$	19.44 $(25.96)^{c}$	19.44 $(25.96)^{c}$	19.44 $(25.96)^{c}$	19.44 $(25.96)^{c}$
Chlorpyriphos 20% EC 225 g a.i ha^{-1} (Chemical check)	5.55 (10.21)	41.66 $(40.17)^{a}$	88.88 $(70.52)^{a}$	100 $(89.04)^{a}$	100 $(89.04)^{a}$	100 $(89.04)^{a}$	100 $(89.04)^{a}$	100 $(89.04)^{a}$	100 $(89.04)^{a}$	100 $(89.04)^{a}$
Untreated Control	0 (0.95)	0 $(0.95)^{c}$	0 $(0.95)^{d}$	0 $(0.95)^{e}$	0 $(0.95)^{e}$	0 $(0.95)^{d}$	0 $(0.95)^{d}$	0 $(0.95)^{d}$	0 $(0.95)^{d}$	0 $(0.95)^{d}$
CD (0.05)	NS	(6.618)	(8.203)	(4.125)	(4.137)	(4.371)	(4.55)	(5.632)	(5.799)	(5.799)

* Mean of 4 replications DAT – Days after treatment Figures in parenthesis are angular transformed values

4.6 EFFECT OF PROMISING TREATMENTS ON *L. coneophora* GRUBS UNDER POT CULTURE

The efficacy of promising treatments *viz. M. anisopliae* (1 x 10^9 spores mL^{-1} and 1 x 10^{10} spores mL^{-1}), *B. bassiana* (1 x 10^9 spores mL^{-1} and 1 x 10^{10} spores mL^{-1}), chlorantraniliprole 0.4% G @ 75 g a.i. ha^{-1}, fipronil 0.3% G @ 75 g a.i. ha^{-1} and chlorpyriphos 20% EC @ 225 g a.i. ha^{-1} (chemical check) from laboratory experiments, evaluated against the first instar coconut root grub under pot culture experiment are shown in Table 7. The mortality is expressed in percentage.

The treatment, fipronil 0.3 % G @ 75 g a.i. ha^{-1} (85.17 %) resulted in highest mortality at 7 DAT, followed by chlorantraniliprole 0.4 % G @ 75 g a.i. ha^{-1} (70.36 %). *M. anisopliae* @ 1 x 10^{10} spores mL^{-1} (40.73 %) and *B.* bassiana @ 1 x 10^{10} spores mL^{-1} (40.73 %) were found to be statistically on par. *M. anisopliae* @ 1 x 10^9 spores mL^{-1} (29.62 %) and *B. bassiana* @ 1 x 10^9 spores mL^{-1} (25.92 %) were also found to be statistically on par. The chemical check chlorpyriphos 20 % EC @ 225 g a.i. ha^{-1} resulted in 100 per cent mortality. No mortality was observed in untreated control and all the treatments were significant from untreated control.

By 14th day, mortality increased to 96.29 per cent in fipronil 0.3 % G @ 75 g a.i. ha^{-1}, which was on par with the chemical check chlorpyriphos 20 % EC @ 225 g a.i. ha^{-1}(100 %) and were found to be superior among all the treatments. The treatments *M. anisopliae* @ 1 x 10^{10} spores mL^{-1} (77.77 %), chlorantraniliprole 0.4 % G @ 75 g a.i. ha^{-1} (74.06 %) and *B. bassiana* @ 1 x 10^{10} spores mL^{-1} (70.36 %), *M. anisopliae* @ 1 x 10^9 spores mL^{-1} (62.95 %) and *B. bassiana* @ 1 x 10^9 spores mL^{-1} (51.84 %) were found to be statistically on par. No mortality was observed in untreated control.

At 21 DAT, a similar trend was observed. Mortality noted in the treatment fipronil 0.3 % G @ 75 g a.i. ha^{-1} remained 96.29 per cent and was on par with the chemical check chlorpyriphos 20 % EC @ 225 g a.i. ha^{-1} (100 %). The treatments

M. anisopliae @ 1 x 10^{10} spores mL^{-1} (81.47 %), chlorantraniliprole 0.4 % G @ 75 g a.i. ha^{-1} (74.06 %) and *B. bassiana* @ 1 x 10^{10} spores mL^{-1} (77.77 %), *M. anisopliae* @ 1 x 10^{9} spores mL^{-1} (62.95 %) and *B. bassiana* @ 1 x 10^{9} spores mL^{-1} (59.25 %) were found to be statistically on par. No mortality was observed in untreated control.

At 28th DAT, fipronil 0.3 % G @ 75 g a.i. ha^{-1} brought about absolute mortality and was on par with the chemical check chlorpyriphos 20 % EC @ 225 g a.i. ha^{-1} (100 %), followed by *M. anisopliae* @ 1 x 10^{10} spores mL^{-1} (85.17 %). *B. bassiana* @ 1 x 10^{10} spores mL^{-1} (77.77 %), *M. anisopliae* @ 1 x 10^{9} spores mL^{-1} (74.06 %) and chlorantraniliprole 0.4 % G @ 75 g a.i. ha^{-1} (74.06 %) were found to be statistically on par with each other.

4.7 NATURAL ENEMIES IDENTIFIED

The common crow (*Corvus splendens* L.) and common egret (*Ardea alba* L.) (Plate. 6) were found to be predacious on the grubs, when they were exposed during intercultural operations.

4.7.1 Isolation of *Ophiocordyceps neovolkiana*

Entomopathogenic fungi, *Ophiocordyceps neovolkiana* was isolated from infected third instar grubs of *L. coneophora* collected from cashew orchard in the Instructional Farm, College of Agriculture, Padannakkad. Infected grubs were seen in areas near to sprinkler heads also. The development of the fruiting body was observed from the cephalic region of grubs. The number and length of the stroma varied from one to four and 0.8 cm to 12.5 cm respectively (Plate 7).

In PDA, the fungus showed a creamish white densely cottony growth with the production of synnemata. It took 55 days for the completion of growth in PDA.

Table 7. Effect of promising treatments on 1st instar grubs of *Leucopholis coneophora*

Treatments	*Percentage mortality			
	7 DAT	14 DAT	21 DAT	28 DAT
M. anisopliae 1 x 10^{10} spores mL^{-1}	40.73 (39.62)^{d}	77.77 (60.37)^{b}	81.47 (64.75)^{b}	85.17 (67.63)^{b}
M. anisopliae 1 x 10^{9} spores mL^{-1}	29.62 (32.88)^{e}	62.95 (52.55)^{cd}	70.36 (57.11)^{bc}	74.06 (59.49)^{c}
B. bassiana 1 x 10^{10} spores mL^{-1}	40.73 (39.62)^{d}	70.36 (57.11)^{bc}	77.77 (60.37)^{b}	77.77 (60.37)^{c}
B. bassiana 1 x 10^{9} spores mL^{-1}	25.92 (30.50)^{e}	51.84 (46.06)^{d}	59.25 (50.36)^{c}	59.25 (50.36)^{d}
Chlorantraniliprole 0.4% G – 75 g a.i ha^{-1}	70.36 (57.11)^{c}	74.06 (59.49)^{bc}	74.06 (59.49)^{b}	74.06 (59.49)^{c}
Fipronil 0.3% G – 75 g a.i ha^{-1}	85.17 (67.63)^{b}	96.29 (82.87)^{a}	96.29 (82.87)^{a}	100 (89.04)^{a}
Chlorpyriphos 20% EC – 225 g a.i ha^{-1}	100 (89.04)^{a}	100 (89.04)^{a}	100 (89.04)^{a}	100 (89.04)^{a}
Untreated Control	0 (0.95)^{f}	0 (0.95)^{e}	0 (0.95)^{d}	0 (0.95)^{e}
CD (0.05)	(6.255)	(9.455)	(9.678)	(7.127)

*Mean of 3 replications DAT – Days after treatment

Figures in parenthesis are angular transformed values

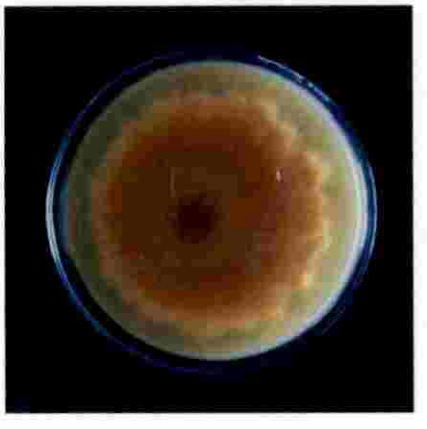
A). Common egret *Ardea alba* L.

B). Common crow *Corvus splendens* L.

Plate 6. Predators encountered

A). Fruiting body on *Leucopholis coneophora*

B). Growth on PDA plates
Upper view



C). Growth on PDA plates
Rear view

Plate 7. *Ophiocordyceps neovolkiana*

Discussion

5. DISCUSSION

White grubs are polyphagous pests of national importance. Root grub complex of palm ecosystem in south India encompasses, *L. coneophora*, *L. burmeisteri* and *L. lepidophora*, among which, *L. coneophora* is the predominant species infesting coconut based cropping system.

Currently, chemical insecticides are the major arsenal used for the management of grubs. Chemical control is often inadequate and harmful to the environment. Hence, there is a strong impetus for the development of alternative eco-friendly and economically feasible strategies for the management of white grubs. Though integrated methods have been suggested by various scientists for the control of root grub complex, the researches on the management of coconut root grub are scanty. Hence, the present investigation entitled "Ecological management of coconut root grub, *Leucopholis coneophora* Burm." was taken up as a preliminary step for assessing the efficacy of botanicals and biocontrol agents during 2017-19 to evolve a suitable eco-friendly management strategy. The results of the study are discussed below.

5.1 EFFECT OF ENTOMOPATHOGENIC FUNGI ON *L. coneophora*

Entomopathogenic fungi are important regulators of the insect population. Among them *Beauveria bassiana* and *Metarhizium anisopliae* have proved to be excellent against grubs of *Holotrichia* spp. (Chelvi *et al.*, 2010; Pandey, 2010). Unlike insect pathogenic viruses and bacteria, the fungi invade hosts by directly penetrating cuticle, which enable them to infect even non-feeding stages of insects like eggs and pupae.

In the present study, *M. anisopliae* was found to be effective EPF against the first instar grubs. At 14th DAT, the highest concentration of *M. anisopliae* (1 x 10^{10} spores mL^{-1}) acquired 100 per cent mortality (Figure 1). Kesarasing *et al.* (2010) also reported that 91.95 per cent reduction in the population of sugarcane

white grub, *Holotrichia serrata* F. at 60 DAT with *M. anisopliae* (Ma-1) at 1 x 10^{13} conidia ha^{-1} and was found to be next best to chlorpyriphos treatment.

In the present study *B. bassiana* @ 1 x 10^{10} spores mL^{-1} attained absolute mortality of grubs within three weeks after treatment application. As cited by Mohi-ud-din *et al.* (2006), an indigenous isolate of *B. bassiana* attained 46.66 per cent mortality of *Holotrichia* sp. on the 6^{th} day and achieved cent per cent mortality on 12^{th} day of treatment.

On the basis of pathogenicity, the *M. anisopliae* (1 x 10^{10} spores mL^{-1}) was deliberated as the most promising treatment causing initial and absolute mortality in a shorter period of time (14 DAT). A reduction in mortality and an increase in time taken to attain the mortality were observed with decreasing concentrations. However, when a long-term management strategy is being considered, second higher concentrations of *M. anisopliae* and *B. bassiana* (1 x 10^{9} spores mL^{-1}) can also be taken into account, as it recorded 92.58 per cent and 85.17 per cent mortality respectively).

Even though mortality was observed with EPF, there were no symptom of mycosis. This result was in accordance with the findings of Sreekumar (2007). He opined that failure in development of mycosis might be due to the action of bacteria present in the body surface as well as in the haemolymph of the grubs. Hence it is assumed that the death was due to the action of fungal toxins such as dextruxins from *M. anisopliae* and beauvericin and bassionolides from *B. bassiana.*

In desert locust, *Schistocerca gregaria* (Forsk.) (Orthoptera), a strong positive correlation was found between percentage mortality of individuals and *in vitro* toxin production in which sporulation did not occur on the cadavers. Before the establishment of the fungus, the toxin produced by the fungus (destruxin) resulted in the death of the locust and the pathogen failed to compete with saprophytic flora and, as a result, failed to sporulate (Kershaw *et al.*, 1999).

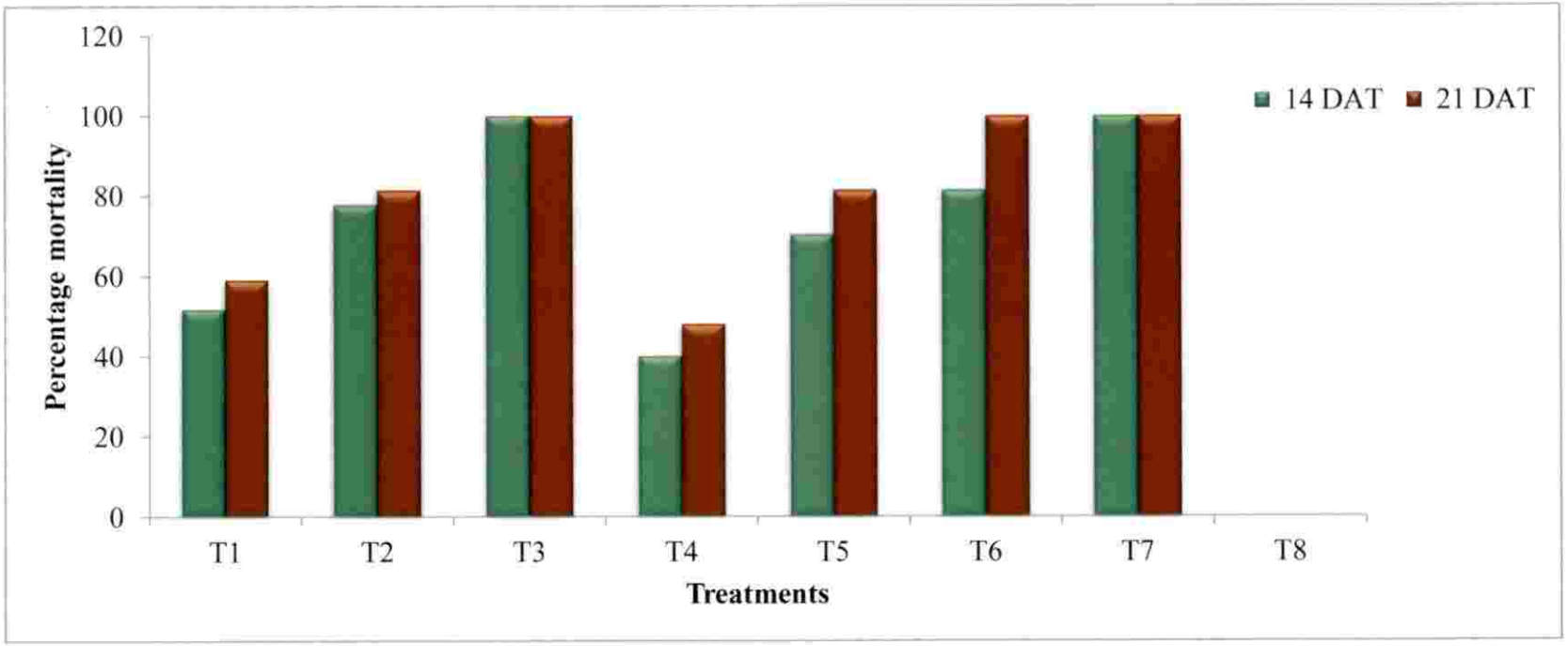


Figure 1. Percentage mortality of first instar grubs of *Leucopholis coneophora* treated with entomopathogenic fungi in laboratory experiment

T1: *M. anisopliae* 1 x 10^{8} spores mL^{-1}
T2: *M. anisopliae* 1 x 10^{9} spores mL^{-1}
T3: *M. anisopliae* 1 x 10^{10} spores mL^{-1}
T4: *B. bassiana* 1 x 10^{8} spores mL^{-1}
T5: *B. bassiana* 1 x 10^{9} spores mL^{-1}
T6: *B. bassiana* 1 x 10^{10} spores mL^{-1}
T7: Chlorpyriphos 20% EC – 225 g a.i. ha^{-1}
T8: Untreated Control

In this study mortality was not observed in third instar grubs treated with, *M. anisopliae* and *B. bassiana* at all tested concentrations (1 x 10^8 spores mL^{-1}, 1 x 10^9 spores mL^{-1} and 1 x 10^{10} spores mL^{-1}). Compared to lower instars, third instar grubs are well sclerotized, stout and hardy. More thickened integument and sclerotized body parts might act as a barrier against the EPF. Body surface and haemolymph may contain a higher quantity of bacteria than that present in lower instars, which is sufficient enough to inhibit the growth of EPF on the grubs.

5.2 EFFECT OF ENTOMOPATHOGENIC NEMATODES ON *L. coneophora* GRUBS

Steinernemae carpocapsae and *Heterorhabditis bacteriophora* at all selected concentrations failed to cause infection in both first and third instar grubs. Reports by Jeevan (2014) substantiate this finding, wherein he reported that the application of *H. indica* on third instar coconut root grubs did not cause any mortality both under laboratory and field conditions.

Interference of the enteric bacteria in the Colorado potato beetle, *Leptinotarsa decemlineata* (Say), resulted in the reproductive failure of *H. marelatus*. The growth of *Photorhabdus temperata*, the enteric symbiont of the nematode was inhibited by the enteric bacteria (Blackburn *et al.*, 2008). The EPN, *H. bacteriophora* provided limited root protection and control of *Phyllophaga anxia*, white grubs of Christmas tree, whereas *S. carpocapsae* did not provide effective control (Liesch and Williamson, 2010).

5.3 EFFECT OF BOTANICAL INSECTICIDES ON *L. coneophora* GRUBS

Botanical insecticides are important alternatives to minimize or replace the use of chemical insecticides. They possess an array of properties such as toxicity to the pest, insect growth regulation, antifeedant and repellent activity (Prakash *et al.*, 2008). Chemical insecticides pose a great problem to the ecosystem due to its high persistence and residual action. Hence, it is the need of the hour for a less persistent and safer alternative. A number of plant extracts

have been reported which have notable insecticidal and antifeedant properties. Plants based extracts are generally less persistent and are hence easily decomposed. Thus the problem produced by the persistent insecticide like the killing of non-target species, development of resistance against the insecticide by the pest, biomagnification etc. are minimal in the case of a bio pesticide (Surendran *et al.*, 2017).

Botanicals for the current study were selected based on its availability. Soil application of finely chopped leaves and tender parts of freshly harvested botanicals was employed for the study since the oil-based emulsions tend to retain in the soil surface (Suhasini *et al.*, 2017).

Higher mortality of both first and third instar grubs was observed with the treatment *Azadiracta indica* @ 25 g kg^{-1} of soil (48.14 % and 33.33 % respectively), followed by *Clerodendrone infortunatum* @ 25 g kg^{-1} of soil (37.03 % and 14.81 % respectively). The most important active principle of neem, azadirachtin, had ovipositional deterrent, antifeedant, growth-regulating, fecundity and fitness reducing properties on insects (Schmutterer, 1990). The presence of active principles in the neem leaves might result in the growth regulation of grubs and higher mortality.

The cumulative larval mortality of *Oryctes rhinoceros* L. was observed to be higher in neem cake @ 200 g kg^{-1} of feed used for rearing, followed by *Annona squamosa* @ 200 g kg^{-1}. NSKE was the third effective botanical. Neem oil and azadirachtin based emulsion were less effective (Suhasini *et al.*, 2017).

LC_{50} values of neem cake powder and neem oil were 29.5 and 24.5 per cent respectively at 96 h after treatment (Mohan and Padmanabahan, 2013).

5.4 EFFECT OF CHEMICAL INSECTICIDES ON *L. coneophora* GRUBS

Among the four insecticides evaluated, fipronil 0.3 % G @ 75 g a.i. ha^{-1} was found to be the best treatment, which caused 97.77 per cent mortality of first

instar grubs at 9th DAT (Figure 2). Shivanna *et al.* (2014) recorded a significantly lower number of arecanut grubs palm^{-1} by the application of fipronil 0.75 ml L^{-1} + imidacloprid 0.75 ml L^{-1} at five days after drenching.

Binding of fipronil and its metabolites (desulfinyl, sulfide, and sulfone) to soil particles reduces its potential to be leached through the soil profile and as a result persistence is more (Bobe *et al.*, 1997; Connelly, 2001). Fipronil, a phenylpyrazole compound is known to have high insecticidal activity against a wide range of insects and many arthropod pests (Tingle *et al.,* 2003). It acts by disturbing the ligand-gated chloride channels from the cell membranes of insects (Bloomquist, 2003). GABA-gated chloride channels are blocked by fipronil, which reduces neuronal inhibition and leads to hyperexcitation of the central nervous system. This eventually leads to convulsions and death. The unique occurrence of these channels in invertebrates was attributed to its high selectivity for invertebrate pests (Zhao *et al.,* 2005).

The results of the present study revealed that chlorantraniliprole 0.4 % G @ 75 g a.i. ha^{-1} caused 74.99 per cent mortality on 9 DAT. Chlorantraniliprole, an anthranilic diamide insecticide with the novel mode of action, is found effective against several lepidopterans as well as coleopteran, dipteran, and hemipteran pests (Sharma *et al.*, 2014). It is a ryanodine receptor modulator acting on nerves and muscles (IRAC, 2019).

Sharma *et al.* (2014) worked out half-life values ($t_{1/2}$) of chlorantraniliprole as 8.36 and 8.25 days, at recommended (100 g a.i. ha^{-1}) and double the recommended dosages (200 g a.i. ha^{-1}) respectively. The average initial deposits of chlorantraniliprole were observed to be 0.88 and 1.59 mg kg^{-1} respectively, which dissipated below the limit of quantification (LOQ) of 0.01 mg kg^{-1} after 56 days of the application of insecticides at both the dosages. Chlorantraniliprole is a green labelled insecticide that is safer for non-target organisms including mammals. Since this chemical has a lower persistence in soil, chances of soil and groundwater contamination are limited (EFSA, 2013).

Insecticides that are generally endorsed for root grub management are banned in Kerala particularly in Kasaragod district by Government of Kerala (G.O. (MS) 310/2010/Agri. Dated 2/12/2010) as it is declared as an organic district. Being a green labelled insecticide, chlorantraniliprole can be a viable option in order to manage the root grub population in the endemic coastal belts of Kasaragod district which will come in line with the organic policies of GOK.

In the present study, application of spinosad 45 % SC @ 73g a.i. ha^{-1} resulted in lower mortality of first instar grubs. Spinosad is a naturally occurring stomach poison with contact activity. Its interaction with the nicotinic acetylcholine receptors activates the central nervous system of insects which results in irreversible tremors, prostrate trembling, paralysis and death (IRAC, 2019).

The comparative lower performance of spinosad in the present study might be due to the rapid dissipation of chemicals from the soil surface. This is in accordance with Sharma *et al.* (2007), who reported deeper movement of spinosad into the soil at a higher rate (35.0 g a.i. ha^{-1}) of application. Rapid dissipation of spinosad with half-lives of less than one day from soil surfaces had been observed under field conditions.

In the present study, the chemical check, chlorpyriphos 20 % EC @ 225g a.i. ha^{-1} stood superior in managing root grubs than EPF and other chemical insecticides evaluated. Chlorpyriphos is an organophosphorus group of insecticide acting on the nervous system by inhibiting acetylcholine esterase enzyme (IRAC, 2019). It is one of the most effective soil insecticide, moderately volatile and acts as a systemic, contact and fumigant poison.

Halogenated organophosphorus insecticides are generally the most active in soil (Mulla, 1964; Harris, 1972). Insecticide that vaporizes in the soil allows better dispersal of the active material throughout the soil and the chemical will

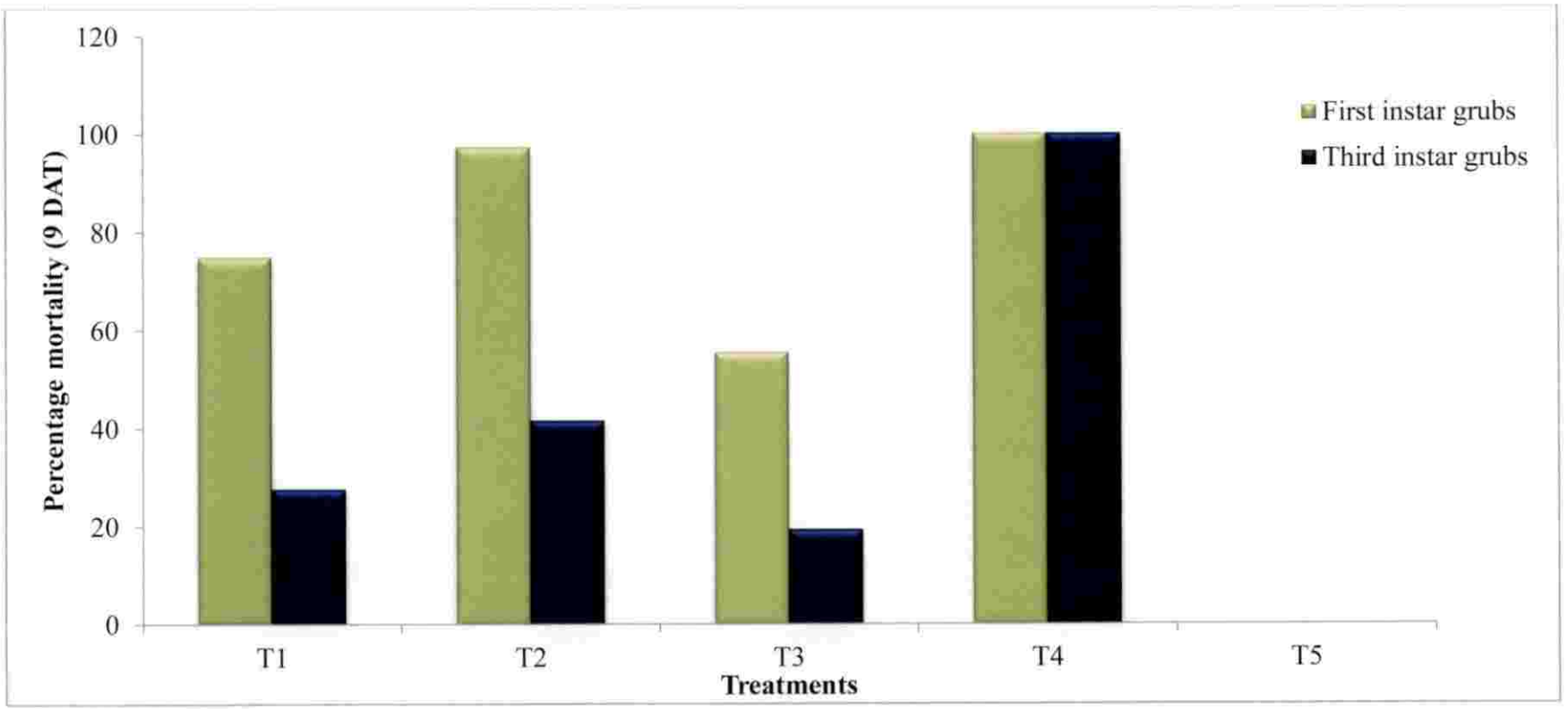


Figure 2. Percentage mortality of grubs of *Leucopholis coneophora* treated with chemical insecticides in laboratory experiment

T1: Chlorantraniliprole 0.4% G – 75 g a.i. ha^{-1}

T2: Fipronil 0.3% G – 75 g a.i. ha^{-1}

T3: Spinosad 45% SC – 73 g a.i. ha^{-1}

T4: Chlorpyriphos 20% EC – 225 g a.i. ha^{-1} (Chemical check)

T5: Untreated Control

act on the insect both through the respiratory system and the cuticle. This made the chemical more effective compared to others.

5.5 EFFECT OF PROMISING TREATMENTS ON *L. coneophora* GRUBS UNDER POT CULTURE

The efficacy of selected EPF and chemical insecticides for the management of coconut root grub was studied in the pot culture experiment. EPF *viz.*, *M. anisopliae* and *B. bassiana* (1 x 10^9 spores mL^{-1} and 1 x 10^{10} spores mL^{-1}) and chemical insecticides, chlorantraniliprole 0.4 % G @ 75 g a.i. ha^{-1} and fipronil 0.3 % G @ 75 g a.i. ha^{-1} found effective in laboratory evaluation were included as treatments along with the chemical check chlorpyriphos 20 % EC @ 225 g a.i. ha^{-1}.

Results of the laboratory experiment were confirmed in the pot culture experiment. Application of fipronil 0.3 % G @ 75 g a.i. ha^{-1} was equally effective as chemical check chlorpyriphos 20% EC @ 225 g a.i. ha^{-1} in controlling the root grubs followed by *M. anisopliae* @ 1 x 10^{10} spores mL^{-1}. *B. bassiana* @ 1 x 10^{10} spores mL^{-1} , *M. anisopliae* @ 1 x 10^9 spores mL^{-1} and chlorantraniliprole 0.4 % G @ 75 g a.i. ha^{-1}were also exhibited comparable performance in managing grubs (Figure 3).

Therefore, it may be concluded that for coping the issues of root grubs in coconut garden, application of entomopathogenic fungi *M. anisopliae* @ 1 x 10^{10} spores mL^{-1} is a benevolent strategy during the early stages of the pest. *B. bassiana* @ 1 x 10^{10} spores mL^{-1} can also be a propitious add-on in order to reduce the infestation and damage addressed from root grubs in coconut gardens. Even though, fipronil 0.3 % G @ 75 g a.i. ha^{-1} achieved promising results in controlling grubs, considering its detrimental effects on the environment and non-target organisms, chlorantraniliprole 0.4 % G @ 75 g a.i. ha^{-1} is the better choice for eco-friendly management of coconut root grub.

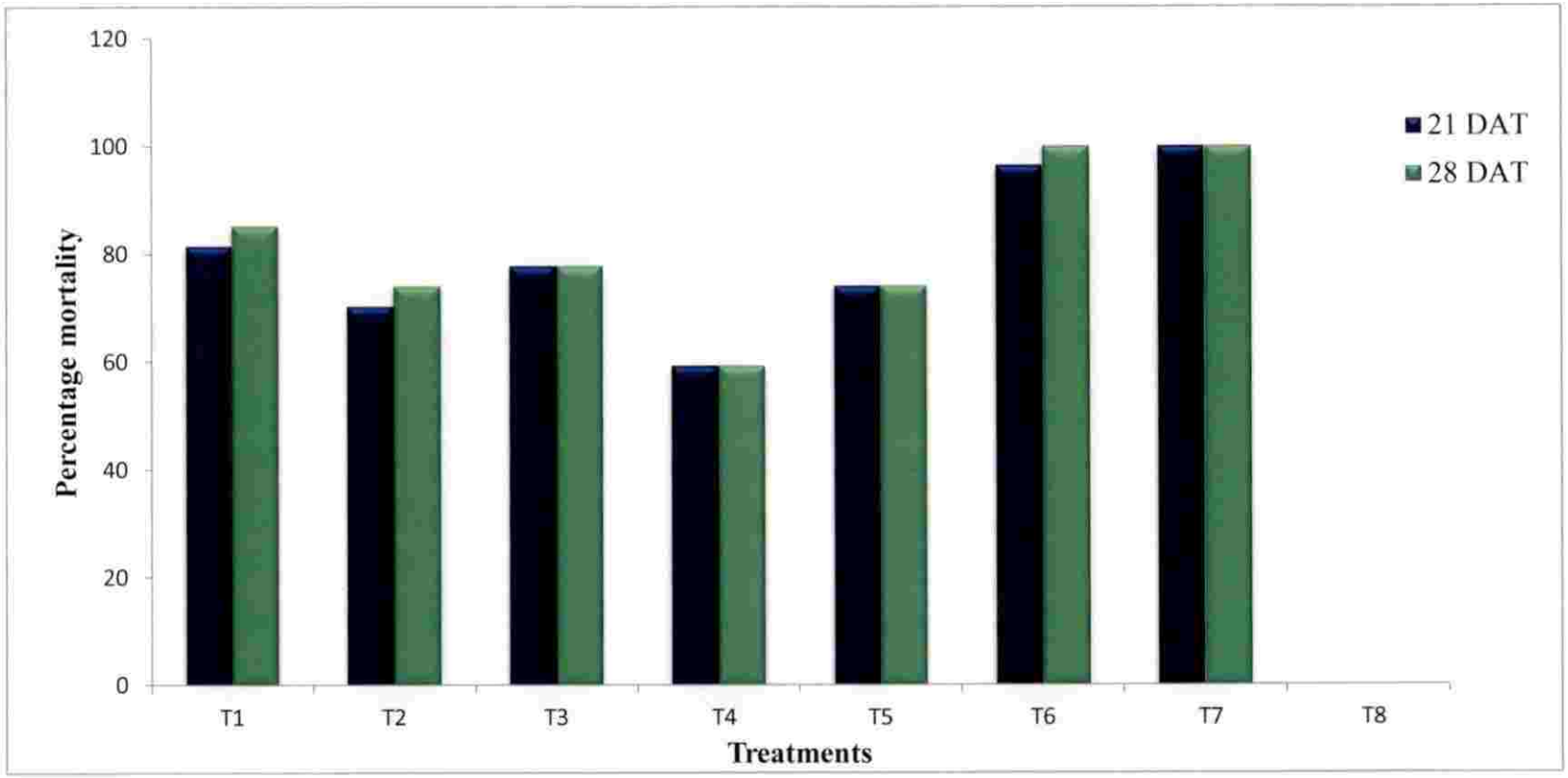


Figure 3. Percentage mortality of first instar grubs of *Leuopholis coneophora* in pot culture experiment

T1: *M. anisopliae* 1 x 10^{10} spores mL^{-1}
T2: *M. anisopliae* 1 x 10^{9} spores mL^{-1}
T3: *B. bassiana* 1 x 10^{10} spores mL^{-1}
T4: *B. bassiana* 1 x 10^{9} spores mL^{-1}
T5: Chlorantraniliprole 0.4% G – 75 g a.i. ha^{-1}
T6: Fipronil 0.3% G – 75 g a.i. ha^{-1}
T7: Chlorpyriphos 20% EC – 225 g a.i. ha^{-1}
T8: Untreated Control

Summary

6. SUMMARY

Coconut is known for its versatility of uses, extending from nourishment to cosmetics with high financial esteem. In spite of the fact that mango is the King of fruits in India, coconut is taken into account as a logo of prosperity, a favouring of nature, a propitious entity of ceremony, a valuable thing of craftsmanship and an integral component for cooking. Coconut farming could be an incredible implies of sustenance for a majority of rural populace over the backwaters of Kerala. Pest management is confronting economic and ecological challenge around the world due to human and environmental hazards caused by larger part of the manufactured pesticide chemicals. Root grub, *Leucopholis coneophora* is a subterranean pest of coconut and its intercrops grown in sandy loam soils and prevalent in coastal belts of peninsular India. Application of a chemical in the soil for managing root grubs may impose a serious negative impact on the environment and lead to the destruction of biodiversity. Botanicals and biocontrol agents have long been touted as alluring choices to synthetic chemical pesticides for pest management since they reputedly pose little threat to the environment or to human health. In this background, the present study, "Ecological management of coconut root grub, *Leucopholis coneophora* Burm." was undertaken to study the efficacy of botanical insecticides and biocontrol agents against coconut root grub *L. coneophora*.

The study was conducted at the Department of Agricultural Entomology, College of Agriculture, Vellayani, and College of Agriculture, Padannakkad during 2017 to 2019. The entire study consisted of two parts, laboratory evaluation and pot culture experiment.

The laboratory experiment was conducted for screening various entomopathogenic fungi (EPF), entomopathogenic nematodes (EPN), botanicals and chemical insecticides against coconut root grub. *Metarhizium anisopliae* (Ma 4) and *Beauveria bassiana* (Bb 5) at different concentrations (1×10^8, 1×10^9 and 1×10^{10} spores mL^{-1}) were tested. Entomopathogenic nematodes

Steinernema carpocasae and *Heterorhabditis bacteriophora* at 100, 500 and 1000 IJ mL^{-1} were used for screening. The botanicals such as *Azadirachta indica, Gliricidia maculata, Clerodendron infortunatum* and *Chromolaena odorata* @ 25 g kg^{-1} of soil were screened for their efficacy against root grub. The chemicals used for the experiment comprised of chlorantraniliprole 0.4% G @ 75 g a.i. ha^{-1}, fipronil 0.3% G @ 75 g a.i. ha^{-1} and spinosad 45% SC @ 73 g a.i. ha^{-1}. chlorpyriphos 25 % EC @ 225 g a.i. ha^{-1} was used as a chemical check along with untreated control. Fifteen kilograms of sterilized moist soil was taken in a plastic basin and fresh potato tubers were given as feed for root grub. Three first instar grubs were released into the basin and treatments were given one week after the release of grubs.

The screening experiment using EPF showed that application of *M. anisopliae* @ 1 x 10^{10} spores mL^{-1} was found to be the most effective (100 % mortality) EPF against root grub and was on par with chemical check @ 14 days after treatment (DAT), followed by *M. anisopliae* @ 1 x 10^{9} spores mL^{-1} (77.77 %), *B.* bassiana @ 1 x 10^{10} spores mL^{-1} (81.47 %) and *B. bassiana* @ 1 x 10^{9} spores mL^{-1} (70.36 %). *B. bassiana* @ 1 x 10^{10} spores mL^{-1}, *M. anisopliae* @ 1 x 10^{10} spores mL^{-1} and chemical check chlorpyriphos 20 % EC @ 225g a.i ha^{-1} resulted in 100 per cent mortality and were found to be on par both at 21 and 28 DAT. *M. anisopliae* @ 1 x 10^{9} spores mL^{-1} (81.47 %) and *B. bassiana* @ 1 x 10^{9} spores mL^{-1} (81.47 %) were statistically on par at 21 DAT. The next best result was exhibited by *M. anisopliae* @ 1 x 10^{9} spores mL^{-1} (92.58 %) and *B. bassiana* @ 1 x 10^{9} spores mL^{-1} (85.17 %) at 28 DAT. No mortality was observed in third instar grubs treated with the EPF, *M. anisopliae* and *B. bassiana* at all tested concentrations (1 x 10^{8} spores mL^{-1}, 1 x 10^{9} spores mL^{-1} and 1 x 10^{10} spores mL^{-1}).

The screening experiment with EPN consisted of eight treatments with three replications and the results revealed that all the treatments failed to cause infection on grubs up to 10 DAT.

Among the botanicals, application of *A. indica* @ 25 g kg^{-1} of soil resulted in 48.14 per cent mortality of first instar grubs followed by *C. infortunatum* @ 25 g kg^{-1} of soil (37.03 %). On third instar grubs, *A. indica* and *C. infortunatum* @ 25 g kg^{-1} of soil recorded significantly different mortality of 33.33 and 14.81 per cent respectively at 30 DAT. The treatments, *G. maculata* @ 25 g kg^{-1} of soil and *C. ododrata* @ 25 g kg^{-1} of soil resulted no mortality of both first and third instar grubs.

The effect of chemical insecticides on root grub was analyzed in five treatments and four replications. The treatment chlorpyriphos 20 % EC @ 225 g a.i. ha^{-1} recorded absolute mortality followed by fipronil 0.3 % G @ 75 g a.i. ha^{-1}, chlorantraniliprole 0.4 % G @ 75 g a.i. ha^{-1} and spinosad 45 % SC @ 73g a.i. ha^{-1} and was significantly different from untreated control at 7 and 8 DAT. At 9 and 10 DAT, fipronil 0.3 % G @ 75 g a.i. ha^{-1} exhibited superiority over all other treatments followed by chlorantraniliprole 0.4% G @ 75 g a.i. ha^{-1} and spinosad 45 % SC @ 73g a.i. ha^{-1}. A similar trend in mortality of third instar grubs were observed from 6^{th} to 10^{th} DAT. Chlorpyriphos 20 % EC @ 225 g a.i. ha^{-1} recorded absolute mortality, followed by fipronil 0.3 % G @ 75 g a.i. ha^{-1} and were significant. The treatments chlorantraniliprole 0.4 % G @ 75 g a.i. ha^{-1} and spinosad 45 % SC @ 73 g a.i. ha^{-1} were statistically on par.

Promising treatments *viz. M. anisopliae* (1 x 10^{10} spores mL^{-1}, 1 x 10^{9} spores mL^{-1}), *B. bassiana* (1 x 10^{10} spores mL^{-1}, 1 x 10^{9} spores mL^{-1}), chlorantraniliprole 0.4% G @ 75 g a.i. ha^{-1}, and fipronil 0.3% G @ 75 g a.i. ha^{-1} from laboratory experiments were selected and evaluated in a pot culture experiment and were laid out in CRD with eight treatments and three replications. Chlorpyriphos 25 % EC @ 225 g a.i. ha^{-1} was used as a chemical check along with untreated control. Fodder grass variety CO-3 was raised in pots and first instar grubs were released after the establishment of the crop. The results of the pot culture experiment indicated that the application of fipronil 0.3% G @ 75 g a.i. ha^{-1} resulted in 100 per cent mortality and was on par with the chemical check at 28 DAT followed by *M. anisopliae* @ 1 x 10^{10} spores mL^{-1} (85.17 %). The

treatments *B. bassiana* @ 1 x 10^{10} spores mL^{-1} (77.77 %), chlorantraniliprole 0.4 % G @ 75 g a.i. ha^{-1} (74.06 %) and *M. anisopliae* @ 1 x 10^{9} spores mL^{-1} (74.06 %) were found to be on par at 28 DAT.

From the present study, it can be concluded that the application of entomopathogenic fungi *M. anisopliae* (Ma 4) @ 1 x 10^{10} spores mL^{-1} is a promising option for the management of first instar grubs of *L. coneophora* followed by *B. bassiana* (Bb 5) @ 1 x 10^{10} spores mL^{-1}. Soil application of neem leaves @ 25 g kg^{-1} of soil can enhance the suppression of root grubs. The results clearly indicate the possibility of reducing the use of chemical insecticides by resorting to botanicals and biocontrol agents.

Future line of work:

- Efficacy of *M. anisopliae* @ 1 x 10^{10} spores mL^{-1}, *B. bassiana* @ 1 x 10^{10} spores mL^{-1}, *M. anisopliae* @ 1 x 10^{9} spores mL^{-1} , chlorantraniliprole 0.4 % G @ 75 g a.i. ha^{-1} and fipronil 0.3% G @ 75 g a.i. ha^{-1} revealed in pot culture experiment may be validated under field conditions.
- Feasibility of combined application of entomopathogenic fungi, botanicals and chemical insecticides may be tested.
- Residue analysis of chemical insecticides which were promising in field trials.

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Abstract

ECOLOGICAL MANAGEMENT OF COCONUT ROOT GRUB, *Leucopholis coneophora* Burm.

by

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Abstract of the thesis

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ABSTRACT

The study entitled 'Ecological management of coconut root grub, *Leucopholis coneophora* Burm.' was conducted at the Department of Agricultural Entomology, College of Agriculture, Vellayani, and College of Agriculture, Padannakkad during 2017 to 2019. The main objectives were to study the efficacy of botanical insecticides and biocontrol agents against coconut root grub, *L. coneophora*. The entire study consisted of two parts, laboratory evaluation and pot culture experiment.

The laboratory experiment was conducted for screening various entomopathogenic fungi (EPF), entomopathogenic nematodes (EPN), botanicals and chemical insecticides against coconut root grub. *Metarhizium anisopliae* (Ma 4) and *Beauveria bassiana* (Bb 5) at different concentrations (1 x 10^8, 1 x 10^9 and 1 x 10^{10} spores mL^{-1}) were tested. Entomopathogenic nematodes *Steinernema carpocasae* and *Heterorhabditis bacteriophora* at 100, 500 and 1000 IJ mL^{-1} were used for screening. The botanicals such as *Azadirachta indica, Gliricidia maculata, Clerodendron infortunatum* and *Chromolaena odorata* @ 25 g kg^{-1} of soil were screened for their efficacy against root grub. The chemicals used for the experiment comprised of chlorantraniliprole 0.4% G @ 75g a.i ha^{-1}, fipronil 0.3% G @ 75g a.i ha^{-1} and spinosad 45% SC @ 73g a.i ha^{-1}. Chlorpyriphos 25 % EC @ 225 g a.i ha^{-1} was used as a chemical check along with untreated control. Fifteen kilograms of sterilized moist soil was taken in a plastic basin and fresh potato tubers were given as feed for root grub. Three grubs were released into the basin and treatments were given one week after the release of grubs.

The screening experiment using EPF consisted of eight treatments with three replications. The application of *M. anisopliae* @ 1 x 10^{10} spores mL^{-1} was found to be the most effective (100 % mortality) EPF against root grub and was on par with chemical check at 14 days after treatment (DAT). At 21 DAT, *B. bassiana* @ 1 x 10^{10} spores mL^{-1} resulted 100 per cent mortality and was on par

with *M. anisopliae* @ 1 x 10^{10} spores mL^{-1} and the chemical check. At 28 DAT, *M. anisopliae* @ 1 x 10^{10} spores mL^{-1} and *B. bassiana* @ 1 x 10^{10} spores mL^{-1} brought about 100 per cent mortality of grubs, which were on par with the chemical check chlorpyriphos 20 % EC @ 225g a.i ha^{-1} (100 %), followed by *M. anisopliae* @ 1 x 10^{9} spores mL^{-1} (92.58 %) and *B. bassiana* @ 1 x 10^{9} spores mL^{-1} (85.17 %). The screening experiment with EPN consisted of eight treatments with three replications and the results revealed that all the treatments except chemical check failed to cause infection on grubs upto 10 DAT. Among the botanicals, *A. indica* application showed 48.14 per cent mortality of root grubs followed by *C. infortunatum* (37.03 %) at 30 DAT. The effect of chemical insecticides on root grub was conducted with five treatments and four replications. Fipronil 0.3% G @ 75g a.i ha^{-1} exhibited 97.22 per cent mortality and was on par with the chemical check at nine DAT followed by chlorantraniliprole 0.4% G @ 75g a.i ha^{-1} (74.99 %).

Promising treatments *viz. M. anisopliae* (1 x 10^{10} spores mL^{-1}, 1 x 10^{9} spores mL^{-1}), *B. bassiana* (1 x 10^{10} spores mL^{-1}, 1 x 10^{9} spores mL^{-1}), chlorantraniliprole 0.4% G @ 75g a.i ha^{-1}, and Fipronil 0.3% G @ 75g a.i ha^{-1} from laboratory experiments were selected and evaluated in a pot culture experiment and were laid out in CRD with eight treatments and three replications. Chlorpyriphos 25 % EC @ 225 g a.i ha^{-1} was used as a chemical check along with untreated control. Fodder grass variety CO-3 was raised in pots and first instar grubs were released after the establishment of the crop. The results of the pot culture experiment indicated that the application of fipronil 0.3% G @ 75g a.i ha^{-1} resulted in 100 per cent mortality and was on par with the chemical check at 28 DAT followed by *M. anisopliae* @ 1 x 10^{10} spores mL^{-1} (85.17 %). The treatments *B. bassiana* @ 1 x 10^{10} spores mL^{-1} (77.77 %), chlorantraniliprole 0.4 % G @ 75g a.i ha^{-1} (74.06 %) and *M. anisopliae* @ 1 x 10^{9} spores mL^{-1} (74.06 %) were found to be on par at 28 DAT.

From the present study, it can be concluded that the application of entomopathogenic fungi *M. anisopliae* @ 1 x 10^{10} spores mL^{-1} is a promising

option for the management of first instar grubs of *L. coneophora* followed by *B. bassiana* @ 1 x 10^{10} spores mL^{-1}. Soil application of neem leaves @ 25 g kg^{-1} of soil can enhance the suppression of root grubs. The results clearly indicate the possibility of reducing the use of chemical insecticides by resorting to botanicals and biocontrol agents.