MANAGEMENT OF BANANA PSEUDOSTEM WEEVIL, *Odoiporus longicollis* (Olivier), USING SAFE CHEMICALS AND BIO-RATIONAL METHODS

by

SIVAKUMAR,T.

(2012-21-111)

THESIS

Submitted in partial fulfillment of the

requirement for the degree of

DOCTOR OF PHILOSOPHY IN AGRICULTURE

Faculty of Agriculture

Kerala Agricultural University

DEPARTMENT OF AGRICULTURAL ENTOMOLOGY

COLLEGE OF AGRICULTURE

VELLAYANI, THIRUVANANTHAPURAM-695522

KERALA, INDIA

2017

DECLARATION

I, hereby declare that this thesis entitled **"Management of banana pseudostem weevil, *Odoiporus longicollis* (Olivier), using safe chemicals and bio-rational methods"** 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 of any degree, diploma, fellowship or other similar title, of any other University or Society.

Vellayani,

Date: 21.01.2017

Sivakumar.T.

(2012 - 21-111)

CERTIFICATE

Certified that this thesis entitled **"Management of banana pseudostem weevil, *Odoiporus longicollis* (Olivier), using safe chemicals and bio-rational methods"** is a record of research work done independently by **Mr. Sivakumar,T. (2012-21-111)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

Vellayani,
Date: 21.01.2017

Dr. Jiji T.
(Chairman, Advisory Committee)
Professor
Department of Agricultural Entomology
College of Agriculture, Vellayani

CERTIFICATE

We, the undersigned members of the advisory committee of Mr. Sivakumar,T., (2012-21-111) a candidate for the **Doctorate degree in Agriculture** with major in Agricultural Entomology, agree that the thesis entitled **"MANAGEMENT OF BANANA PSEUDOSTEM WEEVIL, *Odoiporus longicollis* (OLIVIER), USING SAFE CHEMICALS AND BIO-RATIONAL METHODS"** may be submitted by Mr. Sivakumar,T., in partial fulfillment of the requirement for the degree.

Dr. Jiji T.
(Chairman, Advisory Committee)
Professor
Department of Agricultural Entomology
College of Agriculture, Vellayani

Dr. K. Sudharma
(Member, Advisory Committee)
Professor and Head
Department of Agricultural Entomology
College of Agriculture, Vellayani

Dr. Anitha N.
(Member, Advisory Committee)
Professor
Department of Agricultural Entomology
College of Agriculture, Vellayani

Dr. Thomas George
(Member, Advisory Committee)
Professor
Department of Soil Science and Agrl. Chemistry
College of Agriculture, Vellayani

Dr.A. Naseema
(Member, Advisory Committee)
Professor (Rtd.)
Department of Plant Pathology
College of Agriculture, Vellayani

(Dr. G. Pillai)
EXTERNAL EXAMINER

ACKNOWLEDGEMENT

I take this opportunity to recognise the unswerving and unceasing guidance and supervision of **Dr.Jiji.T.**, *Professor, Department of Agricultural Entomology, College of Agriculture, Vellayani, with which the thesis work has been materialized.*

I express my deep sense of gratitude to **Dr.Anitha.N.**, *Professor, Department of Agricultural Entomology, College of Agriculture, Vellayani, for her valuable support and guidance in every part of this programme*

I pay my heartfelt thanks to **Dr.A.Naseema**, *Professor (Rtd.), Department of Plant Pathology, College of Agriculture, Vellayani, for providing me laboratory facilities and suggestions during the study.*

I wish to thank **Dr. Thomas George**, *Professor, Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani, for his active support and timely advice in this study especially in conducting residue studies.*

I would like to extend my sincere thanks to **Dr.K.Sudharma**, *Professor and Head, Department of Agricultural Entomology, College of Agriculture, Vellayani, for her invaluable suggestions and guidance.*

I take this opportunity to express my gratitude to ICAR and CPCRI for granting study leave to pursue this PhD programme. I would like to thank **Dr. George V Thomas**, *former Director, ICAR-CPCRI and* **Dr. P. Chowdappa**, *Director, ICAR-CPCRI for their support and permission for the study. I also extend my sincere thanks to* **Dr. P.M Jacob**, **Dr. C.P.R.Nair** *(former Heads ICAR-CPCRI, Kayamkulam) and* **Dr. V.Krishnakumar** *(Head, ICAR-CPCRI, Kayamkulam) for their enduring support during my research studies. Great support offered from* **Dr. P.Muralidharan** *(Head, ICAR-KVK-Alappuzha) is also acknowledged.*

My sincere thanks also goes to **Dr. Arthor Jacob** *and* **Dr. Babu Mathew** *(Professor and Head, Instructional Farm, Vellayani) for their support and help for conducting field experiment.*

I also thank for the support and kindness shown by **Dr. Sheela, M.S.** *(Rtd. Professor and Head, Department of Agricultural Entomology, College of Agriculture, Vellayani) starting from the formulation of the programme. The support offered by the present and former Deans of College of Agriculture during this period is acknowledged. The facilities and research funds offered by the Kerala Agricultural University for the study is also acknowledged.*

It is my pleasure to mention with thanks the support and suggestions of **Dr.Gokulapalan, C** *(Rtd. Professor and Head, Department of Plant Pathology,*

College of Agriculture, Vellayani.), Dr.K.Umamaheswaran (Professor, Department of Plant Pathology, College of Agriculture, Vellayani.), Dr.Vijayaraghavakumar (Professor, Department of Agricultural Statistics), Dr.Anith.K.N (Assoc. Professor, Department of Microbiology, College of Agriculture, Vellayani) Dr.Naseema Beevi (Rtd.Professor, Department of Agricultural Entomology, College of Agriculture, Vellayani), Dr.Thomas Biju Mathew (Professor, Department of Agricultural Entomology, College of Agriculture, Vellayani) Dr.N.Kishorekumar (Professor, Department of Agricultural Extension, College of Agriculture, Vellayani), Dr.K.D.Prathapan (Associate Professor, Department of Agricultural Entomology, College of Agriculture, Vellayani) Dr.Dhalin (Asst. Professor, Department of Agricultural Engineering, College of Agriculture, Vellayani) Dr.M.H.Faizal (Professor, Department of Agricultural Entomology, College of Agriculture, Vellayani) and Dr.Susha.S.Thara (Asst. Professor, Department of Plant Pathology, College of Agriculture, Vellayani), during the study period and beyond.

The collection of relevant literature was a great task and it could be achieved by the immense help and support of my friends and good people at various institutes, both national and international. I would like to express my sincere thanks to my former classmate, Dr.Nisha Rakesh (Research Development Advisor, Western Sydney University) and Dr. Rakesh. D (Research Associate, University of Technology, Sydney) for their continued support throughout the study.

I also like to thank Dr.Koppenhoer, A.M., Mrs. Donna Leech (Information Consultant, Department of Agriculture & Fisheries, Queensland Govt., Australia), Mr.R.K.Lohiya (Library Officer, NEERI, Nagpur) and Ms. Lenisha Leni (PG student, IARI) for their help rendered in finding some of the original papers.

I also acknowledge timely help from all the scientific, technical and administrative staff of ICAR-CPCRI during the study, especially Dr.P.Rajan, Dr.Chandrika Mohan, Dr.P.Anithakumari, Mr.G.V.Nair, Mr.Tajudheen, Dr. C.Kesavan Namboodiri, Mr. John George and Mr. Janardhanan.T.E.

Sincere and heartfelt thanks are extended to all the staff at Pesticide Residue Research and Analytical Laboratory (PPRAL), College of Agriculture, Vellayani especially Dr. Ambily Paul, Mr. Vishal, Mr. Pratheesh, Mrs. Neethu, Mrs. Mithra and Mrs. Prathibha for their help and support during the residue studies.

I sincerely acknowledge the support given by Mr. Sajeev (Farm Officer, College of Agriculture, Vellayani) and the laborers especially, Mr.Preman, Vellayani and Mr.Suresh, Konny who worked hard during the field experiment.

I would like to extend my sincere thanks to Dr. Augustus Morris (Asst. Surgeon), Mr. Bobin.B.M, Mr. Arun Murali, Mr. Joseph, Mr. Shaiju for their invaluable help rendered during different stages of the thesis preparation and research work.

The support and cooperation shown by my ICAR-KVK-Alappuzha team members, Mr.Rajeev.M.S., Dr.Ravi.S., Dr. K. Sajnanath, Mrs. Lekha.G., Mrs. Jissy George, Mr. Ansary.K.M. Mrs. Jainamma Job, Mrs. Prema Pillai and Mrs. Rejitha, K.R is greatly acknowledged.

My new colleagues supported me during the course work as well as research work. I am extremely thankful to Mrs. Asha B Nair, Mrs. Shajma, Mrs. Radhika. N.S. for their sincere help rendered during different experiments. I extend my thanks to Dr. Saravanan, Dr. Malini Nilamudheen, Mr. Lokesh, Mr. Hemanth, Mr.Shivamoorthy, Ms. Aswathy, Ms. Arya.V.C. and Dr.Deepa Rani for their co-operation during the entire PhD programme. The support given by Mr.Krishnaraj and Ms. Subina for laboratory experiments is thankfully acknowledged. I thankfully acknowledge the help rendered by Mr. Santhosh V.S and Mrs. Aswathy during this study.

The support and co-operation from the State Department of Agriculture is greatly acknowledged. I am thankful to Mr. Harikumar (Agrl. Officer), Mrs. A.R.Renjini (VFPCK), Mrs. Maya Santhan (VFPCK), Mrs. Saritha V Nair (VFPCK), Mrs. Shyla Pillai (DM.VFPCK, Pathanamthitta), Mr. Arunkumar (DM, VFPCK, Kollam), Mrs. Reena Ravindran (Agrl. Officer), Mr. Sunil.K (Agrl. Officer), Mrs. Deepa.S. (Agrl. Officer), Mr. Santhoshkumar S.R (Agrl. Officer) and all the officers, staff and farmers who cooperated with me to fulfill this research programme.

I thank my relatives and family members especially my mother Mrs. Rajamma.P., wife Mrs.Prathibha R. and son Mas.Gowrinandan.S., who wholeheartedly supported and encouraged to pursue the study without any hindrance.

Last but not least, I bow my head to Lord Vighneswara with whose blessings this work is materialized.

Sivakumar. T.

Dedicated to

My...

beloved

Father

Family

Farmer Friends

&

Friends of Farmers

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

Abbreviations/Symbols used in this thesis

Abbreviation/ Symbol	*Expansion*
@	at the rate of
AINP	All India Network Project
BC ratio/ BC	Benefit cost
cfu	Colony forming units
cm	Centimeter
COA	College of Agriculture, Vellayani
CPCRI	Central Plantation Crops Research Institute
CRD	Completely randomised design
CTCRI	Central Tuber Crops Research Institute
DAI	Days after inoculation
DAT	Days after treatment
EAG	Electro antenogram
EC	Emulsifiable concentrate
et al.	et alii (Latin) and others
FAO	Food and Agricultural Organisation
FIB	Farm information bureau
FSSAI	Food safety and standards authority of India
g	Gram
G	Granule
GC	Gas chromatography
ha	Hectare
HAT	Hours after treatment
HDPE	High density polyethylene
HPLC	High performance liquid chromatography
ICAR	Indian Council of Agricultural Research
IIHR	Indian Institute of Horticultural Research
IJ	Infective juveniles
IRAC	Insecticide resistance action committee
ITCC	Indian type culture collection
KAU	Kerala Agricultural University

KB	Krishi Bhavan
kg	Kilogram
L/l	Litre
LAF	Leaf axil filling
LC/MS/MS	Liquid Chromatography/Mass Spectrometry/Mass Spectrometry
LOD	Limit of detection
Log	Logarithm
LOQ	Limit of quantification
MAP	Months after planting
ml	Millilitre
mm	Millimetre
MRL	Maximum residue limit
MRM	Multiple reaction monitoring
MS	Mass spectroscopy
NHB	National Horticultural Board
NRCB	National Research Centre for Banana
NSKE	Neem seed kernel extract
PDA	Potato dextrose agar
ppm	Parts per million
QuEChERS	Quick Easy Cheap Effective Rugged Safe
RBD	Randomised block design
Rs.	Rupees
RSD	Relative standard deviation
SP	Soluble powder
t	ton
UPLC	Ultra performance liquid chromatography
VFPCK	Vegetable & Fruit Promotion Council, Keralam
WDP	Wettable dispersible powder
WG	Wettable granule

Introduction

1. INTRODUCTION

Banana, *Musa* sp., occupies an important position among the tropical fruits, the centre of origin of which is considered to be South East Asian and Western Pacific regions (Robinson and Sauco, 2010). This crop has achieved great importance as cash or subsistence crop in many parts of the World. Among the banana producing countries in the World, India ranks first in production followed by China and Philippines. Ecuador, Philippines, Guatemala, Costa Rica and Colombia are the top five dessert banana exporting countries. USA, European Union, Russia, Japan and Canada are the major importers of dessert banana (FAOSTAT, 2014). In India, banana is cultivated in an area of 802570 ha with a production of 29724550 t (NHB, 2015).

Tamil Nadu, Maharashtra, Gujarat, Andhra Pradesh and Karnataka are the major banana producing states. In Kerala, banana and plantains are cultivated in an area of 59069 and 48747 ha with a production of 514045 and 330634 t, respectively (FIB, 2014). Their total area constitutes 34.65 per cent of the area under fresh fruits in the state. According to banana production statistics, Kerala has very low productivity (15.33 t ha^{-1}) when compared to neighbouring states like Tamil Nadu (47.87 t ha^{-1}) and Karnataka (26.05 t ha^{-1}) (NHB, 2015). Banana is often infested with a variety of pests and diseases, for which timely plant protection measures has to be taken failing which crop damage and economic loss occurs, which is one of the main impediments in achieving high productivity. Banana is being cultivated both as monocrop and intercrop in the state. Monocropping is common in garden as well as reclaimed wet lands; whereas intercrop is practiced in coconut gardens and homesteads, with multiplicity of varieties.

Almost all parts of the banana plant are useful. Leaves are used to serve food as 'eco-friendly disposable plates' which drastically reduce environmental pollution. The whole plant with bunches are being used for biological arches

during auspicious functions. Fiber extracted from harvested stem is used to make bags, mats and clothes. Various preparations using pseudostem and peduncle are consumed to prevent stomach related disorders. Extracts from bracts of 'Nendran' can be used as a corrosion inhibitor on mild steel (Gunavathy and Murugavel, 2014). Leaves and stem are commonly used to feed cattle and poultry. Bananas are rich in many essential nutrients required for human body, especially potassium.

The banana growers are in a state of predicament as the crop succumbs to a plethora of pests attacking the rhizome to pipe leaf. Among the 470 species of insect and mites, recorded globally in banana as major and minor pests, 250 feed on foliage, 70 feed on roots and rhizomes, 130 feed on fruits and flowers and ten are pseudostem borers (Ostmark, 1974). Padmanaban and Sathiamoorthy (2001) observed that banana pseudostem weevil, *O. longicollis* alone can cause heavy crop loss up to 90%, depending on the growth stage and management efficiency. According to Gold *et al.* (2002) banana pseudostem weevil (*O. longicollis* [Olivier]) and rhizome weevil (*Cosmopolitus sordidus* [Germar]) are the major weevil pests.

Pseudostem weevil on banana has been reported from Delhi (Batra, 1952), Kathmandu Valley (Singh, 1966), Uttar Pradesh (Shukla and Kumar, 1969), Bihar (Tiwary, 1971) West Bengal (Dutt and Maiti, 1972), Assam (Isahaque, 1978), Kerala (Visalakshi *et al.*, 1989), Tamilnadu (Padmanaban and Sundararaju, 1999), Karnataka (Jayanthi and Verghese, 1999) and Jammu and Kashmir (Azam *et al.*, 2010).

Female weevil lays eggs inside the air chamber of the outer sheath of pseudostem. The emerging grubs are yellowish white and apodous (Padmanaban and Sathiamoorthy, 2001). Grubs feed on leaf sheath and may reach up to peduncle (Padmanaban *et al.*, 2001b). Grubs pupate inside the pseudostem in a cocoon weaved from banana fiber. Total development period may vary from 40 to 90 days (Anitha, 2000 and Thippaiah *et al.*, 2011).

20

Volatile market price and escalating input costs warrant farmers to take pest control methods against pseudostem weevil menace. Banana growers resort to insecticide application, sometimes not even the chemical or recommended dose, immediately after they notice the infestation. Early detection of the pest becomes very difficult because of its secluded habitat. Detection at later stages is futile, as curative measures at this stage of infestation fail, as the plant already might have reached the irreparable stage. Farmers notice infestation when brown jelly exudates come out of wound holes made by the grub.

Various control measures including botanicals (Anitha, 2000; Sivasubramaniyam *et al.*, 2009), biocontrol agents (Anitha, 2000; Beegum, 2005) and chemicals (Visalakshi *et al.*, 1989; Reghunath *et al.*, 1992; Anitha, 2000) are recommended against *O. longicollis*. Carbofuran granular formulation and carbaryl WDP were the two insecticides (carbamates) commonly used against *O. longicollis* by the farmers in Kerala. As per the Kerala Government Order no. 116/2011/Agri. Dated 7th May 2001, use of carbofuran has been discontinued in the state. Chlorpyrifos is one of the commonly used and recommended insecticides against *O. longicollis* in banana. But its harmful effects on humans as well as environment have been reported (Alavanja *et al.*, 2003; Lee *et al.*, 2004). More over the availability of carbaryl is drastically reduced. This situation force farmers to use different insecticides that are neither recommended for the crop nor proved effective against *O. longicollis*. Many such chemicals are suspected to cause environmental pollution as well as serious health problems. It is high time to solve the pest problem with new, effective as well as environmentally safe, user friendly and economically feasible pest management methods.

In this context, a detailed study on pseudostem weevil/borer management using safe chemicals, botanicals and bio-agents in banana var. Nendran was undertaken with the following objectives:

- documenting the pest status and farmers' practices for controlling banana pseudostem weevil
- evaluating the efficacy of new generation insecticides, botanicals and bio-agents on *O. longicollis in vitro*
- testing the effect of chemicals on entomopathogenic fungus
- evaluating different application methods under field condition
- evaluation of prophylactic and curative methods of pest control in the field
- estimating harvest time residues in various edible parts of the banana plant.

Review of Literature

2. REVIEW OF LITERATURE

Banana production is threatened by a large number of pests and diseases, including the sigatoka leaf spot disease, bunchy top disease, *Fusarium* wilt, *Xanthomonas* wilt, nematodes, weevils and borers and many more with regional significance (Uma, 2007). In Kerala, *Odoiporus longicollis* (Olivier) emerged as a major pest of banana especially that of 'Nendran', from 1980s onwards.

This weevil pest has the potential of causing complete crop failure in farms where efficient pest management is not adopted (Padmanaban and Sathiamoorthy, 2001). The pest's distribution, bioecology and different management practices are reviewed in detail. Pesticide residue and its estimation in banana are also reviewed here.

2.1 TAXONOMIC POSITION

O. longicollis was first described by Olivier (1807) as *Calandra longicollis*. Later, Chevrolat (1885) placed it in the genus, *Odoiporus*. He put *Sphenophorus planipennis, S. glabricollis, S. castaneus* and *S. politus* as synonym to *O. longicollis*. Marshall (1930) recorded *Sphenophorus glabridiscus* Walk. as synonym to *O. longicollis.* Taxonomic position of *O. longicollis* is given below:

Kingdom	Animalia
Phylum	Arthropoda
Class	Insecta
Order	Coleoptera
Family	Dryophthoridae
Genus	*Odoiporus*

2.2 DISTRIBUTION

Many pests have their centre of origin, same as of that their host plants. *O. longicollis* is also considered to be originated in the same place of origin of banana, Indo-Malayan region, but it has spread to almost all banana growing parts in Asia. Contradictory to the wide spread occurrence of the other pest, *Cosmopolites sordidus*, literature on *O. longicollis* reveal that it did not attain a major pest status either in Africa or in Latin America and was restricted mainly to South East Asia (Ploetz *et al.,* 2015).

Chevrolat (1885) mentioned in his taxonomic paper that specimens of *O. longicollis* were recorded from India, far Eastern countries, Java, Andaman Islands, China and Ceylon (Sri Lanka). Hutson (1921) observed attack of *O. longicollis* in plantations maintained for more than two years without replanting in Ceylon. Pinto (1928) reported the occurrence of *O. longicollis* and *C. sordidus* in Ceylon and stated that *O. longicollis* occurred in North-East India, Burma and Ceylon. He extensively studied the life history, habits and control measures of *O. longicollis* and *C. sordidus.*

Froggatt (1928) observed *O. longicollis* (*Sphenophorus planipennis)* on all varieties of banana in Java. Field observations made by him indicated that the borers were much more active at altitudes above 1000 ft and more destructive during wet monsoon. Wide distribution of *O. longicollis* on bananas and plantains in Kwangtung Province, China was reported by Hoffmann (1933). He also noticed occurrence of the pest in Hainan Island and Hong Kong. A survey made in Mindanao and neighbouring islands of Philippines recorded infestation of *O. longicollis* in plantains at an altitude of 2600 ft (Uichanco, 1936). A detailed account of field observations on *O. longicollis* in Formosa, Taiwan was given by Kung (1955). He observed that summer season was unfavourable for its

development. Singh (1966) reported the occurrence of *O. longicollis* in Kathmandu, Nepal. He collected weevils during pre-monsoon period.

Luo *et al.* (1985) recorded *O. longicollis* on banana in Guizhou, China. Guang *et al.* (2009) observed that among the 21 insect pests of banana in Hainan Province, China, *O. longicollis* and *C. sordidus* were the major pests.

Waterhouse (1993) grouped insect and weeds of major crops in South East Asia. According to him *O. longicollis* was present in Thailand, Vietnam, Cambodia, Malaysia, Mynanmar and Indonesian with varying intensity. He classified *O. longicollis* as very important and widely spread pest of banana in Vietnam.

Kojima and Kaga (2011) reported the emergence of *O. longicollis* as a serious pest of cultivated banana in Toterunoshima Island, Japan

Lefroy (1909) in his book, 'Indian Insect Life' mentioned *O. longicollis* as a common pest of plantain. Fletcher (1917) stated that *O. longicollis* was a serious pest of plantain in North-East India, Bihar (Pusa) and Burma. Damage to banana plants by *O. longicollis* in Assam was reported by McSwiney (1920) and Gupta (1927).

Shukla and Kumar (1970) collected *O. longicollis* from Campierganj, one of the biggest plantain growing centers in Eastern Utter Pradesh. Their survey revealed that every field was infested with the weevils. In Allahabad, *O. longicollis* was recorded from banana and found to add severity of the disease, *Erwinia* rot (Edward *et al.*, 1973).

Prasad and Singh (1987) during a survey in four districts of Manipur recorded *O. longicollis* as one of the major pests on banana. Ram and Pathak

(1987) conducted a survey during 1975-77 in hilly and valley areas of Manipur and identified the presence of *O. longicollis* in banana.

Jayanthi and Varghese (1999) recorded *O. longicollis* at Hessarghata, Karnataka with 100 per cent loss to cv. Nendran. Patel and Jagadale (2003) reported the incidence of *O. longicollis* for the first time in Gujarat, causing up to 54 per cent damage in var. Gandevi selection. *O. longicollis* was collected from banana in Samba district of Jammu and Kashmir by Tara *et al.* (2010). Reports from Punjab revealed that banana weevils, *C. sordidus* and *O. longicollis* were not identified as major threat to banana crop in that region (Sharma, 2010).

O. longicollis was mentioned as a major pest of banana in North Eastern Himalayas, especially, in Meghalaya (Thakur *et al.,* 2014). Of late, Khairmode *et al.* (2015) observed wide spread attack of *O. longicollis* in G-9 and Deshi varieties of banana in Kohlapur, Maharashtra. The highest incidence occurred during April-June and September-October.

In Kerala, the occurrence of *O. longicollis* was reported for the first the time from Vengola Panchayat of Ernakulam district during 1986 by Visalakhshi *et al.,* (1989). They reported the incidence of *O. longicollis* in Nendran and Red Kappa. Abraham and Thomas (1995) stated that the pest had assumed the status of a devastating pest of 'Nendran' and 'Palayankodan' varieties in Ernakulam district by 1988. The survey conducted by Anitha (2004) corroborated the severe incidence of *O. longicollis in* Southern districts of Kerala. She recorded the highest incidence of *O. longicollis* in Thiruvananthapuram district and among the varieties, Nendran was the most susceptible one, followed by Red Banana.

27

2.3 BIOECOLOGY

Understanding the biology of a pest will clearly define methods for successful pest management. Several authors studied the biology and ecological aspects of *O. longocollis* in detail.

In a laboratory study conducted at West Bengal, temperature range between 17 and 27 degree Celsius was found to be most suitable for normal adult activity of *O. longicollis*. Temperatures below and above this range were found to shorten the life span (Shukla and Tripathi, 1978). Significant positive correlation between mean number of adults and minimum temperature, morning relative humidity (RH), evening RH, average RH, rainfall as well as rainy days were observed in studies conducted in Gujarat (Tayade *et al*., 2014). Priyadarshini *et al*. (2014), Biswas *et al*. (2015) and Devi *et al*. (2015) observed that incidence of *O. longicollis* was positively correlated with minimum temperature and negatively correlated with maximum RH.

Some authors opined that the population of the weevil is low in winter (Singh, 1966; Isahaque, 1978; Devi *et al*., 2015).

Zhou and Wu (1986) in a study conducted in China observed that there were six overlapping generations in a year. They also observed that there were two population peaks in April-May and September-October. According to their findings, weevils preferred to lay eggs on taller stems. Visalakshi *et al*. (1989) observed that adult weevils preferred banana plants nearing to bunch with pseudostem of 25-50 cm circumference.

In an earlier attempt Singh (1966) measured the size of adult *O. longicollis* weevils and recorded their size as 1.3 to 2.0 cm. Adult weevils measure about 15-20 mm in length excluding rostrum (Shukla and Kumar, 1969). Vevai (1971)

observed the mean length of the weevils as 2.5 cm whereas Visalakshi *et al.* (1989) observed the same as 2.3 to 2.8 cm. Padmanaban *et al.* (2001a) measured the size of weevils and found that they had 16.0 mm length and 5.5 mm width with 5.0 mm rostrum.

Life cycle of the pest had been studied by many authors. The total life cycle from egg to adult depending on weather parameters and varieties ranged from 40 to 100 days (Pinto, 1928; Dutt and Maiti, 1972; Visalakshi *et al.*, 1989, Anitha and Nair, 2004; Thippaiah *et al.*, 2011).

In Srilanka, Pinto (1928) observed that a single female weevil laid up to 185 eggs during five month time. Studies in China by Lu *et al.*, (2002 a) revealed that fecundity of female weevils was higher in spring and autumn than summer and winter.

Padmanaban and Sathiamoorthy (2001) reported that a female weevil can lay nine eggs following a single mating @ one egg day^{-1}. According to the observations made by Anitha and Nair (2004), female weevil can lay 7 to 13 eggs depending upon the variety. Thippaiah *et al.* (2011) recorded a mean fecundity rate of 18.5±2.0 eggs female^{-1}.

An incubation period of 3-4 days had been reported by Pinto (1928). Later, an incubation period of three to five days was reported by Dutt and Maiti (1972) and three to eight days by Padmanaban and Sathiamoorthy (2001). Anitha and Nair (2004) observed slightly lesser average incubation period of 2.0 to 3.4 days on different varieties. Thippaiah *et al.* (2011) observed three to five days for incubation during January to August; whereas five to eight days in December-February. Grubs emerging from eggs will feed on the internal tissue of the leaf sheath and undergo five instars.

Larval period varied depending up on atmospheric temperature. Dutt and Maiti (1972) observed that larval period lasted for 26.2 days in summer and 68.1 days in winter. Anitha and Nair (2004) studied larval period on different banana cultivars and found that on 'Nendran', larval period lasted for 25.82 days. Thippaiah *et al.* (2011) observed that *O. longicollis* had a larval period of 33.10 days during June-August and 58.7 days during December-February.

Exarate pupa is found inside a cocoon made of fibrous materials. After pupal period, adult remains inside the cocoon for some day before coming out. Pinto (1928) observed a pupal period of seven to ten days only; whereas Anitha (2000) and Thippaiah *et al.* (2011) observed a longer pupal period of 12 to 21 days.

Adult weevils have different longevity depending on the weather. Fletcher (1917) observed that adult weevils live up to two years. Pinto (1928) could observe longevity up to five months. Visalakshi *et al.* (1989) recorded 90 to 120 days life span for adult weevils of *O. longicollis*. Anitha and Nair (2004) also had similar observation. They could observe adult weevils living to a maximum of 94.9 to 177.4 days depending on variety; maximum for female weevils in cv. Red Banana. Thippaiah *et al.* (2011) observed maximum adult longevity (90 days) during December to February than during June to August (60 days).

Studies conducted at Vellayani showed that Nendran and Poovan clones were more susceptible to *O. longicollis,* based on specific survival and natality. The net reproductive rate varied from 2.18 for Njalipoovan and 5.89 for Nendran (Anitha and Nair, 2004).

Tripathi and Chaturvedi (1978) observed cannibalistic behavior by adults of *O. longicollis* on larvae in the presence of food material. They observed that in the absence of natural diet, cannibalism increased. Jayanthi and Verghese (2000)

also had similar observations on cannibalism in *O. longicollis* grubs in laboratory. The rate of cannibalism varied from 12.5 to 47.2 per cent when food was given and from 33.3 to 83.3 per cent when grubs were starved.

Tripathi and Pallavi (2009) while studying *O. longicollis* in Jammu observed the existence of tetraploid (4x=52) and hexaploid (6x=78) parthenogenetic races. They also noted the diploid bisexual races having 2n=26 chromosomes.

Pallavi *et al.* (2015) based on their molecular work suggested a male biased gene flow between populations of *O. longicollis* because males are smaller than females which enable them for easy dispersal by flight.

2.4 COLOURMORPHS AND SEXUAL DIMORPHISM

Pinto (1928) observed variation between the two sexes of *O. longicollis* and recorded that males were smaller than females and dorsal surface of rostrum in males was roughened; while it was smooth, shiny and slightly longer in females.

Singh (1966) mentioned the existence of sexual dimorphism and suggested that black coloured smaller weevils were males and reddish brown adults having bigger body size were females. However, Dutt and Maiti (1971) conclusively proved that the colour difference was not due to sexual dimorphism but a phenomenon of non-sex limited variation and of sympatry. They stated that sexes can be separated by rostral characters. Presence of black and reddish-brown colourmorphs of *O. longicollis* was reported by a few authors (Lalitha and Ranjith, 2000 a; Azam *et al.*, 2010).

2.5 SYMPTOMS OF INFESTATION BY *O. longicollis*

The various life stages of *O. longicollis* are seen inside or on the pseudostem of banana. Any external manifestation of internal feeding and presence of adult weevils on the stem are the only ways to detect whether the plant is succumb to infestation.

Attacked plants are generally marked by circular holes along the sides of the stem and inside is usually riddled (Batra, 1952). In case of severe infestation, pseudostem becomes pale, foliage bends and becomes yellow (Shukla and Kumar, 1970). According to Padmanaban and Sathiamoorthy (2001), infestation starts at five month old plants. Early symptoms of attack will be presence of pin head holes resulting from oviposition which may be inconspicuous. Gummy exudation from these holes can be noticed. Later, feeding holes will be visible and infested plant show reduction in leaf size and yellowing of leaf lamina (Anitha and Nair, 2004). In advanced stages of infestation, extensive tunneling can be noticed inside the stem. Azam *et al.* (2010) observed that the holes on the pseudostem were occurring in a vertical line and equidistantly placed. In older plants they observed holes up to a height of six feet.

Padmanaban *et al.* (2001b) observed occurrence of *O. longicollis* inside the peduncle of banana bunch. They also found that weevils damaged the apical portion of the plant.

As a result of infestation, plants showed reduction in leaf size, bunch weight and finger size. Severely infested plants toppled down as they got weakened due to extensive tunneling by the grubs. The infestation by *O. longicollis* when not properly managed, it lead to 10 to 90 or even cent per cent yield loss depending on the growth stage of the crop and management efficacy

(Jayanthi and Verghese, 1999; Padmanaban and Sathiamoorthy, 2001; Anitha and Nair, 2004).

2.6 METHODS OF SCORING PEST INFESTATION

Several authors tried different pest scoring technique to categorise the different rate of infestation to compare varietal susceptibility and effectiveness of a treatment.

Charles *et al.* (1996) at Banana Research Station, Kannara developed a simple scoring method to assess the susceptibility of different banana cultivars to *O. longicollis*. They gave scores from zero to four based on the number of holes on the stem at the time of observation. In another attempt Mathew *et al.* (1997) grouped infested plants into no infestation, mild, moderate and severe infestation category with grade ranging from zero to three. Anitha (2000) while studying the bioecology and management of *O. longicollis*, gave a similar score from zero to four based on holes, but differed from earlier scoring method in number of holes in each score. Another rating technique which considered surface area of infestation and size of feeding holes along with number of holes was also reported (Lalitha and Ranjith, 2001).

2.7 HOST PREFERENCE

Earlier works indicated preference of the pest towards certain banana cultivars. *O. longicollis* was recorded as a pest of manila hemp, *Musa textilis* in Philippines (Uichanco,1936). Shukla and Kumar (1970) opined *O. longicollis* as a monophagous pest on cultivated and wild type of *Musa* sp.

Lu *et al.* (2002a) found that female *O. longicollis* laid more eggs when fed with Gungdong banana II, Thailand banana, Bengal AAB Cavendish, than with Brazil banana (AAA Cavendish) and Saba banana Fen banana (ABB Cavendish).

Dutt and Maiti (1972) observed that all the common banana varieties in West Bengal such as Martaman, Champa, Kanchakala and Kabuli were susceptible to *O. longicollis*. Martaman was the most susceptible one. Later, a detailed field survey carried out at Regional Fruit Research Station, Kahikuchi, Assam revealed that banana variety Bhimkal was free from *O. longicollis* infestation; where as Malbhog and Chenichampa varieties were highly susceptible (Isahaque, 1978). He concluded that resistance may be associated with the possession of broad, thick and compact leaf sheaths and pseudostems, along with some chemical antibiosis.

Dutt and Maiti (1979) observed some relationship between the ovipositor length of *O. longicollis* and outer wall thickness of air chamber of the outermost leaf sheath. According to their observation, the preferred oviposition site was chosen when the ratio between ovipositor length and outer-wall thickness ranged from 1:0.7 to 1:0.9. Preference decreased when the outer-wall thickness increased or decreased the ratio.

Among the 200 accessions screened under laboratory conditions, Bhimkol (BB), Athiakol (BB), Elavazhai (BB), Saapkal (AAB), Dudhsagar (AAA) and Pisang Jari Buaya (AA) were found to be resistant against *O. longicollis* (Padmanaban and Sathiamoorthy, 2004). In an experiment at NRCB, Trichy, 100 accessions were screened under laboratory conditions. The popular varieties such as 'Nendran', 'Monthan' and 'Karpooravalli' were among the most susceptible accessions to banana stem weevil. None of the accessions were immune to the pest (Padmanaban *et al.*, 2004). Arun *et al.* (2012) recorded *O. longicollis* infestation in Silk Banana (AAB) from Bangalore.

Seventeen banana genotypes were evaluated under field conditions against pseudostem weevil at Horticultural research Station, Anantharajupet, Andhra Pradesh by Reddy *et al.* (2015). They found that Red Banana was the most susceptible variety as it registered 100 and 90.4 per cent infestation, respectively during two consecutive years. Red Banana was followed by Bontha selection, Karpuravalli, Ellai Bale and Nendran in the order of susceptibility towards *O. longicollis*.

Visalakshi *et al.* (1989) observed that 'Nenthran' and 'Red Kappa' varieties were susceptible to the pest in Kerala. Out of the 229 banana accessions evaluated in Kerala, 37 were free from infestation (Padmanaban *et al.*, 2001c). These accessions belonged to ABB, AAB, AB, AA, BB, AAA, ABBB and AAAA genomic groups. Maximum infestation was recorded in AAB genome and *O. longicollis* exhibited a high degree of plant preference.

In the field survey carried out at three southern districts of Kerala, Nendran was found with high level of infestation by *O. longicollis* (Anitha, 2004). The lowest level of infestation was observed in Robusta and Njalipoovan. In the laboratory studies on *O. longicollis* bionomics Anitha and Nair (2004) found that the clones Nendran and Poovan were more susceptible to *O. longicollis* and better suited for the population build up. Evaluation of nine improved banana hybrids at Banana Research Station, Kannara revealed that the hybrid CRPB-39 showed susceptibility to pseudostem borer (Menon *et al.*, 2004). Nendran and Chenkadali were the most preferred varieties by pseudostem weevil while Big Ebanga, Myndoli and Njock Kon were highly susceptible while hybrids like BRS-1, BRS-2, Kunnan, Kadali, Njalipoovan, Yangambu, KM 5 were free from attack (KAU, 2011b). Kavitha *et al.* (2015) could note no pest attack on cv. Kannan, Aattinkombu, Kadali and Thenkaali in fields at Chittar, Pathanamthitta District, Kerala and classified them as resistant cultivars. *O. longicollis* grubs when reared on stems of 'Thenkaali' and 'Aattinkombu' showed significant difference in weakness and movements, compared to control maintained in 'Palayankodan'.

They concluded that the resistance shown by these varieties towards *O. longicollis* might be due to the presence of volatile secondary metabolites. They also found that var. Thenkaali possess three additional compounds over the 9-10 common compounds, compared to cv. Palayankodan and Aattinkombu.

Lalitha and Renjith (2000b) observed maximum oviposition (6.2 eggs female^{-1}) in pseudostem of Nendran of seven months and above, while oviposition was absent in the pseudostem of one and two months old plants. Studies conducted at College of Agriculture, Vellayani showed that six to eight month old plants were ideal for feeding and development of grubs and this age of the plants was the most vulnerable (Anitha, 2004).

The quantitative and qualitative changes in polyphenol oxidase in relation to the resistance of *Musa* sp. to *O. longicollis* was studied by Lalitha *et al.* (2002). They found that enzyme activity as well as oxidation factor of ortho-dihydric phenols was higher in the resistant clone, Njalipoovan, than the next susceptible clone, Nendran. According to studies conducted using scanning electron micrograph by Nahif *et al.* (2003) the host selection of *O. longicollis* was attributed by the presence of an array of chemoreceptors on the antennae, mouth parts and tibia.

2.8 MANAGEMENT OF *O. longicollis*

Management of borer pests is difficult owing to their habitat. The control of banana pseudostem weevil is an eluding and complex problem because its life cycle is completed inside the pseudostem (Dutt and Maiti, 1972) and as it is extremely difficult to control the pest after establishment (Abraham and Thomas, 1995).

2.8.1 Cultural Control

Cultural methods of pest control were given more emphasis by early scientists. Pinto (1928) recommended healthy and uninfested suckers for planting, cutting of harvested stem into slices and burying as deeply as possible with lime. He also advocated crop rotation after every three year of banana crop. Based on the observations from the fields of Kwangtung in China, Hoffmann (1933) advocated removal of trash, broken and decaying plants from plantation as a method of reducing the pest attack. Kung (1962) mentioned cultural methods such as clean cultivation, prompt destruction of old plants and treating felled plants with chemicals or exposing to the Sun. Phytosanitory measure like eradication of affected plants from the stool had appreciable degree of efficacy in controlling *O. longicollis* (Tiwary, 1971).

Removal of dry leaves, leaf sheaths, dead or cut pseudostems and burning them in a pit during winter gave good results in reducing the pest population (Isahaque, 1978). Anitha (2000) also recommended removal of dried leaves to reduce pseudostem weevil attack. Removal of old, dried leaves to detect early symptoms of attack and to increase efficacy of chemical application was recommended by Padmanaban and Sathiamoorthy (2001). Padmanaban and Kandasamy (2003) found that banana stumps kept in the field after harvest served as weevil refuge and breeding sites and hence it should be destroyed. They recorded 19.5±7.32 banana stem weevil surviving on banana stumps discarded after harvest.

2.8.2 Botanicals for *O. longicollis* Control

Marotti oil and lemon grass oil at 5 per cent concentration was found to be the most effective repellants against *O. longicollis* adults, in a laboratory experiment at the College of Agriculture, Vellayani (Anitha, 2000).

Leaf extract of *Vitex negundo* L., seed extract of *Terminalaia chebula* Retz., rhizome extract of *Acoras calamus* L. caused mortality of adult weevils (Padmanaban and Sathiamoorthy, 2004).

In the laboratory experiments conducted at the Assam Agricultural University, neem oil (0.5%) and pongamia oil (0.5%) showed strong repellent effect on the borers. In the no choice test conducted, maximum toxicity was found in Pongamia (0.5%) oil (Bhagawathi *et al.*, 2009).

Azadirachtin 1.2 EC (Neem Azal1.2 EC) as stem injection at a ratio 4:4 with water recorded 93.81 per cent mortality of *O. longicollis* after 96 hours of application. Swabbing of pseudostem with 4% Neem Azal 1.2 EC also gave good results (Sivasubramanian *et al.*, 2009). Results of experiments at the Kerala Agricultural University with commercially available neem based insecticides against banana pseudostem borer revealed that Neemazal (1% EC @ 0.5%) recorded the lowest percentage of attack by weevil, highest bunch weight and good BC ratio (KAU, 2011b). Banana plants treated with Azadirachtin 1000 ppm as stem injection @ 2ml plant^{-1} gave good yield and recorded only 7.25 per cent infestation in the field (Irulandi *et al.*, 2012).

In curative mode of treatment against banana pseudostem weevil, cassava leaf distillate (CLD) was found very effective. CLD, when applied @10 ml at three points on banana stem infested with *O. longicollis* using injection syringes, positive response on ooze out from stem and death of weevils were recorded (Krishnan, 2013). Cassava based biopesticide at 5% concentration was recommended against *O. longicollis* (Krishnan *et al.*, 2015).

The repellency effect of essential oils from the plants, *Tephrosia purpurea* (L.) and *Ipomoea carnea* Jacq. was studied by Sahayaraj *et al.* (2015). They found that *T. purpurea* stem oil showed maximum repellency, followed by *I. carnea*

stem oil. It was also observed that tested oils deterred male adults of *O. longicollis*, than females.

Experiments conducted at ICAR-NRCB, Trichy proved the efficacy of zimmu extracts against *O. longicollis*. When aqueous extract of zimmu at 100% concentration was used in insect dip and leaf sheath feeding methods maximum weevil mortality on tenth day after treatment was 100 and 87.5 per cent, respectively. Similarly when solvent extract was tested by leaf feeding method, 100 per cent mortality was recorded on fourth day after treatment (ICAR-NRCB, 2015).

2.8.3 Bio Agents/ Biological Control

Unlike the lepidopteran borers, only very limited number of successful bio agents had been reported against *O. longicollis* with limited success in actual field conditions. Mortality of *O. longicollis* grubs and adults when treated with fungal pathogens *in vitro* has been reported by some authors. Reports on parasitoids and predators are more focused on banana rhizome weevil than pseudostem borer (Koppenhofer *et al.*, 1992; Hasyim *et al.*, 2009).

2.8.3.1 Entomopathogenic Fungi

Green muscardine fungus, *Metarhizium anisopliae* (Metschinkoff) Sorokin when used at $2.9x10^6$ spores ml^{-1} was found to cause 100 per cent mortality of *O. longicollis* grubs and adults in four and eight days, respectively (Anitha *et al.*, 1998).

Entomopathogenic fungus, *Fusarium solani* (Mart.) Sacc. was isolated from *O. longicollis* and gave 93.3 per cent mortality on eighth day of treatment when applied @ $2x10^5$ spores ml^{-1} to grubs (Anitha *et al.*, 1999b). Another

species, *F. oxysporum* Schlecht. was reported from *O. longicollis* by Krishnakumar *et al.* (2006).

Infection by *Mucor hiemalis f. hiemalis* Wehmer was recorded by Anitha *et al.* (1999a) from field collected grubs. When grubs were treated in the laboratory, ninety per cent mortality was recorded at a concentration of 300 spores/microscopic field.

In a field survey conducted at Thiruchirapalli and Coimbatore, Padmanaban *et al.* (2002a) could obtain two entomopathogenic fungi from weevils of *O. longicollis*. They were identified as *Aspergillus flavus* Link and *Scopulariopsis brevicaulis* (Saccardo) Bainer. When tested in laboratory, *A. flavus* @ $7x10^6$ spores ml^{-1} recorded 32.82 and 52.97 per cent mortality of weevils on four and eight days after treatment, respectively. However, *S. brevicaulis* @ $3x10^6$ spores ml^{-1} recorded only 20.32 and 30.43 per cent mortality of weevils on four and eight days after treatment, respectively. Beegum (2005) could isolate another species of *Aspergillus*, *A. parasiticus* Speare from diseased grubs and adults of *O. longicollis* collected from the field.

Beegum and Anitha (2006) reported *Beauveria bassiana* (Bals.) Vuillemin as a potential bio control agent against pseudostem weevil. They found that $1.8x10^7$ spores ml^{-1} gave the highest mortality (99.99 per cent) of *O. longicollis* grubs in laboratory. Laboratory and screen house studies revealed great potential of *B. bassiana* for use against the banana weevil, *O. longicollis* (Prabhavathi and Ghosh, 2014). Their study revealed that in tissue cultured plant, *B. bassiana* can colonise internal banana tissues for at least four months when dipped in a spore suspension. The presence of the fungus inside treated plants led to a reduction in pseudostem weevil damage more than 50 per cent.

Three isolates of *B. bassiana* from different locations were evaluated *in vitro* at ICAR- NRCB, Trichy. The NRCB isolate recorded 80 per cent mortality whereas the other two isolates recorded 40 per cent only (ICAR-NRCB, 2014).

2.8.3.2 Entomopathogenic Nematodes

The entomopathogenic nematode, *Steinernema carpocapsae* (Weiser) when applied as injection into the tunnels made by banana pseudostem weevil could suppress the weevil population (Lu *et al*., 2002 b).

When the third instar grubs of *O. longicollis* was inoculated with the entomopathogenic nematode, *Heterorhabditis indica* Poinar, after 72 hours of inoculation grub mortality was to the tune of 33.3 per cent and 66.6 per cent in treatments with 10-70 IJs and 80-100 IJs per grub, respectively (Padmanaban *et al.*, 2002 b). Similarly Banu and Rajendran (2002) also recorded *O. longicollis* as a host of a native isolate of *H. indica.*

In a study at the College of Horticulture, Vellanikkara, Jayasree (1992) found that DD-136 (*Steinernema glaseri* [Steiner]) caused hundred per cent mortality of pseudostem weevil grubs at 10 days after inoculation. Studies conducted at the College of Agriculture, Vellayani by Remya (2007) revealed that maximum mortality (88.7 per cent) of *O. longicollis* grubs *in vitro* were obtained using a native isolate of EPN (N1) @100 IJ grub^{-1}, 72 hours after treatment. This was followed by *H. indica*. Maximum mortality among *O. longicollis* adults (70.36 per cent) was obtained in treatment with *H. indica* @ 200 IJ adult^{-1}, 72 hours after treatment. But the effectiveness of EPN was less when applied inside the pseudostem as N1 isolate could cause only 56.3 per cent mortality of grubs, 96 hours after treatment.

2.8.3.3 Invertebrate Predators/ Parasites

Froggatt (1928) in a study conducted in Java revealed that larvae of *Chrysopilus ferruginosus* Wied. and larvae and adult of *Plaesius javanus* Erichson. were predacious on the larvae and pupae of both *O. longicollis* and *C. sordidus*. China (1935) identified some predators of *Cosmopolites* and *Odoiporus* collected from Malay region. He identified a reduvid bug which was predacious on grubs of the weevils as *Physoderes curculionis* China. *Phorticus pygmaeus* Popp. (Fa. Nabidae) and *Fulvius nigricornis* Popp. (Fa. Capsidae) were found preying on eggs of *Cosmopolites* and *Odoiporus*. In Formosa, *P. javanus* was found predacious on the larvae but could not been established even after several introductions (Kung, 1962).

Literature on parasites and predators on *O. longicollis* is scanty, but many scientists worked on identification, preying potential and introduction of predators of the related weevil, *C. sordidus.* Koppenhofer *et al.* (1992) could identify twelve egg, larvae and pupal predators of *C. sordidus* in Western Kenya. Koppenhofer and Schmutterer (1993) found that an indigenous Hydrophilid, *Dactylosternum abdominale* (Fabr.) could reduce weevil multiplication in suckers up to 50 per cent and in residual stumps of harvested suckers by 39 per cent. Another predator, *Thyreocephalus interocularis* (Eppelsheim) reduced weevil population by 42 per cent. Three histerids *viz.*, *Plaesius javanus*, *P. laevigatus* (Marseul) and *Hololepta* sp., three staphylinids [*Belonochus ferrugatus* (Erichson) and *Leptochirus unicolor* Laporte], three Dermaptera and 13 formicids were recorded as predators associated with banana residues in Indonesia (Abera *et al.*, 2006). They tested feeding potential of these predators in laboratory and found that *P. javanus* was a potential predator of *C. sordidus*, the banana rhizome weevil.

Release of ectoparasitic mite, *Uropodia* sp. on adult weevils could yield moderate efficacy in controlling *O. longicollis* (Tiwary, 1971). Luo *et al.* (1985) reported mites and dermaptera as natural enemies of *O. longicollis* in China. Anitha (2000) found two mites of *Uropodina* with the adults of *O. longicollis*. One species rested on dorsal and ventral sides while the other was bigger and found fewer in number.

Fifty species of spiders from 15 families were recorded from banana field of Vidarbha, Maharastra (Keswani and Vankhede, 2014). They observed that spiders fed on banana pests like *C. sordidus*, *O. longicollis*, aphids, thrips and moths.

2.8.3.4 Avian Predators

Basheer and Thomas (2012) observed Indian treepie, *Dendrocitta vagabunda parvula* (Latham) as a natural enemy of pests of coconut and arecanut palm plantations. Diet analysis of this avian predator revealed *O. longicollis* as one of the major preys. They attributed the presence of banana stem weevil as a food item resulted from the intercropping of banana plants in coconut plantations and the foraging of Indian Treepie among the banana plants.

2.8.4 Semiochemicals as a Component in Pest Management

Developing a suitable semiochemical to attract adult weevils will be a key success in managing the borer pests, especially due to their secluded habitat. Many successful attempts were made for managing the other serious pest of banana, rhizome weevil, *C. sordidus*, but no field level success has been reported so far, for *O. longicollis.*

The use of stem traps to attract adult weevils was described in one of the earliest records by Pinto (1928). He advocated spreading pieces of sliced stems

and bulbs with side down on ground near to growing plants. Replacement of baits at least once in a fortnight and destruction of old pieces containing eggs and grubs were also recommended. Trapping was considered as one of the most practical methods of reducing pest attack by Hoffmann (1933). He recommended use of slices of stem as traps, so thin to be insufficient for the insects to complete within.

Gunawardena and Dissanayake (2000) could identify 4 compounds *viz*, n-hexanol, n-hexanal, n-pentanol and cis-3-hexanol as host attractants for *O. longicollis* among which n-hexanol elicited maximum EAG response. When tested in field, n-hexanol singly or in combination with the aggregation pheromone failed to attract any weevils into traps.

In the laboratory experiment conducted at Vellayani to evaluate the effectiveness of different attractants, decaying pseudostem attracted maximum number of weevils (11.68) and found superior to other treatments (Anitha, 2000).

Studies by Ravi and Palaniswami (2002) could establish the presence of a female produced sex pheromone in *O. longicollis*. Responsiveness of males to females varied with age groups of females.

Effectiveness of pseudostem cut pieces along with other locally available and commonly used insect bait materials such as toddy, dried fish and ripe banana pulp were tested by Nair *et al.* (2004). They found that maximum weevils (43 weevils/ week) were caught when pseudostem pieces of 0.5 to 0.75 m length were placed at ground level and the pieces remained effective up to three weeks during rainy season.

In a basic research at Indian Institute of Chemical technology, scientists studied the olfactory responsiveness of *O. longicollis* towards semiochemicals from conspecifics and host plants (Prasuna *et al.*, 2008). Using

electroantennogram and olfactometer bioassays, they found that male weevils showed greater responsiveness to all the experiments and were responsive to both male and female extracts, but females showed significant response to male extracts only.

A study conducted in Tamil Nadu by Sahayaraj and Kombiah (2009) revealed that seven days decayed pseudostem and its extract showed maximum attractant property of 53.35 per cent and 75 per cent, respectively, compared to lesser decayed pseudostem and its extracts.

A low cost semiochemical based trapping method for *O. longicollis* management was tried by Palanichamy *et al.* (2011a). In their field experiments, they used an aggregation pheromone, 2-methyl-4-heptanol in single and in combination with host plant extract. The combination of pheromone and host plant extract caught more weevils than traps baited with either pheromone or host plant extract alone. The number of weevils caught in the trap was very meager, to the tune of three weevil $trap^{-1}$ only.

Maximum EAG response in female could be elicited when microwave oven assisted pseudostem extract was used in an experiment by Palanichamy *et al.* (2011 b).

It was found that maximum number of weevils was attracted to pseudostem pieces without any bait material (KAU, 2011b). It was also observed that horizontally placed stem pieces attracted more number of weevils than vertically placed ones and as decaying progressed, attraction of weevils also increased.

Different volatiles which included hydrocarbons, esters, ketones and heterocyclic compounds were identified in the extracts from fresh rotten pseudostems. In this study by Jiong *et al.* (2012) found that both male and female

O. longicollis were attracted to the volatiles from banana pseudostems in different physiological states. Compared to fresh pseudostems, beetle feeding activity and rottenness enhanced the attractiveness of the extracted volatiles from banana pseudostems to male and female *O. longicollis*.

Shanmugam *et al.* (2013) concluded from their on farm trials that use of pseudostem traps @ 100 ha^{-1}, each embedded with *B. bassiana* 25 g was effective in reducing banana stem weevil infestation along with the highest BC ratio.

Studies using Gas Chromatography- Electroantenographic Detector (GC-EAD) revealed the presence of banana stem weevil active volatile compounds in the susceptible cultivar, Poovan. These attractive volatile components were lacking in moderately resistant accession (Padmanaban *et al.*, 2014).

Field tests conducted in endemic areas of Theni and Dindigul in Tamil Nadu using funnel trap showed that maximum weevils (80 per cent) were attracted to the treatment with semiochemical No.1 + host plant volatile extract from Nendran (ICAR-NRCB, 2015).

2.8.5 Sterile Insect Techniques (SIT)

In Formosa, Chiang (1965) investigated the effects of exposure to X-rays and γ-rays on pupae of *O. longicollis*. Out of the three doses tested, 1000 R, 2000 R, 4000 R and 8000 R, 2000 R was found the maximum practical dose for control by sterile male release when administered to three day old pupae.

Different doses of γ-rays were tried on freshly emerged male weevils of *O. longicollis* to standardize the effective dose at the Kerala Agricultural University. The different doses tried were 2.0, 2.2, 2.5, 2.7 and 3.0 k rad. Among the doses

tried, 2.2 k rad was the most effective and no difference in reproductive system of irradiated and normal insect was observed (KAU, 2011b).

2.8.6 Chemical Control

Luo *et al.* (1985) from their experiment in China observed deltamethrin as effective insecticide against weevils only whereas, trichlorfon and dichlorvos were effective against both the adults and larvae. Studies by Wijesekara and Menike (1991) in Sri Lanka showed that carbofuran3G @ 6.0 g banana^{-1} pseudostem trap and benfuracarb 3G @ 3 g trap^{-1} were effective in controlling weevils attracted to traps.

Spraying of banana plants with 0.05% endrin, follidol or dieldrin could yield excellent efficiency in controlling *O. longicollis* (Tiwary, 1971). Tests conducted by Dutt and Maiti (1972) revealed that application of contact insecticide, endrin around the pseudostem or soil treatment with aldrin failed to control *O. longicollis*, but treatment of infested plants with Celphos tablet @ 0.5 g x3 tablets plant^{-1} could control all stages of the pest inside the stem. They also observed phytotoxicity of Celphos, if treated during vegetative phase, as death of central immature rolled leaf; nevertheless it could recover within four weeks after treatment.

Thiodan35 EC (endosulfan) at 0.1% or Sevin 50 WP (carbaryl) at 0.1% spray solution by drenching in the leaf whorls and leaf sheaths from top to lower pseudostem at monthly interval gave effective control of *O. longicollis* infestation (Isahaque, 1978).

Field experiments conducted in Tamil Nadu at two locations showed the highest recovery and bunch yield for monocrotophos (3.0 ml in 5.0 ml water) and aluminium phosphide (1.5 g plant^{-1}) (Janakiraman and Rao, 2001).

Justin *et al.* (2006) injected plants with monocrotophos and dimethoate along with water in 1:5 ratio at 60 cm and 150 cm height and obtained an average bunch yield of 10.86 kg plant^{-1} and 10.58 kg plant^{-1}, respectively. Similar observations with monocrotophos were obtained by Irulandi *et al.* (2012). They recorded 96.15 per cent mortality and increased fruit yield with monocrotophos stem injection @ 4 ml plant^{-1}. Monocrotophos 36WSC as injection @ 4 ml at two heights; at 45 and 150 cm in the pseudostem at monthly interval from fifth to eighth month gave good results in controlling *O. longicollis* infestation and recorded the highest BCR in studies conducted by Shanmugam *et al.* (2013).

Kumar and Tiwary (2009) observed that treatment of three celphos tablets plant^{-1} gave 100 per cent mortality of eggs inside the sheath; but adversely affected immature central rolled leaves. But it did not affect the proper stem, as the treated plants showed normal growth of inflorescence and fruit bunch during the reproductive phase.

Studies by Reghunath *et al.* (1992) in Kerala showed that spraying either aldrin (0.1% a.i.) or HCH (0.3% a.i.) was effective in controlling *O. longicollis*. They observed that application of monocrotophos (0.1%) as a curative method failed to give any significant results.

Swabbing of chlorpyrifos (0.05%) at monthly intervals from fourth month after planting until shooting, resulted in complete protection against *O. longicollis*. The same level of control was also obtained with carbaryl 0.2% swabbing and injection with chlorpyrifos (0.2%), quinalphos (0.4%) and cypermethrin (200 ppm) (Mathew *et al.*, 1997).

Anitha (2000) found that leaf axil filling of either chlorpyrifos @ 0.05% or carbaryl @ 0.15% when applied as curative treatments, showed no increase in damage grade index and was significantly superior to other treatments.

In the field trial conducted at Pathanamthitta, Vijayalalitha and Kannan (2006) recorded the highest yield with the lowest cost of monocrotophos (1.2 ml in 2.8 l of water) in injection with monocrotophos on pesudostem at 60 cm and 150 cm height from the base on opposite directions at 45^0 angles during the fourth month.

2.8.7 Methods of Insecticide Application in Banana

The habit and behavior of *O. longicollis* is unique that even the chemicals which showed high rate of mortality in direct contact tests may not give the same results in real field conditions (Dutt and Maiti, 1972). So an appropriate delivery system for the pesticide has to be designed for desired results in field conditions. The pesticide application method should also ensure minimum impact on environment and other non targeted organisms.

Swabbing of pseudostem with slurry by adding 1.5 l of insecticide to 1.0 kg moist soil was tried by Abaraham and Thomas (1995). This application using carbaryl 0.25%, chlorpyrifos or neem oil 0.5% was found effective against *O. longicollis*. Swabbing was effective with chlorpyrifos 0.05% or carbaryl 0.5% in mud slurry also when used as prophylactic treatment. But spraying method was found less effective than the swabbing method (Mathew *et al.*, 1997).

Mathew *et al.* (1997) tried stem injection of three chemicals as a curative treatment using syringe and needle. All chemicals *viz.*, chlorpyrifos 0.2%, quinalphos 0.4% and cypermethrin 200 ppm, except endosulfan 0.2% @ 30-40 ml $plant^{-1}$, gave 100 per cent recovery at 15 days after treatment.

Stem injection with carbaryl 0.15%, endosulfan 0.05%, fenvalerate 0.02% and *M. anisopliae* ($15x10^5$ spores) did not significantly differ from stem injection or leaf axil filling using distilled water. Comparison between leaf axil filling and

stem injection using the insecticides carbaryl, endosulfan and chlorpyriphos, leaf axil showed a slight advantage over stem injection in terms of number of hands and fingers produced (Anitha, 2000).

Anitha (2000) advocated application of *M. anisopliae* spore suspension ($15x10^5$ spores ml^{-1}) for the management of the pest as leaf axil filling @1.0 l $plant^{-1}$ when oviposition punctures were noticed. She also recommended application of mud slurry mixed with 5.0% neem oil on the pseudostem of five month old plants to prevent oviposition.

According to the results obtained from the studies conducted by Janakiraman and Rao (2001) injection of monocrotophos (3.0 ml in 5.0 ml water) should be given during six to seven months of age and three more injection at 45 days interval to control *O. longicollis*.

Justin *et al.* (2006) tried pseudostem injection with systemic insecticides, at different concentrations. The chemicals were injected @ 2 ml injection $point^{-1}$ at 60 cm and 150 cm, opposite to the first point, from the ground level. They observed that stem injection of monocrotophos 1 ml+5 ml water or dimethoate 1:5 ratio was superior among the treatments tried. Vijayalalitha and Kannan (2006) also reported similar observations. In their study, monocrotophos 1.2 ml in 2.8 l of water when applied at 60 and 150 cm height from the base on opposite directions at 45^0 angle during fourth month gave the highest yield, complete control of weevil and the lowest cost.

Injection of different doses of Neem Azal 1.2 EC using banana injector was tested in a field experiment by Sivasubramanian *et al.* (2009). They found that stem injection of Neem Azal @ 4:4 ratio applied thrice at 30 days interval was more effective than swabbing with 4% Neem Azal in reducing borer infestation.

Shanmugam *et al.* (2013) tried monocrotophos and azadirachtin 1000 ppm@ 4 ml and 2 ml per plant, respectively applied as injection into the stem at 45 and 150 cm from the base. Stem injection was found better than spraying.

Swabbing the pseudostem with 0.06% chlorpyrifos up to 1.2 m height during five to eight month stage completely controlled banana stem weevil (ICAR-NRCB, 2015).

2.9 COMPATIBILITY OF INSECTICIDES AND FUNGICIDES TO ENTOMOPATHOGENIC FUNGI

Survival of entomopathogens like fungi in agroecosystem depends on many biotic and abiotic factors such as temperature, sunlight, humidity, predators, hyperparasites and presence of agro chemicals. Plant protection chemicals can exert synergestic or antagonistic effect on growth and sporulation of the beneficial fungi in the field (James and Elzen, 2001; Kassab *et al.*, 2014). Understanding the compatibility of various pesticides on both the naturally occurring as well as inundated beneficial fungal flora will facilitate suitable adoption of integrated strategies against pests. In banana agro-ecosystem, fungicides are often adopted to fend off diseases and hence it is imperative to know the interactions between these chemicals and entomopathogenic fungi to schedule their application.

Loria *et al.* (1983) observed that mancozeb and metiram at 1.918 ppm totally inhibited spore germination of *B. bassiana in vitro*. When the effect of these chemicals at the same concentration was observed in the potato field, it was noticed that the inhibition was lower and lesser consistent, than laboratory studies.

Some researchers have the outlook that it is the kind of formulation rather than active ingredient important in inhibiting fungal spore germination (Anderson and Roberts, 1983). Anderson *et al.* (1989) concluded that wettable powders and

flowable formulation of pesticides caused no inhibition and often increased colony counts, but EC formulation often inhibited *B. bassiana* germination.

In a study by Li and Holdom (1994), *M. anisopliae* isolates were found more tolerant towards insecticides and herbicides than fungicides. They observed that the growth of the fungi was unaffected by carbofuran and aldicarb at a concentration of 0.01% a.i.

The neonicotinoid insecticide, thiamethoxam was found compatible with entomopathogenic fungi including *M. anisopliae*. Thiamethoxam when used @ 800 g a.i. ha^{-1} in *in vitro* studies, the colony diameter of *M. anisopliae* and *B. bassiana* was on par with the control; whereas imidacloprid @ 400g a.i. ha^{-1} was found moderately toxic to *B. bassiana* and *M. anisopliae* (Filho *et al.*, 2001).

Neves *et al.* (2001) studied the effect of three neonicotinoids; acetamiprid, imidacloprid and thiamethoxam at three doses on growth, conidia germination and conidiogenisis of *M. anisopliae*, *B. bassiana* and *Paecilomyces* sp. They used 25 g 200SP/100 l, 30 g 700WDG/100 l and 20 g 250WG/100 l as average recommendation for field application (AR) for acetamiprid, imidacloprid and thiamethoxam, respectively. When lower (0.7AR) and higher (1.3AR) doses of these chemicals were tested all insecticides, except acetamiprid at higher dose, were found compatible with fungal bioagents. Conidia production by *B. bassiana* was increased by 13.38 per cent, compared to control but was reduced (-22.98 per cent) for *M. anisopliae* at lower dose of thiamethoxam treated plates. At higher doses of thiamethoxam, conidia production by *M. anisopliae* was found increasing even though a reverse trend was observed in case of *B. bassiana*. They concluded that these neonicotinoids did not affect the entomopathogenic fungi and partially attributed to the formulation of insecticides.

Oliveira *et al.* (2003) tested eight insecticides at three different concentrations on *B. bassiana* conidia germination and growth. Insecticides fenpropathrin, deltamethrin, endosulfan, chlorpyrifos and triazophos recorded no fungal growth in any of the concentrations tried. Thiamethoxam at recommended field dose showed same colony growth as that in control. Germination of conidia in cyfluthrin and alpha cypermethrin treated media were on par with control. Conidia production was found to increase under higher concentration of thiamethoxam.

Studies conducted by Beegum (2005) revealed that Neemazal (0.4%) caused 58.99 per cent mycelia growth inhibition; whereas chlorpyrifos @ 0.03% caused 90.41 per cent inhibition of *M. anisopliae* fungal growth. The same trend was observed with *B. bassiana* also. Among the fungicides tested for compatibility, copperoxychloride (0.4%) and mancozeb (0.3%) recorded maximum growth inhibition of 92.19 and 92.49 per cent, respectively for *M. anisopliae*. Since major insecticides and fungicides used in banana agroecosystem were found inhibiting the growth of *M. anisopliae* and *B. bassiana*, she opined that use of entomopathogenic fungi and chemicals in combination may not be advantageous in IPM against *O. longicollis*.

Mochi *et al.* (2005) studied the effect of certain acaricides, fungicides, insecticides and herbicides on *M. anisopliae* in soil under controlled conditions. They evaluated action of different pesticides based on respiratory activity of the fungus by estimating CO_2 production and observed no significant effect on *M. anisopliae* when imidacloprid and deltamethrin were applied to soil. No significant reduction in fungal activity was observed in case of herbicides and acaricides. Fungicides chlorothalonyl (2.5 l ha^{-1}), copperoxychloride (3.5 kg ha^{-1}) and tebuconazole (0.75 l ha^{-1}) caused maximum reduction in respiratory activity of *M. anisopliae* during 6 to 14 days after inoculation. Insecticides recorded difference in reducing fungal activity only 30 days after inoculation. Trichlorfon and imidacloprid recorded minimum CO_2 concentration (1.5 and 1.8 mg

CO_2/100g soil, respectively) indicating less respiratory activity of the fungus. Isaiah *et al.* (2005) observed an inverse relation between concentration of chemical and radial growth of the fungus, *B. bassiana.* They observed a radial growth of 4.2 cm in plates treated with 'Multineem', a neem based formulation @ 0.03%; whereas 0.06% concentration recorded only 3.1 cm. Chlorpyrifos recorded 3.5 cm radial growth at 0.015%, while 2.5 cm only for 0.3% concentration. Fungicide mancozeb inhibited fungal growth at higher concentration (3.0 cm at 0.2% and 3.3 cm at 0.1%).

Ali *et al.* (2007) demonstrated that flufenoxuron @ 0.0025% concentration caused 99.5 per cent reduction in vegetative growth and 96.0 per cent reduction in conidia germination of *B. bassiana* while imidacloprid @ 0.0175% caused least reduction in conidia germination and vegetative growth of the fungus.

Insecticides *viz.*, chlorpyriphos, endosulfan, dichlorvos, malathion and dicofol were found inhibiting the mycelia growth of *M. anisopliae* from 58 to 69 per cent. But neonicotinoid imidacloprid and spinosad were found safe to the fungi by inhibiting only 5.1 and 11.1 per cent growth. Fungicides carbendazim, propioconazole, hexaconazole and chloranthalonil totally inhibited fungal growth in vitro but wettable sulphur recorded only 33 per cent reduction in fungal growth (Rachappa *et al.*, 2007).

Dhar and Kaur (2009) studied the compatibility of *B. bassiana* and *M. anisopliae* with acetamiprid. They tested five isolates of each fungus from different countries and concluded that they were compatible with the field recommended doses of acetamiprid @ 0.2g l^{-1}. In another study, chlorpyrifos 0.05%, endosulfan 0.02% and malathion 0.03% inhibited growth of *B. bassiana* by more than 90 per cent (Haseeb, 2009). Thiophanate methyl (0.5g l^{-1}) recorded 71.38 per cent germination of spores of *M. anisopliae in vitro* while azoxystrobin

(0.05g l^{-1}) and captan (2.4 g l^{-1}) recorded 31.01 and zero per cent, respectively (Bruck, 2009).

Asi *et al.* (2010) tested 13 insecticides on growth and conidia germination of *M. anisopliae*. In their experiment, Chlorpyrifos (Lorsban 40 EC) at a dose of 100 ml $acre^{-1}$ recorded maximum reduction in germination and mycelia growth of the fungi. Spinosad (Tracer 240 SC @ 80ml $acre^{-1}$) proved the safest among the chemicals tested as it recorded the lowest percentage of inhibition on growth and conidial germination. A similar observation on toxicity of chlorpyrifos was reported by Akbar *et al.* (2012). They found chlorpyriphos, lufenuron and profenophos were not compatible, while spinosad, indoxacarb, imidacloprid and acetamiprid compatible with *M. anisopliae*.

In vitro studies conducted at University of Tehran, Iran by Rashid *et al.* (2010) revealed that hexaflumuron, fipronil and pyriproxyfen at 50 ppm caused 100, 28.2, 3.31 per cent reduction in conidial germination of *M. anisopliae*. Significant reduction in spore germination and vegetative growth of *M. anisopliae* was observed in treatments with hexaflumuron; whereas pyriproxyfen and fipronil showed relatively less inhibition at concentration of 50 and 100 ppm. Studies by Yanez and France (2010) on compatibility of various strains of *M. anisopliae* var. *anisopliae* to fungicides showed that benomyl and fenhexamid were compatible while azoxystrobin and fludioxonil were incompatible at 1 mg l^{-1}.

The compatibility of various chemicals and botanical pesticides used in coconut pest management with *M. anisopliae* was studied at CPCRI(RS), Kayamkulam. The results showed that various doses of azadirachtin (0.001 to 0.008%), chlorpyrifos (0.0125 to 0.1%) and monocrotophos (0.0125 to 0.1%) were very toxic to the vegetative growth and sporulation of the fungus. Carbaryl @ 0.01% and aqueous extract of *Clerodendron infortunatum* Linn. @ 5 to 20% were found compatible with *M. anisopliae* (Soman and Mohan, 2011).

Hexaconazole 5EC @ 2ml l^{-1} and Bordeaux mixture 1% recorded 100 and 99.6 per cent conidia inhibition in the germination over control of *B. bassiana* when tested under *in vitro* condition (Raj *et al.*, 2011).

Amutha and Banu (2012) tested compatibility of *M. anisopliae* with twelve insecticides and found that chlorpyrifos and econeem were hazardless; spinosad, acetamiprid, quinalphos, endosulfan and thiodicarb as slightly toxic, while imidacloprid and triazophos as moderately toxic. Silva *et al.* (2013) studied compatibility of pesticides used in rice with *M. anisopliae* strain CG 168. They found that azoxystrobin (25 ml ha^{-1}) was compatible, while difenoconazole, propioconazole and trifloxystrobin were moderately toxic to *M. anisopliae*. They also reported thiamethoxam (31 g ha^{-1}), methyl parathion (240 ml ha^{-1}) and lambda-cyhalothrin (6.3 ml ha^{-1}) as compatible insecticides with *M. anisopliae* CG 168 .

Vijayasree (2013) reported that the mycelia growth of *M. anisopliae* was minimum and significantly different from control in plates poisoned with emamectin benzoate 10 g a.i. ha^{-1} and thiodicarb 750 g a.i. ha^{-1} while growth was on par with control in plates treated with spinosad (75 g a.i. ha^{-1}), chlorantraniliprole (30 g a.i. ha^{-1}), indoxacarb (60 g a.i. ha^{-1}), carbaryl (750 g a.i. ha^{-1}), malathion (500 g a.i. ha^{-1}), novaluron (100 g a.i. ha^{-1}) and fipronil (50 g a.i. ha^{-1}). In another study at Vellayani conducted by Anis (2014) imidacloprid 0.006% was found compatible with *B. bassiana* and *M. anisopliae* and not significantly different from control in colony growth at two and five days after inoculation. Among the all pesticides tested, malathion @ 0.15% was most inhibitory on the growth of *B. bassiana* and *M. anisopliae*. Among the fungicides, carbendazim (0.1%) was more suppressive to the growth of *B. bassiana* whereas mancozeb showed more inhibition to growth of *M. anisopliae*.

Acetamiprid 20 SP @ 50 g 500 l^{-1} was found compatible with *M. anisopliae* and produced $1.36x10^9$ conidia, compared to $1.95x10^9$ in control (Singh *et al.*, 2014). Hemalatha *et al.* (2015) observed that field concentration of dimethoate and prophenophos, inhibited bio mass production of *B. bassiana* in broth and from their experiment they found that 3.0% neem oil and imidacloprid at field dose were compatible with *B. bassiana*.

2.10 PESTICIDE RESIDUE AND ITS ESTIMATION IN BANANA

Different extraction and quantification methods are used by various scientists for estimation of multi class pesticide residues in several vegetables and fruits. The main criteria for opting any methodology is that analytical method should be fast, easy, inexpensive and applicable to different matrices (Sharma *et al.*, 2010).

2.10.1 Pesticide Residue Estimation Methods in Banana

Curbelo *et al.* (2011) used a modified version of QuEChERS method in combination with GC-NPD for analyzing insecticides in banana leaves. This method was simple, rapid, reliable and required low consumption of organic solvents.

A simple, fast and cost effective method for pesticide residue determination in banana was developed by Wang (2013). The residues in banana were extracted using QuEChERS method, followed by dSPE (dispersive solid phase extraction) cleanup using $MgSO_4$, PSA and C18. He reported excellent accuracy and precision for this method even to the sensitive pesticides like pymetrozine.

Madureira *et al.* (2012) developed and validated a multi residue method for 90 pesticides in high water content matrices using QuEChERS method of

extraction and analysis using LC-MS/MS. Carnerio *et al.* (2013) developed a MRM for rapid and simultaneous determination of 128 pesticides including neonicotinoids using a modified QuEChERS procedure and UHPLC-MS/MS analysis.

Bakirici *et al.* (2014) analysed fruit and vegetable samples in Turkey using QuEChERS extraction procedure and detection by GC-ECD, GC-MS and LC-MS/MS. They analysed thiamethoxam by UPLC-MS/MS and found LOD range as 0.26-1.25 μg kg^{-1} and LOQ as 0.87-4.18μg kg^{-1}.

Kannaujia *et al.* (2012) analysed fruit samples collected from Jhansi using Multi Residue Analysis (MRA) by Gas Liquid Chromatography and recorded presence of pesticide residues. Kapoor *et al.* (2013) followed QuEChERS method for extraction and HPLC-MS for quantification of residues in fruits, vegetables, fruit juices, cereals and baby foods. The samples were collected from local markets in Lucknow. They found that banana samples contained imidacloprid from non detectable levels to 0.04 mg kg^{-1}.

2.10.2 Pesticide Residue in Banana

Superfluity of pests in banana warrants the pesticide application by the cultivators. A number of insecticides as well as fungicides have been recommended for management of noxious pest flora and fauna (KAU, 2011a). Injudicious and rampant use of these pesticides may become bane than boom by polluting environment and causing various health hazards.

Improper use of pesticides leads to accumulation of residues in the final products. Irrespective of the site of application such as soil or aerial, pesticides applied in banana can pollute water streams (Castillo *et al.*, 2006).

Banana samples from market were analysed to determine the presence of any pesticide residue in Canary Islands (Spain) by Borges *et al.* (2009). They could detect presence of chlorpyriphos, fenitrothion, malathion and buprofezin, but below their MRLs, in the samples. Chlorpyrifos was detected in most of the samples (88 per cent), but analysis revealed that most of the pesticide remained in the peel and did not penetrate into the fruit. Studies in Japan showed that captan, kresoxin-methyl, iprodione and acetamiprid were frequently found as residue in fruits (Akiyama *et al.*, 2011). Bakirici *et al.* (2014) analysed fruit and vegetable samples in Turkey using UPLC/MS/MS and GC-MS. They found that acetamiprid, carbendazim and chlorpyrifos were the most detected pesticides.

Analysis of samples collected from different cultivars of banana from Canary Islands by Curbelo *et al.* (2011) showed presence of chlorpyrifos in ten out of twelve samples. Presence of residues of organophosphates (6.8 per cent), carbamates (10.7 per cent) and pyrethroids (3.9 per cent) was detected in banana samples from 2001-2010 in Brazil (Jardim and Caldas, 2012).

Banana was the only fruit not contaminated by pesticide residues among the eight fruit samples tested by Anwar *et al.* (2011) in Sindh, Pakistan.

Sanghi and Tewari (2001) detected 1.37mg kg^{-1} malathion residue in banana collected from Kanpur, India. They did not get residues of pesticides like endosulfan, dimethoate, dieldrin, BHC or DDT in banana in their study. The obsolete organochlorine insecticides *viz.*, aldrin and chlordane were detected and found to be above the MRL in samples collected and tested in Utter Pradesh (Project Coordinating Cell, 2009). Paranthaman *et al.* (2012) analysed ten banana varieties and detected carbendazim in seven *viz.*, Hill Banana, Monthan, Nendran, Pachanadan, Poovan, Rasthali and Robusta. Meantime, chlorpyifos and endosulfan were detected in Robusta samples. Kannaujia *et al.* (2012) analysed fruit samples collected from Jhansi and found that banana samples contained

residues of malathion as 1.03 mg kg^{-1}, whereas ADI for malathion was only 0.02 mg kg^{-1} day^{-1}. Analysis of banana samples collected from Lucknow markets contained imidacloprid from non detectable levels to 0.04 mg kg^{-1} (Kapoor *et al.*, 2013). Samples of banana collected from local retail shops in Howrah, West Bengal recorded residues of tebuconazole (0.06 ppm) and carbendazim (0.32 ppm) at slightly higher than the Codex MRL value for the chemicals *i.e.*, 0.05 ppm and 0.2 ppm respectively. Even though the residue of carbendazim recorded was high according to Codex MRL, it was well below the MRL fixed by FSSAI (5 ppm). HCH-C residue detected in banana (2.39 ppm) samples was well above the MRL value fixed by FSSAI (1.0 ppm) in samples collected from Sitapur, Uttar Pradesh (Project Coordinating Cell, 2014).

Apart from contaminating the final produce, improper pesticide application also caused adverse impacts on soil and water in banana agro ecosystem. Devasia *et al.* (2011) found an inverse relation between the acidic nature of soil and absorption/adsorption of carbofuran and detected carbofuran residues in water from banana plantations.

Analysis of soil samples from banana fields of five districts (Thiruvananthapuram, Kollam, Thrissur, Wayanad and Kasaragod) in Kerala detected the presence of chlorpyriphos, quinalphos, beta endosulphan, cypermethrin and *p,p'*-DDD in soils of four out of five districts. Samples from Kasaragod, an organic district of the State did not show any residue. Chlorpyrifos was present in samples collected from Thiruvananthapuram, Thrissur and Wayanad districts and ranged from 0.075 to 6.442 mg kg^{-1} (Paul *et al.*, 2015).

CODEX Alimentarius has fixed MRLs of various pesticides for banana. According to CODEX, MRL of thiamethoxam, clothianidin, imidacloprid, carbofuran, fipronil and chlorpyrifos were 0.02, 0.02, 0.05, 0.01, 0.005 and 2 mg kg^{-1}, respectively (FAO, 2013).

Materials and Methods

3. MATERIALS AND METHODS

A field survey on banana pseudostem borer incidence and farmers' pest management practices in four Southern districts *viz.*, Thiruvananthapuram, Kollam, Pathanamthitta and Alappuzha, followed by three laboratory and three field studies comprised the research programme. The study was carried out during 2012-2015. Initial field experiment on standardizing application methods of pesticides was laid out at Instructional Farm, College of Agriculture, Vellayani, Thiruvananthapuram and the field experiments on prophylactic and curative methods of treatments were laid out at Aruvappulam, Konny, Pathanamthitta. Pesticide residue analysis was carried out at Pesticide Residue Research and Testing Laboratory, College of Agriculture, Vellayani. The materials and methods followed in the study are mentioned hereunder.

3.1 DOCUMENTATION OF PEST STATUS AND FARMERS' PRACTICES

Survey was conducted in four Southern districts of Kerala *viz.*, Thiruvananthapuram, Kollam, Alappuzha and Pathanamthitta using a pre planned proforma (Appendix I). Twenty five farmers were selected at random from each of the district under survey. In each plot, fifty plants at random were observed for pest incidence. The survey was conducted during June 2013 to December 2014.

3.1.1 Observations

Information gathered on various aspects from each plot/farmer was:

i. Problems encountered by farmers in banana cultivation
ii. Pest incidence on different variety/clone
iii. Major pests associated with banana
iv. Incidence of parasites, predators and bio control agents
v. Sucker treatment

vi. Pesticides applied, their dose and source of knowledge on pesticides

vii. Opinion on the effectiveness of different pest management components

viii. Adoption of safety measures while spraying

3.1.2 Use of Semiochemicals for Pest Monitoring

Pheromone for *O. longicollis* purchased from M/s. Chemtica International, Costa Rica was used to monitor the adult beetles in the selected field. The pheromone sachet was hung under the lid in a plastic bottle. The bottle was then tied on the pseudostem, three feet above the ground. Poisoned pseudostem pieces were kept inside the bottle to kill the trapped adult weevils. Traps were used at the rate of two traps for 10 cents (100 plants).

3.1.2.1 Testing Efficacy of Semiochemical in the Laboratory

The semiochemical was tested under laboratory conditions to record its efficacy in attracting *O. longicollis* adults. Pheromone sachet, pseudostem pieces, pheromone sachet + pseudostem pieces were placed on the inner periphery of a 45 cm diameter plastic basin. Twenty adult weevils were released at the middle of the basin and their movement was observed for 12 hour. Three replications of such unit were kept.

3.2 *IN VITRO* EVALUATION OF EFFICACY OF INSECTICIDES, BOTANICALS AND BIO-AGENTS

Grubs and adults for the experiment were reared on Nendran psueodostem pieces. Fresh psueodostem pieces were provided daily. The different treatments were,

T1 Chlorantraniliprole (18.5 EC @ 0.0075%)

T2 Thiamethoxam (25 WG @ 0.01%)

T3 Emamectin benzoate (5 G @ 0.002%)

T4 Indoxacarb (15.8 EC @ 0.01%)

T5 Cartap hydrochloride (50 SP @ 0.05%)

T6 Neem soap (1%)

T7 Neem oil emulsion (3%)

T8 Azadirachtin based formulation (1%EC @ 0.3%)

T9 Neem Seed Kernal Extract (NSKE) (5%)

T10 Cassava based preparation (CTCRI) (5%)

T11 *Beauveria bassiana* (NRCB) (2%)

T12 *Beauveria bassiana* (ITCC6063) (2%)

T13 *Metarhizium anisopliae* (CPCRI) (2%)

T14 Control

A. Details of chemicals and botanicals evaluated

Active ingredient and strength tested	**Commercial formulation used**	**Main and subgroup as per IRAC classification ver.8.0**	**Mode of action**
Chlorantraniliprole (18.5 EC @ 0.0075% ai)	Coragen 18.5EC (M/s. Dupont India Ltd.)	28	Ryanodine receptor modulators
Thiamethoxam (25 WG @ 0.01% ai)	Extra Super 25WG (M/s. Crystal, Jammu.)	4A	Nicotinic acetylcholine receptor (nAChR) agonists
Emamectin benzoate (5G @ 0.002% ai)	Proclaim 5SG (M/s. Syngenta, India)	6	Chloride channel activators
Indoxacarb (15.8 EC @ 0.01% ai)	Ammate 15.8EC (M/s. Dupont India Ltd.)	22A	Voltage-dependent sodium channel blockers
Cartap hydrochloride (50 SP @ 0.05% ai)	Fast 50SP (M/s. Tropical Agro, Chennai.)	14	Nicotinic acetylcholine receptor (nAChR) channel blockers

B. Details of bio agents evaluated

Bio agent used for the study	Source	Spore Concentration	Formulation and dose tested
Metarhizium anisopliae (Metschnikoff) Sorokin var. *majus* (Johnston) Tulloch renamed as *M. majus* Bisch, Rehner and Humber	CPCRI (RS), Kayamkulam	$1x10^9$	Talc based 20 g l^{-1}
Beauveria bassiana (ITCC 6063)	RARS, Onattukara	$1x10^9$	Talc based 20 g l^{-1}
Beauveria bassiana (NRCB)	Tari Bio-Tech, Thanjavur	$1x10^9$	Talc based 20 g l^{-1}

3.2.1 Maintenance of *O. longicollis* Stock Culture

Grubs were reared on 'Nendran' pseudostem pieces of sufficient size kept in plastic bottle of adequate size (21x40 cm). Fresh pseudostem pieces were given on every second day. Tissue paper was provided at the bottom to absorb excess moisture and water that oozed out from the pseudostem piece. Bottles were covered using nylon net to avoid entry of predators and to facilitate air circulation and these were kept in plastic trays filled with water to ward off ants. Pupae were collected and kept for adult emergence as described by Anitha, 2000.

3.2.2 Mortality of Adults

One week old adults were collected and used for the study. One ml each of the test solutions prepared at the desired concentrations were poured into a nine cm diameter Petri plate and prepared a dry film. After air drying, five adults were released into each Petri plate. Two such plates served as one replication. Three replications for each treatment were maintained. A control was also kept using

water as dry film. After one hour, banana pseudostem pieces of size 4x4cm were provided as food.

Mortality was observed in every 12 hour. The percentage mortality was calculated using Abotts' formula as

Mortality = X-Y/X x 100

where as X = the per cent living in the control

Y = the per cent living in the treatment

(Abbott, 1925)

3.2.3 Mortality of Grubs

Third instar grubs were collected from the stock culture and used for the experiment. One ml each of the test solutions prepared in the desired concentration was poured into a nine cm diameter Petri plate and prepared a dry film. Control plate was treated with water. The grubs were allowed to move on the dry film at the rate of two grubs per plate after which they were transferred to pesticide free pseudo stem pieces of 'Nendran' variety. Ten grubs represented one replication. Mortality was observed in every 12 hour. Each treatment was replicated thrice.

3.2.4 Repellency of Botanicals

Five botanical preparations *viz*., neem seed kernel extract (5%), neem soap (1%), cassava leaf distillate, 'Nanma' (3%), neem oil (3%) and azadirachtin formulation 1% EC (0.3%) were tested for their repellent effect on adult weevils both in single as well as multiple choice test.

3.2.4.1 Preparation of Neem Seed Kernel Extract

Five percent neem seed kernel extract (NSKE) was used for testing. Fifty gram crushed neem seed was taken in a muslin cloth and soaked overnight in one litre water and squeezed to extract the contents to get 5% neem seed kernel extract.

3.2.4.2 Preparation of Neem Oil Emulsion

Sixty gram washing soap was dissolved in 500 ml water and mixed with 30 ml neem oil with constant agitation and this was made up to one liter using water to get 3% neem oil emulsion.

3.2.4.3 Preparation of Neem Soap

Neem soap preparation from Mithraniketan KVK, Vellanad, Thiruvananthapuram was used for the study. Ten gram neem soap was mixed with one litre water to get one per cent solution.

3.2.4.4 Preparation of Neem Based Cassava Leaf Extract 'Nanma'

'Nanma', a ready to use preparation based on neem oil and cassava leaf distillate supplied from Central Tuber Crops Research Institute, Sreekaryam, Thiruvananthapuram was used. Thirty ml preparation was mixed with one liter water to get 3.0% solution.

3.2.4.5 Preparation of Azadirachtin 1%EC

Three ml of commercial formulation containing azadirachtin 1% EC (Neemazal) by M/s. Parry Agro was used in one litre to get 3.0% solution.

3.2.5 No Choice Test

Banana pseudostem pieces (var. Nendran) of size 15x6 cm were dipped in the botanical solutions *viz.*, neem seed kernel extract (5%), neem soap (1%), cassava leaf distillate, 'Nanma' (3%), neem oil (3%) and azadirachtin formulation 1% EC (0.3%) for one hour. A control was also set by dipping pseudostem pieces in water. After one hour the pieces were taken out and excess solution was drained off. Ten weevils were released per pseudostem piece and three replications for each treatment were kept in completely randomized design. The movement and feeding behavior were observed for 24 hour. Each treatment was tested in plastic bottles of size 21x40 cm.

3.2.6 Multiple Choice Tests

Pseudostem piece of cv. Nendran with 10x5 cm size was dipped in test solutions *viz.*, neem seed kernel extract (5%), neem soap (1%), cassava leaf distillate, 'Nanma' (3%), neem oil (3%) and azadirachtin formulation 1% EC (0.3%) and placed at equidistance towards the edge of round plastic basin and covered with nylon net. Twenty adult weevils were released at the middle of the basin and their movement and feeding behavior were observed for 24 hour. The test was replicated thrice under completely randomized design.

3.3 EFFECT OF CHEMICALS ON ENTOMOPATHOGENIC FUNGUS UNDER *IN VITRO* CONDITION

The effect of insecticides and botanicals found effective in experiment 3.2 and fungicides on the growth, sporulation and viability of entomopathogenic fungi (*M. majus*) found effective against *O. longicollis* in 3.2 was tested using poison food technique as described by Nene and Thapliyal (1993).

The details of different insecticides, botanicals and fungicides tested for their compatibility with *M. majus* are given below.

Pesticides tested for compatibility with *M. majus*

Treatments	**Concentration tested**	**Commercial formulation used & colour code**	**Manufactures**
Thiamethoxam 25 WG	0.01%	Tagxone (Blue)	M/s. Tropical Agrosystem (india) Pvt.Ltd., Chennai.
Thiamethoxam 25 WG	0.03%	Tagxone (Blue)	M/s. Tropical Agrosystem (india) Pvt.Ltd.
Cartap hydrochloride 50SP	0.05%	Fast 50SP (Yellow)	M/s. Tropical Agrosystem (india) Pvt.Ltd.

Neem soap	1.0%	IIHR- Neem Soap	ICAR-IIHR, Bengaluru.
Neemoil + Cassava leaf distillate	5.0%	'Nanma'	ICAR-CTCRI, Sreekaryam, Thiruvananthapuram.
Chlorpyrifos	0.05%	Tagban (Yellow)	M/s. Tropical Agrosystem (india) Pvt.Ltd., Chennai.
Carbendazim	0.1%	Bavistin 50WP (Green)	M/s. BASF Industries ltd., Mumbai.
Mancozeb	0.3%	Indofil M.45 (Green)	M/s. Indofil Industries Ltd., Mumbai.
Copperoxychloride	0.3%	Fytran 88WDP (Blue)	M/s. Travancore copper fungicide (P) Ltd., Ernakulam.
Azoxystrobin	0.1%	Amistar 23EC (Green)	M/s. Syngenta, Pune.
Propiconazole	0.1%	Tilt 25EC (Blue)	M/s. Syngenta, Pune.
Tebuconazole	0.1%	Folicur 25.9EC (Blue)	M/s. Bayer, Mumbai.

3.3.1 Effect of Pesticides on Growth of *M. majus*

The required quantity of chemicals was added to separate conical flasks each containing 100 ml sterilised molten potato dextrose agar (PDA) media before solidification at 45±3°C to get the concentrations mentioned in the table. The media was thoroughly shaken and 25 ml was poured into each sterile Petri plate (9 cm diameter). After solidification, plates were inoculated aseptically with 5 mm fungal discs cut out from 10 day old actively growing cultures of *M. majus* using a sterile cork borer. The plates were incubated at room temperature (28±2°C). Plates containing PDA without chemicals inoculated with test fungi served as control. The experimental design was CRD with three replications for each treatment.

Radial growth of fungi was measured once in two days, till the growth of fungi in control reached the maximum.

3.3.2 Effect of Pesticides on the Sporulation of the Fungi

Five discs having diameter of 0.5cm each were cut from the plates in 3.3.1 21 days after inoculation, representing different growth regions and put them in 1.0 ml sterile water taken in eppendorf tube, vortexed for three minutes to dislodge the spores. Spores were observed under 10 and 40X magnification using Neubauer Haemocytometer and quantified. In haemocytometer, spore count was calculated as;

$$\text{Spore ml}^{-1} = \text{Total spores counted/ Total number of cells} \times 10^4$$

3.3.3 Effect of Pesticides on Spore Viability of the Fungi

0.1 ml of the spore suspension prepared as described in 4.3.2 for each treatment pipetted and added to 0.9 ml sterile water taken in eppendorf tube. The suspension was serially diluted to get desired spore strength. Pipetted out 0.1 ml of the desired strength and was spread plated on sterilized PDA plates which were prepared on the previous day. The suspension was spread on the media using a glass L-rod by keeping the plates on a 'Spread Master'. The plates were incubated and counted the number of colonies and the colony forming units (cfu) was calculated as

Cfu=number of colonies counted x dilution factor / quantity of aliquot taken

3.3.4 Compatibility of *M. majus* with Pesticides

Compatibility of various pesticides used in banana agro-ecosystem with the entomopathogenic fungus was calculated using 'T' value as used by Neves *et al.* (2001). 'T' value was calculated as,

$$T = \frac{[20 \times VG] + [80 \times SP]}{100}$$

Where, VG = percentage of vegetative growth as compared to control

SG = percentage of sporulation as compared to control

Compatibility based on 'T' value are given below

'T' value	Compatibility classification
00 - 30	Very toxic
31 - 45	Toxic
46 - 60	Moderately toxic
> 60	Compatible

3.4 EVALUATION OF APPLICATION METHODS UNDER FIELD CONDITION

A banana plot (cv.Nendran) at the Instructional Farm, Vellayani was selected for the experiment. Recommended Package of Practices for Nendran banana was followed except pesticide application. Cutting of old leaf and leaf sheaths were followed as cultural control measure in all plants. Five plants were taken as one replication and each treatment was replicated twice. The design was randomaised block design (RBD). The treatments were given at five and six months after planting. Pest incidence was recorded using the index scoring (Anitha, 2000) and the yield was recorded.

The following treatments were evaluated in the 'Nendran' banana plot at Instructional Farm, Vellayani

T1 Thiamethoxam 0.01% swabbing

T2 Thiamethoxam 0.01% leaf axil filling

T3 Thiamethoxam 0.03% stem injection

T4 Thiamethoxam 0.01% spraying

T5 Thiamethoxam 0.01% swabbing+ leaf axil filling

T6 Thiamethoxam 0.01% spraying+ leaf axil filling

T7 Neem soap 1% swabbing

T8 Neem soap 1% leaf axil filling

T9 Neem soap 3% stem injection

T10 Neem soap 1% spraying

T11 Neem soap 1% swabbing+ leaf axil filling

T12 Neem soap 1% spraying+ leaf axil filling

T13 *M. majus* 2% leaf axil filling

T14 *M. majus* 2% swabbing

T15 *M. majus* 2% stem injection

T16 *M. majus* 2% spraying

T17 *M. majus* 2% swabbing+ leaf axil filling

T18 *M. majus* 2% spraying+ leaf axil filling

T19 Cassava based distillate ('Nanma') 5% spray+ leaf axil filling

T20 Chlorpyrifos (insecticide check) 0.03% leaf axil filling

T21 Cartap hydrochloride 0.05% swabbing

T22 Cartap hydrochloride 0.05% leaf axil filling

T23 Cartap hydrochloride 0.15% stem injection

T24 Cartap hydrochloride 0.05% spraying

T25 Cartap hydrochloride 0.05% swabbing+ leaf axil filling

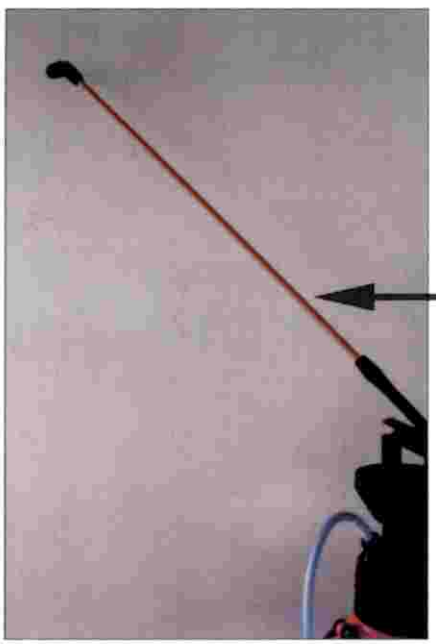
T26 Cartap hydrochloride 0.05% spraying+ leaf axil filling

T27 Control

3.4.1 Leaf Axil Filling

Starting from outermost leaf axil, all leaf axils except two adjacent leaf axils to the pipe leaf were filled with the test solution. Sprayer with extensible lance (Plate 1) was used to apply the solution into the leaf axil. For treating each plant, 200 ml solution was used.

A. Sprayer



B. Extensible lance

Plate 1. Application devices used in the study-HDPE sprayer with extensible lance

3.4.2 Swabbing on Pseudostem

3.4.2.1 Preparation of Chemicals for Swabbing

The desired concentration of insecticides and neem soap were prepared in water and mixed with water soluble starch powder (Alive) @10 g l^{-1}.

A four inch hair brush was used to swab the test solution all around the pseudostem from soil level to the base of the existing oldest live leaf axil.

3.4.2.2 Preparation of Bio Agent for Swabbing

M. majus formulation (ICAR-CPCRI, Kayamkulam) in partially cooked rice was used. Twenty grams of the formulation was mixed with water to get the desired concentration. Surfactant @ 3 ml l^{-1} and soluble starch powder (Alive) @10 g $l^{-1}$was added to the solution.

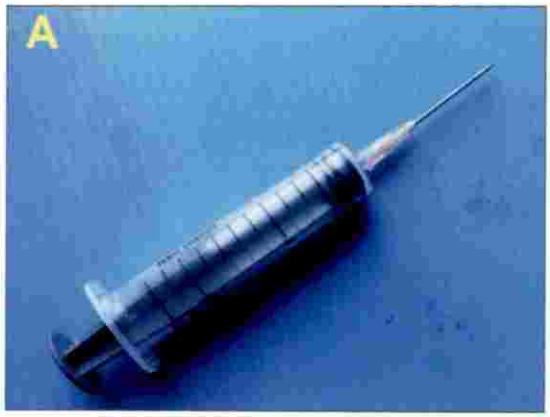
Swabbing was done as explained in 3.4.2.1.

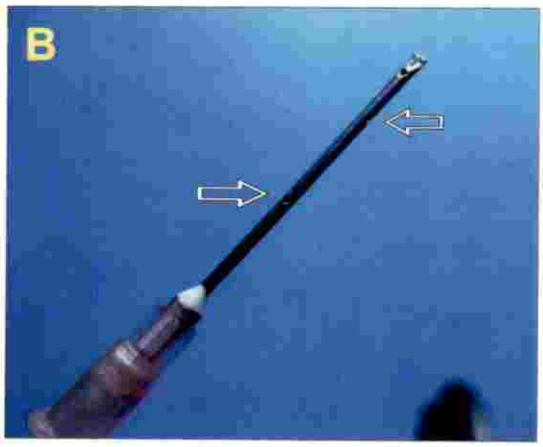
3.4.3 Spraying

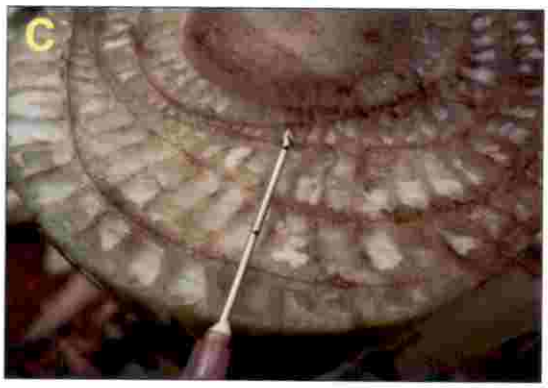
Aqueous solutions of chemical, botanical and bio agent were prepared with liquid starch as sticker @ 5ml l^{-1} and sprayed on the pseudostem from soil level to the base of the existing oldest live leaf axil.

3.4.4 Stem Injection

Three times the concentration of insecticides and botanicals used for spraying was used for injection. A special injection needle (1.2 mm diameter and 38 mm length) was made with closed tip and holes were made on the needle shaft (Plate 2). This will deliver the injection liquid to different pseudostem layers and prevent clogging of needle holes by fibre. This needle was attached to 12 ml syringe. A total of 10 ml of solution was injected per plant, at four points diagonally opposite to each other at 60, 90, 120 and 150 cm @ 2.5 ml per







A- Special needle assembled to 12 ml syringe
B- Multiple holes on needle
C- Reach of needle inside the pseudostem

Plate 2. Application devices used in the study-special needle assembly

injection point. The needle was inserted into the stem at 30^0 angles to the stem to avoid any possible injury to inner developing core.

3.5 FIELD EVALUATION - PROPHYLACTIC METHOD

A farmer's plot was selected at Aruvappulam Panchayath, Konny, Pathanamthitta district for the experiment. The selected field and nearby area were epizootic to *O. longicollis* infestation.

Prophylactic method with insecticide, botanical, bio-agent and their combinations treatments for managing *O. longicollis* were tested in the field for their efficacy in cv. Nendran. Application method for each was selected based on the results of the experiment 3.4. The treatments were applied on 5^{th} and 6^{th} month after planting. Design of the experiment was randomized block design with three replications and each replication consisted of four plants.

The various treatments were;

T1 Thiamethoxam 0.03% injection at 5&6MAP

T2 Neem soap 1% at 5&6MAP

T3 *M. majus* 2% at 5&6MAP

T4 Thiamethoxam 0.03% injection at 5MAP + *M. majus* 2% at 6MAP

T5 Thiamethoxam 0.03% injection at 5MAP + neem soap 1% at 6MAP

T6 *M. majus* 2% at 5MAP + thiamethoxam 0.03% injection at 6MAP

T7 *M. majus* 2% at 5MAP + neem soap 1% at 6MAP

T8 Neem soap 1% at 5MAP + thiamethoxam 0.03% injection at 6MAP

T9 Neem soap 1% at 5MAP + *M. majus* 2% at 6MAP

T10 Cassava leaf distillate ('Nanma') 5% at 5&6MAP

T11 Chlorpyrifos 0.03% at 5&6MAP

T12 Thiamethoxam 0.01% LAF at 5&6MAP

T13 Thiamethoxam 0.01% LAF at 5MAP + *M. majus* 2% at 6MAP

T14 Thiamethoxam 0.01% LAF at 5MAP + neem soap 1% at 6MAP

T15 *M. majus* 2% at 5MAP + thiamethoxam 0.01% LAF at 6MAP

T16 Neem soap 1% at 5MAP + thiamethoxam 0.01% LAF at 6MAP

T17 Control

3.5.1 Calculation of BC Ratio

Benefit cost ratio for all the treatments was calculated by slight modification to the method used by Justin *et al.* (2006) as.

$$BCR = \frac{\text{Mean yield for treatment (kg) x Market price (Rs. kg}^{-1})}{\text{Cost of cultivation (Rs.) + Cost for treatment (Rs.)}}$$

3.6 FIELD EVALUATION - CURATIVE METHOD

Effect of different curative method against *O. longicollis* in cv. Nendran with insecticide, botanical, bio-agent using their suitable application method based on the results of the experiment 3.4 was tested in farmers' field at Aruvappulam, Konny, Pathanamthitta district. The treatments were applied based on the ooze out and holes formed on the stem by *O. longicollis* and according to the damage score developed earlier by Anitha (2000). Design of the experiment was randomized block design with three replications and each replication consisted of five plants.

The various treatments were;

T1 Thiamethoxam 0.03 % injection

T2 Thiamethoxam 0.01 % LAF

T3 Neem Soap 1.0 % spray and LAF

T4 *M. majus* 2.0 % swabbing and LAF

T5 Cassava leaf distillate ('Menma') 15 ml plant^{-1} injection

T6 Chlorpyrifos 0.03 %

T7 Control

3.6.1 Application of Cassava Based Preparation- 'Menma'

'Menma', another formulation of cassava leaf extract for injection was used in curative method. Fifteen ml of 'Menma' was injected at three points on the stem at 5.0 cm below the injury hole by *O. longicollis* grubs using the specialized needle @ 5 ml/injection point.

3.6.2 Calculation of BC Ratio

Benefit cost ratio for all the treatments was calculated as explained in 3.5.1

3.7 ESTIMATION OF HARVEST TIME RESIDUES OF INSECTICIDE IN BANANA

The estimation of thiamethoxam residues in banana was done in the Pesticide Residue Research and Analytical Laboratory, AINP on Pesticide Residues, College of Agriculture, Vellayani using LC-MS/MS (Applied Biosystems API-3200 triple quadrupole MS-MS with electro spray ionisation (ESI) in the positive mode coupled to a Waters LC (Acquity UPLC). Residues of thiamethoxam were estimated from edible parts *i.e.*, male bud, raw fruit and peduncle. Validation parameters *viz.,* Limit of Detection, Limit of Quantification, Linearity, Recovery and Repeatability were evaluated.

3.7.1 Fortification and Recovery Experiment

Banana (500 g) harvested from control plots were chopped and ground to a fine paste. Five replicates of 25 g representative samples of the fruits were taken in 50 ml centrifuge tubes and spiked at 0.05, 0.25 and 0.5 mg kg^{-1} levels with the pure analytical standards of the insecticide, thiamethoxam. The extraction and clean-up was done following the QuEChERS (Quick, Easy, Cheap, Effective, Rugged and Safe) method (Anastassiades *et.al.*,2003) and quantified using UPLC-MS/MS under optimized conditions.

3.7.2 Sample Collection

3.7.2.1 Collection of Male Bud Sample for Residue Estimation

Male buds of thiamethoxam treated plants were collected after full blooming of fingers. One bud was taken from every treatment involving insecticide and loose bracts were removed. Then it was blended and homogenized. Twenty five gram sample was taken from the whole blended sample for residue estimation.

3.7.2.2 Collection of Fruits for Residue Estimation

A total of 500 g of fruit with peel was taken from each harvested bunch in every thiamethoxam treatment for analysis.

3.7.2.3 Collection of Peduncle for Residue Estimation

The inner core or peduncle of the plant was tested for any residue present. From every thiamethoxam treatment, peduncle from above one meter from the ground was collected at harvest. The outer sheaths were peeled off and inner core obtained was used for residue estimation.

3.7.3 Estimation of Pesticide Residue from Banana Samples

A sub- sample of 500 g banana, male bud and peduncle were taken from each of the thiamethoxam treatment plot by quartering and comminuting.

Pesticide residues in the samples collected were estimated at PRRL, College of Agriculture, Vellayani. The standard procedures under QuEChERS method for pesticide residue analysis in fruits and vegetables were followed.

3.7.3.1 Clean up and Extraction

The blended sample (25g) was taken from each replicate, homogenized at 14,000 rpm using a tissue homogenizer for two minutes after adding 50 ml acetonitrile. The samples were shaken for one minute and 10 g sodium chloride was added. The sample was centrifuged for five minutes at 2500 rpm. A 16 mL supernatant was transferred into 50 mL centrifuge tube containing 6 g anhyd. Na_2SO_4 and mixed well using high speed vortex shaker for 2 min. A 12 ml extract was transferred to a 15 mL centrifuge tube containing 0.2 ± 0.01 g PSA sorbent and 1.2 ± 0.01 g anhydrous $MgSO_4$. The sample was shaken and centrifuged for about three minutes at 2500 rpm. Five ml of supernatant was evaporated in turbovap and made up with two ml using methanol for LC-MS/MS analysis.

3.7.3.2. Estimation of Pesticide Residue in Samples

The chromatographic separation was achieved using Waters Acquity UPCL system equipped with a reversed phase Atlantis C-18 (2.1 × 100 mm, 5 micron particle size) column. A gradient system involving the following two eluent components: A: 10 per cent methonal in water + 0.1 per cent formic acid + 50 mM ammonium acetate; B: 10 per cent water in methonal + 0.10 per cent formic acid + 50 mM ammonium acetate was used as mobile phase for the separation of residues.

The residue of thiamethoxam was estimated using LC-MS/MS operated under the following conditions.

Make & Model	Waters Acquity-UPLC + API 3200 (AB SCIEX) LC -MS/MS
Column	Atlantis $dC_{18,}$ 5 µm, 2.1 X 100 mm column
Detector	Mass detector
Mobile Phase	A-10 % Methanol in water + 5 millimolar Ammonium Acetate B- 10% water in Methanol + 5 millimolar Ammonium Acetate
Flow rate	0.8 ml min^{-1}
Injected volume	10 µL
Column temp.	40°C
Retention Time	
Retention time of Thiamethoxam	0.88 m
Limit of quantification (LOQ)	0.05 mg kg^{-1}
Limit of detection (LOD)	0.05 mg kg^{-1}

Based on the peak area of the chromatogram obtained for various insecticides, the quantity of residue was determined as detailed below.

Pesticide Residue (mg kg^{-1}) = Concentration obtained from chromatogram by using calibration curve × Dilution factor

$$\text{Dilution factor} = \frac{\text{Volume of the solvent added} \times \text{Final volume of extract}}{\text{Weight of sample (g)} \times \text{Volume of extract taken for conc.}}$$

The Limit of Quantification (LOQ) of this method was 0.05 mg kg^{-1}.

Calibration curve and chromatograms are attached as appendix II and III.

3.8 MATRIX SCORING OF FARMER'S CHOICE ON DIFFERENT APPLICATION DEVICES OF PESTICIDE

Evaluation of different pesticide application devices such as conventional metal sprayer, HDPE sprayer with extensible lance and syringe with modified needle was carried out among selected twenty farmers.

Response of twenty farmers to different pesticide application devices such as conventional metal sprayer, HDPE sprayer with extensible lance and syringe with modified needle was recorded. The farmers were asked to evaluate different pesticide application devices such as conventional metal sprayer, HDPE sprayer with extensible lance and syringe with modified needle.

Scores from 1 to 3 was given according to their perception from bad to best for each device with respect to corresponding attribute. The proforma is given as appendix IV. The scores were presented in a matrix and scores were compared.

Results

4. RESULTS

The current study included documentation of pest status and farmers' practices, evaluation of efficacy of insecticides, botanicals and bio agents against *O. longicollis*, standardizing different application methods, evaluating both prophylactic as well as curative method and estimation of harvest time residues in edible parts of treated plants. The results of these experiments are elaborated below.

4.1 DOCUMENTATION OF PEST STATUS AND FARMERS' PRACTICES

Documentation of pest status and farmers practices was done in four southern districts of Kerala *viz*. Thiruvananthapuram, Kollam, Pathanamthitta and Alappuzha. From each district 25 farmers cultivating not less than 50 'Nendran' plants of five months old, were selected for the study. Personal interviews using an approved proforma were conducted for collecting pertinent information. In each district, three banana growing villages were selected. From each village farmers were selected at random and collected data in the approved proforma (Appendix I). Infestation of *O. longicollis* on 'Nendran' and other varieties was recorded from each plot. The study was conducted during June to December in 2013.

4.1.1 Intensity of *O. longicollis* Infestation

O. longicollis infestation in cv. Nendran and other varieties was observed in the survey. The details are presented in table 1.

Maximum infestation of *O. longicollis* was noticed in cv. Nendran (6.41 per cent), followed by Palayankodan (5.21per cent). Red banana and Njalipoovan recorded a mean infestation of 4.59 and 2.13 per cent, respectively. In survey, Robusta did not show any infestation by *O. longicollis*.

Table 1. Intensity of *O. longicollis* infestation on different banana varieties in southern districts of Kerala

Variety	Damage by *O. longicollis* (n=50) (%)				
	Thiruvanan-thapuram	Kollam	Pathanamthitta	Alappuzha	Pooled mean
Nendran	6.88 (3.257)	5.36 (3.818)	7.64 (4.76)	5.76 (3.333)	6.41
Njalipoovan	1.6 (0.548)	1.5 (0.707)	3.63 (2.387)	1.8 (0.837)	2.13
Palayamkodan	4.11 (1.779)	3.71 (1.139)	8.95 (7.392)	4.05 (1.779)	5.21
Red banana	4.3 (1.869)	4.35 (2.206)	5.00 (2.391)	4.71 (2.812)	4.59
Robusta	0.00	0.00	0.00	0.00	0.00

Figures in parenthesis are standard deviation values

Infestation in cv. Nendran was maximum in Pathanamthitta district (7.64 per cent) followed by Thiruvananthapuram district (6.88 per cent). The infestation was the least in Kollam district (5.36 per cent).

Popular cultivars *viz*. Njalipoovan, Palayankodan and Red Banana were found infested with the pest, but with varying percentage of damage. The cv. Njalipoovan recorded maximum infestation in Pathanamthitta district (3.63 per cent) and the least in Kollam (1.5 per cent). Maximum infestation in Palayankodan variety was also noted in Pathanamthitta district (8.95 per cent), followed by Thiruvananthapuranm (4.11 per cent) and Alappuzha (4.05 per cent). Kollam district registered the lowest infestation by *O. longicollis* in cv. Palayankodan. Maximum infestation by the pest in Red Banana was observed in Kollam district (5.00 per cent), while the least in Thiruvananthapuram (4.30 per cent).

Pseudostem borer, *O. longicollis* was ranked as a major problem by the farmers. Out of the 25 farmers surveyed, 23 in Pathanamthitta, 24 each in Kollam and Alappuzha and 25 in Thiruvananthapuram recorded *O. longicollis* as a major pest (Fig. 1).

4.1.2 Other Emerging Pests

The data collected on other emerging pests of banana are presented in fig. 1. Rhizome weevil, *C. sordidus* was a major concern to farmers in Thiruvananthapuram (8), Kollam (9), Pathamnamthitta (8) and Alappuzha (18).

Leaf eating caterpillar (*Spodoptera litura* F.) especially in early months of the crop establishment was also cited as a problem by farmers. Banana skipper, *Erionota* sp. (Plate 3) was recorded from all the four districts. The infestation was noted in all popular cultivars of banana in the surveyed districts. But a preference was noticed towards the cv. Nendran, Njalipoovan and Palayankodan.

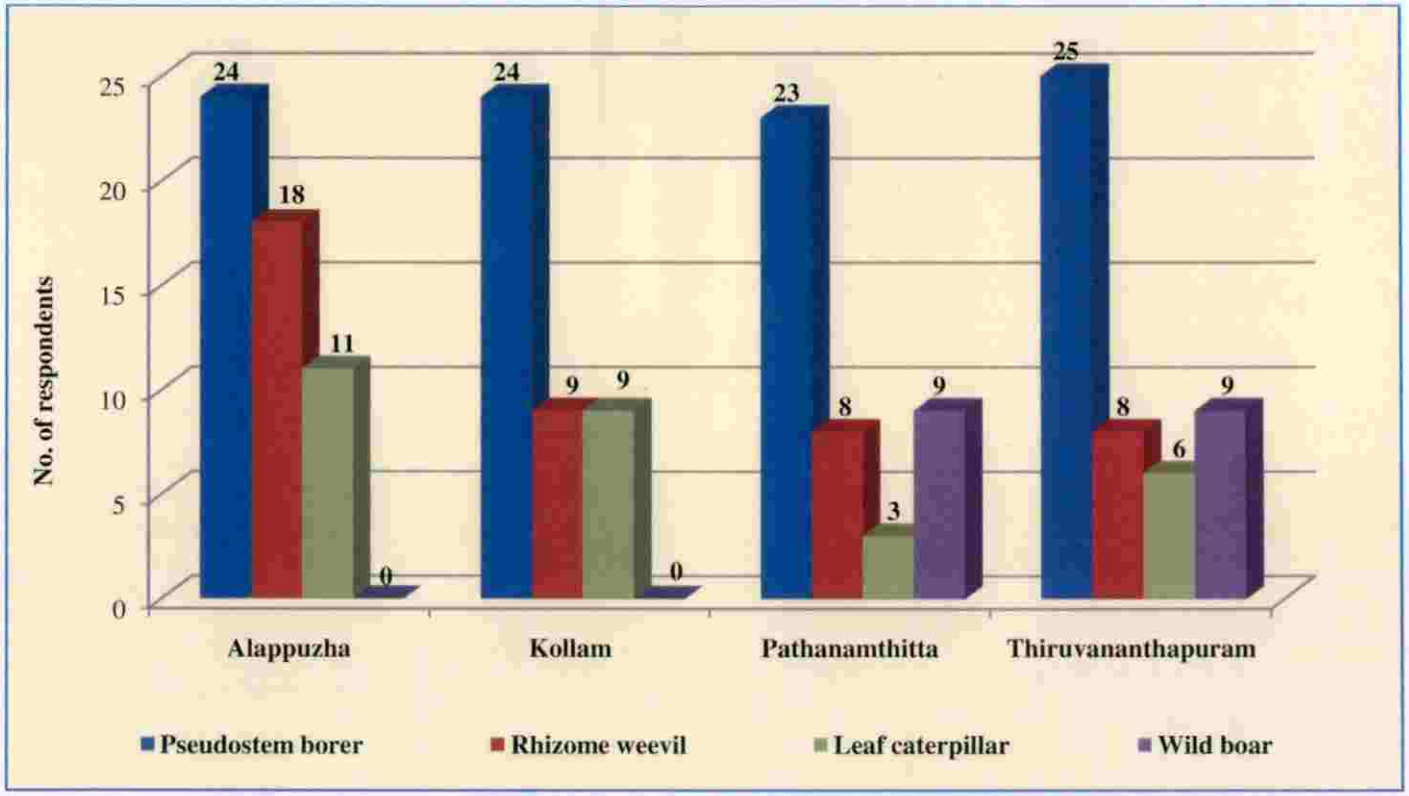


Fig. 1 Farmers' responses on pest problems in banana

A

B

C

A-Larva
B-Adult
C-Leaf roll made by larva

Plate 3. Different life stages and symptoms of *Erionota* sp.

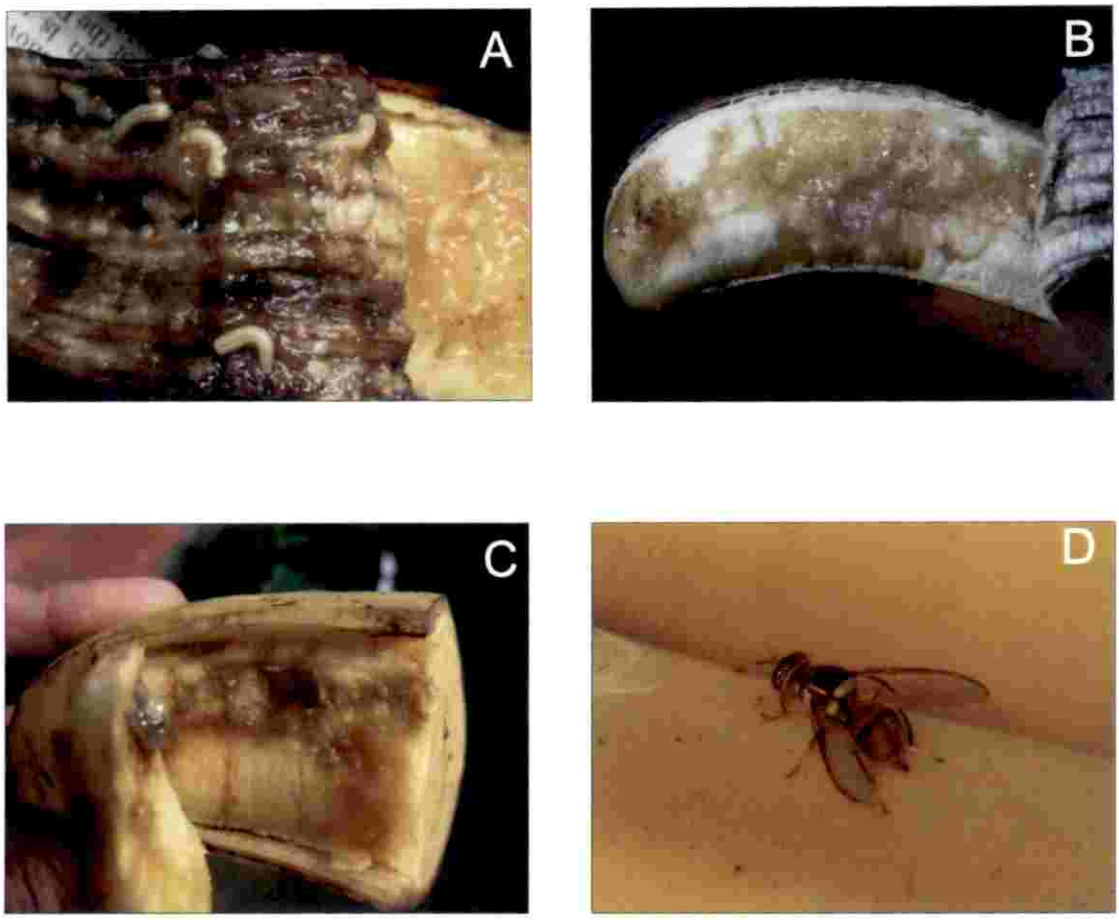
Rhinoceros beetle was recorded as pest of banana from Thiruvananthapuram (2), Kollam (2), Pathamnamthitta (1) and Alappuzha (2) districts. Wild boar (*Sus scrofa* L.) was a problem in banana cultivation, particularly in area near to forest in Pathanamthitta and Thiruvananthapuram. Nine out of the 25 respondents from each of these districts registered wild boar as their main vertebrate pest in banana cultivation.

Fruit fly infestation on fruits of cv. Nendran, Palayankodan, Robusta, Red Banana and Njalipoovan from retail shops was observed during the survey in 2013 and 2014. The infested fruits were kept for adult emergence and the species was identified as *Bactrocera dorsalis* (Hendel) (Plate 4). Fruit fly infested fruit samples of Nendran, Red Banana and Palayankodan were collected from three locations (Adoor, Konni and Kodumon) in Pathanamthitta district. In Kollam district the infestation was noticed in Robusta, Palayankodan and Red Banana at Kottarakkara and Kollam, while in Thiruvananathapuram fruit fly infested fruits of Palayankodan, Red Banana and Poovan were observed from Vellayani.

During the survey, adult weevils of *Polytus mellerborgi* (Boheman) were collected from leaf sheaths of Palayankodan from Kollam (Plate 5A). Infestation of brown scale, *Coccus hesperidium* L. was noticed on bunches and fruits of Red Banana in Thiruvananthapuram and Kollam district (Plate 5B). .

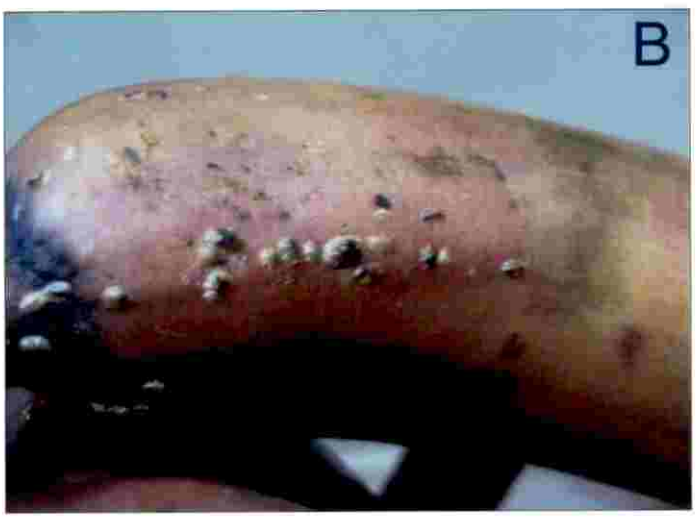
4.1.3 Insecticides Used by Farmers in Banana

Different pesticides were used by the farmers against insect pests and diseases of banana. Farmers used organic preparations also against psuedostem weevil, but with a lesser frequency. Details of insecticide use by farmers in all four districts are given in table 2. The data on pesticide use in banana agro eco system revealed the dominance of chlorpyrifos (40 per cent) followed by quinalphos (37 per cent). Granular formulations of fipronil and cartap hydrochloride were used by 20 and four per cent farmers, respectively. Synthetic



A- *B. dorsalis* maggots on the fruit skin
B- *B. dorsalis* infestation in Red Banana
C- *B. dorsalis* infestation in Nendran
D-Adult *B. dorsalis*

Plate 4. Emerging pests in banana- Fruit fly (*Bactrocera dorsalis*)



A- *Polytus mellerborgi* adult
B- *Coccus hesperidium* on Red Banana fruit

Plate 5. Emerging pests in banana

pyrethroids like λ-cyhalothrin (7.0 per cent), fenvalerate (5.0 per cent), cypermethrin (3.0 per cent) and deltamethrin (1.0 per cent) were also used for pest management. Carbaryl which is one of the recommended insecticides for the management of *O. longicollis* was used by five per cent of the respondents. None of the surveyed farmers in Thiruvananthapuram and Kollam was found using carbaryl.

The insecticides, carbofuran and carbosulfan were used by five and two per cent farmers, respectively. The banned insecticide, carbofuran use was observed among four respondents in Thiruvananthapuram and one in Alappuzha district.

Chlorpyrifos was the most preferred insecticides for banana growers in Thiruvananthapuram (12) and Pathanamthitta (9) districts. Quinalphos was applied by fifteen and ten out of the 25 respondents in Alappuzha and Kollam districts, respectively.

Organic preparation like neem oil (8.0 per cent), 'Nanma' (6.0 per cent), Panchagavya (1.0 per cent), tobacco decoction (1.0 per cent) and cow's urine + pepper (2.0 per cent) were also used by farmers to contain pest problems in banana.

Among the fungicides used, propiconazole (18 per cent) was the most preferred chemical against various diseases, followed by mancozeb (10 per cent). Three per cent farmers followed disease management using the bio agent *Pseudomonas fluorescens* Migula.

From the data recorded in this study, it is obvious that farmers relied on insecticides to manage the pests rather than any bio rational methods.

Table 2. Insecticides used in banana for pest management by farmers

Insecticide	Number of respondents*				
	Thiruvanan-thapuram	Kollam	Pathanamthitta	Alappuzha	Total (%)
Quinalphos	6	10	6	15	37
Chlorpyrifos	12	10	9	9	40
Imidacloprid	0	1	0	3	4
Neem oil	4	3	0	1	8
Dimethoate	0	0	2	1	3
Cartap hydrochloride	0	0	2	2	4
δ cyhalothrin	5	0	0	2	7
Pseudomonas	0	2	0	1	3
Carbofuran	4	0	0	1	5
Carbaryl	0	0	1	4	5
Mancozeb	4	2	2	2	10
Naphthelene balls	0	0	0	1	1
Fipronil	4	9	6	1	20
Propiconazole	3	8	2	5	18
Nanma	1	2	0	3	6
Carbendazim	0	2	1	1	4
Panchagavyam	0	1	0	0	1
Cow's urine +pepper	1	1	0	0	2
Carbosulfan	0	1	1	0	2
Fenvalerate	2	0	3	0	5
Cypermethrin	0	0	3	0	3
Hexaconazole	2	0	1	0	3
Tobacco decoction	0	0	1	0	1
Deltamethrin	1	0	0	0	1

*In each district, 25 respondents

4.1.4 Protective Gadgets Used by Farmers

Details of use of personal protective gadgets and post-spray personal hygienic practices were recorded and presented in table 3. All the respondents (100 per cent) practiced washing off their clothes and taking bath after spraying.

Based on the study, 72 per cent of the respondents used full sleeve shirts while spraying to cover their hands and body while 71 per cent used mask to avoid accidental inhalation of spray. Head covering using clothes, caps, hats or plastic covers were practiced by 67 per cent of the respondents. But use of goggles or glasses for eye protection and gloves were used only by 11 per cent. In the four districts, protection gadgets such as goggles, masks and gloves were used by farmers but its use varied from zero to 96 percent. Use of gloves and goggles/glasses was the highest in Thiruvananthapuram district (28 and 36 per cent, respectively). Proper disposal of the used pesticide containers/covers was practiced by 36 per cent farmers only; maximum in Thiruvananthapuram (48 per cent) and minimum in Kollam (20 per cent) district.

Consuming foods, chewing and smoking in between spraying were done only by 1, 2 and 3 per cent farmers, respectively. But only two per cent of the respondents used boots to cover their foot while spraying.

4.1.5 Source of Knowledge

Data was also collected from farmers on the information source with respect to type and quantity of pesticide, its time of application and other pesticide recommendations. In all the districts, Vegetable and Fruit Promotion Council – Keralam (VFPCK) and Krishi Bhavan (KB) served as the main source of information for banana farmers (Tables 4 to 7). It was observed that farmers use multiple sources for getting knowledge regarding pest management.

Table 3. Use of protective gadgets and activities related to pesticide application in four southern districts of Kerala

Parameter	Percentage of surveyed farmers using different protection gadgets (n=25/district)				
	Thiruvanan-thapuram	Kollam	Pathanamthitta	Alappuzha	Pooled mean
Using gloves while handling pesticides	28.00	8.00	8.00	0.00	11.00
Using bottle opener	0.00	12.00	4.00	8.00	6.00
Using goggles while spraying	36.00	4.00	0.00	4.00	11.00
Using mask while spraying	96.00	60.00	72.00	56.00	71.00
Wearing full sleeve shirt while spraying	84.00	76.00	64.00	64.00	72.00
Using head cap	88.00	56.0	52.00	72.00	67.00
Using boots	4.00	0.00	4.00	0.00	2.00
Consuming foods/drink between spraying	4.00	0.00	0.00	0.00	1.00
Smoking between spraying	8.00	0.00	0.00	4.00	3.00
Chewing between spraying	4.00	0.00	0.00	4.00	2.00
Drinking water while spraying	32.00	16.00	4.00	12.00	16.00
Wash clothes immediately after spraying	100.00	100.00	100.00	100.00	100.00
Taking bath after spraying	100.00	100.00	100.00	100.00	100.00
Disposing off bottles promptly	48.00	20.00	32.00	44.00	36.00

Banana growers in Thiruvananthapuram district mainly depended on KBs and VFPCK centers as their sources of technical empowerment. Sixteen persons approached Krishi Bhavans for information regarding type of pesticides (Table 4). For queries such as quantity of pesticide, time of application and other pests, majority of the farmers relied on KBs.

In Kollam district, maximum of 15 and 10 farmers approached VFPCK and KB, respectively to collect information on plant protection in banana (Table 5). But time of application of pesticides was judged by themselves (15 no.).

Krishi Bhavans and VFPCK served as the main knowledge centers in Pathanamthitta, but pesticide shop keepers also influence farmers especially in deciding the quantity of pesticide (Table 6).

In Alappuzha district, farmers depended on VFPCK, KB, Krishi Vigyan Kendra (KVK) and lead farmers for type and dose of pesticide (Table 7). But they depended on their own experience in deciding the time of application of pesticide.

4.1.6 Parasites and Predators

No major and promising parasites/predators/pathogens of *O. longicollis* were encountered in the survey. Common predators such as earwigs (*Forficula* sp. Dermaptera: Forficulidae) (Plate 6) and ants [*Oecophylla smaragdina* (F.) Hymenoptera: Formicidae)] were observed in the field (Plate 7). Different spiders were also observed in the banana agro- ecosystem. The bacterial pathogen isolated from the dead grub collected was identified at Cashew Export Promotion Council Laboratory as *Enterobacter aerogenes* Hormaeche and Edwards.

Table 4. Farmers' dependence on various technology sources for pesticide application in banana - Thiruvananthapuram district

Nature of information	Number of respondents*						
	Shopkeeper	Lead farmer	KVK	VFPCK	KB	Own experience	COA
Type of pesticide	3	3	2	10	16	5	1
Qty of pesticide	4	2	2	10	14	3	1
Time of application	3	4	2	8	14	7	0
Recommendations for pesticides other than BPSW	2	8	2	8	15	6	1

(*n=25, multiple response)

Table 5. Farmers' dependence on various technology sources for pesticide application in banana - Kollam district

Nature of information	Number of respondents*					
	Shopkeeper	Lead farmer	KVK	VFPCK	KB	Own experience
Type of pesticide	0	1	3	15	10	10
Qty of pesticide	3	0	2	13	7	9
Time of application	0	0	2	12	4	15
Recommendations for pesticides other than BPSW	1	2	3	13	9	7

(*n=25, multiple response)

KVK=Krishi Vigyan Kendra, VFPCK- Vegetable & Fruit promotion-Keralam;
KB-Krishi Bhavan

Table 6. Farmers' dependence on various technology sources for pesticide application in banana - Pathanamthitta district

Nature of information	Number of respondents*					
	Shopkeeper	Lead farmer	KVK	VFPCK	KB	Own experience
Type of pesticide	6	7	0	8	11	2
Qty of pesticide	9	5	0	4	8	6
Time of application	4	3	0	3	7	10
Recommendations for pesticides other than BPSW	4	6	0	8	12	2

(*n=25, multiple response)

Table 7. Farmers' dependence on various technology sources for pesticide application in banana - Alappuzha district

Nature of information	Number of respondents*					
	Shopkeeper	Lead farmer	KVK	VFPCK	KB	Own experience
Type of pesticide	1	4	3	15	10	3
Qty of pesticide	0	3	2	14	4	7
Time of application	1	2	2	10	4	11
Recommendations for pesticides other than BPSW	1	2	3	16	6	3

(*n=25, multiple response)

KVK=Krishi Vigyan Kendra, VFPCK- Vegetable & Fruit promotion-Keralam;
KB-Krishi Bhavan

Plate 6. Earwig collected from pseudostem

Plate 7. *Oecophylla smaragdina* attacking on *Odoiporus* adults

4.1.7 Evaluation of Efficacy of Semiochemical

Semiochemical purchased from M/s. Chem Tica International, Costa Rica was tested in laboratory and field conditions (Plate 8). In the laboratory, the attractiveness of the semiochemical lure was tested in confined environment in a plastic basin. The lure and banana pseudostem pieces of different stages were arranged on the periphery of the vessel and twenty adults were released at the centre as described in 3.1.2.1. Examination after one hour showed no adults on or near the lure, instead they were attracted towards pseudostem pieces. No orientation toward the lure was noticed in the laboratory experiment.

The lure was placed in a one litre container with holes, for using it in the field as detailed in 3.1.2. No *O. longicollis* weevils were caught in any trap kept at different places showed the inefficiency of the lure to attract weevils. Further investigations were not done, as the lure was not effective under laboratory and field conditions.

4.2 *IN VITRO* EVALUATION OF EFFICACY OF INSECTICIDES, BOTANICALS AND BIO AGENTS

Efficacy of five insecticides, five botanicals and three bio agents on adults and grubs of *O. longicollis* was tested in laboratory conditions at the College of Agriculture during 2013.

4.2.1 Effect of Insecticides on Mortality of *O. longicollis* Grubs

Effect of different insecticides on *O. longicollis* grubs is described in table 8. Mortality of grubs treated with different insecticides after 12HAT ranged from zero to 86.67 per cent. At twelve hours after treatment, grubs treated with

Plate 8. Testing of semiochemical in the field

Table 8. Effect of new generation insecticides on *O. longicollis* grubs under laboratory conditions

Insecticide	Mortality of grubs (%)					
	12 HAT	24 HAT	36HAT	48 HAT	60 HAT	72 HAT
Chlorantraniliprole 0.0075%	0.0 [d] (0.909)	0.0 [c] (0.909)	6.67 [b] (12.599)	6.67 [b] (12.599)	6.67 [b] (12.599)	10.0 [b] (15.309)
Thiamethoxam 0.01%	43.33 [c] (41.073)	100.0 [a] (89.090)	100.0 [a] (89.090)	100.0 [a] (89.090)	100.0 [a] (89.090)	100.0 [a] (89.090)
Indoxacarb 0.01%	66.67 [b] (54.996)	83.33 [b] (66.149)	100.0 [a] (89.090)	100.0 [a] (89.090)	100.0 [a] (89.090)	100.0 [a] (89.090)
Cartap hydrochloride 0.05%	83.33 [a] (66.149)	93.33 [a] (80.540)	100.0 [a] (89.090)	100.0 [a] (89.090)	100.0 [a] (89.090)	100.0 [a] (89.090)
Emamectin benzoate 0.002%	86.67 [a] (68.85)	100.0 [a] (89.090)	100.0 [a] (89.090)	100.0 [a] (89.090)	100.0 [a] (89.090)	100.0 [a] (89.090)
Control	0.0 [d] (0.909)	0.0 [c] (0.909)	0.0 [c] (0.909)	0.0 [c] (0.909)	0.0 [c] (0.909)	0.0 [c] (0.909)
CD(0.05)	9.662	11.283	7.357	7.357	7.357	9.526

Treatment means with same alphabets are on par
Figures in parenthesis are arc sine transformed values
HAT- Hours after treatment

emmamectin benzoate (0.002%) and cartap hydrochloride (0.05%) showed maximum mortality of 86.67 per cent and 83.33 per cent, respectively. Both these chemicals were significantly superior to other chemicals. Grubs treated with indoxacarb (0.01%) recorded 66.67 per cent mortality while chlorantraniliprole (0.0075%) and control did not have any effect on mortality of grubs.

Cent percent mortality of grubs was recorded for thiamethoxam (0.01%) and emamectin benzoate (0.002%) at 24HAT followed by cartap hydrochloride 0.05% (93.33 per cent) and indoxacarb 0.01% (83.33 per cent) while chlorantraniliprole 0.0075% and control showed no mortality.

Insecticides *viz.*, thiamethoxam 0.01%, indoxacarb 0.01%, emamectin benzoate 0.002 % and cartap hydrochloride 0.05% registered 100.00 per cent mortality of grubs at 36HAT. Cartap hydrochloride 0.05% and indoxacarb 0.01% registered 100 per cent mortality of grubs only after 36 hours of treatment and became on par with thiamethoxam 0.01% and emamectin benzoate 0.002%. Chlorantraniliprole 0.0075% showed only 6.67 per cent mortality of grubs whereas all control grubs were alive. No further change in mortality percentage was noticed for next 24 hours.

Examination of data on mortality of grubs of *O. longicollis* after 72 hours of treatment showed that thiamethoxam, indoxacarb, emamectin benzoate and cartap hydrochloride were significantly superior to chlorantraniliprole (10 per cent) and control (0.0 per cent).

4.2.2 Effect of Insecticides on the Mortality of *O. longicollis* Adults

Mortality of adults of *O. logicollis* at different time intervals when treated with different insecticides is given in table 9.

Table 9. Effect of new generation insecticides on *O. longicollis* adults under laboratory conditions

Insecticide	Concentration (%)	Mortality of weevils (%)					
		12 HAT	24 HAT	36HAT	48 HAT	60 HAT	72 HAT
Chlorantraniliprole 0.0075%	0.0075	0.0 (0.91)	0.0 (0.91)	36.67 [b] (36.15)	36.67 [b] (36.15)	36.67 [b] (36.15)	36.67 [b] (36.15)
Thiamethoxam 0.01%	0.01	43.33 [c] (41.15)	70.0 [b] (56.99)	100.00 [a] (89.09)	100.00 [a] (89.09)	100.00 [a] (89.09)	100.00 [a] (89.09)
Indoxacarb 0.01%	0.01	0.0 (0.91)	0.0 (0.91)	0.0 (0.91)	0.0 (0.91)	0.0 (0.91)	0.0 (0.91)
Cartap hydrochloride 0.05%	0.05	100.00 [a] (89.09)	100.00 [a] (89.09)	100.00 [a] (89.09)	100.00 [a] (89.09)	100.00 [a] (89.09)	100.00 [a] (89.09)
Emamectin benzoate 0.002%	0.002	86.67 [b] (68.85)	100.00 [a] (89.09)	100.00 [a] (89.09)	100.00 [a] (89.09)	100.00 [a] (89.09)	100.0 [a] (89.09)
Control	0.0	0.0 (0.91)	0.0 (0.91)	0.0 (0.91)	0.0 (0.91)	0.0 (0.91)	0.0 (0.91)
CD(0.05)		4.183	4.609	11.908	11.908	11.908	12.529

Treatment means with same alphabets are on par
Figures in parenthesis are arc sine transformed values,
HAT- Hours after treatment

On twelve hours after treatment with the chemicals, adult mortality ranged between zero to 100 per cent. Nereistoxin analogue insecticide, cartap hydrochloride 0.05% showed cent percent mortality which was statistically superior to all other treatments followed by emamectin benzoate 0.002% (86.67 per cent) and thiamethoxam 0.01% (43.33 per cent).

On 24HAT, emamectin benzoate 0.002% also recorded 100 per cent mortality as in the case of cartap hydrochloride 0.05%. Mortality of adults treated with thiamethoxam 0.01% increased to 70.00 per cent while indoxacarb 0.01% and chlorantraniliprole 0.0075% treated adults showed no mortality and were alive.

Adults treated with thiomethaxam 0.01% showed 100 per cent mortality on 36HAT which was on par with cartap hydrochloride 0.05% and emamectin benzoate 0.002%. Chlorantraniliprole 0.0075% treated adults registered mortality only after 36 hours of treatment (36.67 per cent). No further mortality was recorded as time progressed in chlorantraniliprole treated weevils. So at the end of 72HAT, thiamethoxam 0.01%, cartap hydrochloride 0.05% and emamectin benzoate 0.002% treated adults showed same and maximum mortality rate (100 per cent) followed by chlorantraniliprole 0.0075% (36.67 per cent) . Adults kept on control and indoxacarb 0.01% did not record any mortality during this period, and significantly differed from all other treatments.

4.2.3 Effect of Different Botanical Preparations on the Mortality of *O. longicollis* Grubs

Five different botanical preparations viz., 'Nanma' (cassava leaf distillate based formulation) 3%, neem oil emulsion 3%, neem soap 1%, azadirachtin 1% EC 3% and neem seed kernel extract (NSKE) 5% were tested to evaluate their efficacy against grubs and adults of *O. longicollis*. The effect of these treatments on mortality of grubs is presented in table 10.

Table 10. Effect of botanical insecticides on *O. longicollis* grubs under laboratory conditions

Botanical insecticide	Concentration (%)	Mortality of grubs (%)			
		2 DAT	5 DAT	10 DAT	15 DAT
Cassava leaf distillate-'Nanma'	3.0%	0	3.333	26.67	36.67 (37.23)
Azadiractin 1% EC 'Neemazal'	0.3%	0	0	6.67	6.67 (12.59)
Neem soap	1.0%	0	0	6.67	6.67 (12.59)
Neem oil emulsion	3.0%	0	0	3.33	3.33 (6.75)
NSKE	5.0%	0	0	3.33	6.67 (12.59)
Control		0	0	3.33	3.33 (6.75)
CD (0.05)		-	NS	NS	16.625

Figures in parenthesis are arc sine transformed values
DAT- Days after treatment

None of the tested botanical preparations registered any mortality of *O. longicollis* grubs up to four days after treatment. On fifth day, 'Nanma' caused 3.33 per cent mortality but it did not significantly differ from any other treatments tested. All treatments including control recorded mortality on tenth day but without any significant difference among the treatments.

'Nanma' ranked first (26.66 per cent) in causing mortality of grubs on tenth day after treatment, but did not show any significant difference from other treatments. Similarly on 15 DAT also 'Nanma' topped with 36.67 per cent mortality among the treatments and it differed significantly from other treatments. Only on 15DAT statistical difference among the treatments was noticed.

4.2.4 Effect of Different Botanical Preparations on Mortality of *O. longicollis* Adults

The effect of different botanical preparations on *O. longicollis* adults are presented in table 11.

The five botanical preparations proved more effective against adults than grubs in causing mortality. Even though three treatments; neem soap 1%, neem oil emulsion 3% and azadirachtin 1% EC 0.3% caused death of adult weevils within one day of treatment, their effect was not significantly different from control. After two days, the treatments showed difference from control in causing mortality. Treatments with neem soap 1%, 'Nanma' (cassava leaf distillate based formulation) 3% and neem oil emulsion 3% were equally effective in imparting mortality per cent of 23.33, 16.67 and 10.0, respectively.

Table 11. Effect of botanical insecticides on *O. longicollis* adults under laboratory conditions

Botanical insecticide	Concentration (%)	Mortality of weevils (%)			
		1 DAT	2 DAT	5 DAT	10 DAT
Cassava leaf distillate- 'Nanma'	3.0%	0	16.67^{ab} (23.36)	36.67^{a} (37.23)	36.67^{a} (37.23)
Azadiractin 1% EC 'Neemazal'	0.3%	6.67	6.67^{bc} (12.59)	16.67^{b} (23.85)	16.67^{b} (23.85)
Neem soap	1.0%	6.67	23.33^{a} (28.78)	36.67^{a} (37.23)	36.67^{a} (37.23)
Neem oil emulsion	3.0%	6.67	10.00^{abc} (15.31)	13.33^{b} (21.15)	13.33^{bc} (21.15)
NSKE	5.0%	0	3.33^{c} (6.75)	3.33^{c} (6.75)	6.67^{c} (12.59)
Control		0	0^{c} (0.91)	0^{c} (0.91)	0^{d} (0.91)
CD (0.05)		NS	15.657	9.483	9.483

Treatment means with same alphabets are on par
Figures in parenthesis are arc sine transformed values
DAT- Days after treatment

Mortality rate was increased on fifth day where all treatments except control recorded mortality of adults. Adults treated with NSKE 5% did not show any difference in mortality (3.33 per cent) compared to control (0.0 per cent). 'Nanma' and neem soap treated adults had 36.67 per cent mean mortality followed by azadirachtin (16.67 per cent) and neem oil emulsion (13.33 per cent).

On tenth day after treatment, all treatments differed significantly from control. The treatments with 'Nanma' (36.67 per cent) and neem soap (36.67 per cent) stood superior to other treatments.

From the data recorded in this experiment, 'Nanma' 3% and neem soap 1% was found superior to other treatments in causing mortality of *O. longicollis* grubs from 5DAT onwards.

4.2.5 Effect of Different Botanical Preparations on Repellency of *O. longicollis* Adults Under Multi Choice Method

The repellency effect of different botanical preparations on *O. longicollis* adults under multi choice method is depicted in fig. 2.

Adults when released freely on pseudostem pieces previously treated with different botanical preparations showed various degrees of repellency. 'Nanma' (cassava leaf distillate) 3% and neem soap 1% showed maximum repellency to adult weevils.

Initially, pieces of pseudostem treated 'Nanma' (cassava leaf distillate) 3% and neem soap 1% did not attract any weevils closely followed by neem oil emulsion 3% (0.67). Stem pieces in control which were dipped in water without any treatment attracted maximum number of adult weevil ranging from six to seven during 24 hours after release of weevils (Fig. 2). In all the four observations made during the test period of 24 hours, 'Nanma', neem soap and neem oil emulsion recorded maximum repellency showing minimum number of adults harbouring on these stem pieces. On the other hand, neem seed kernel

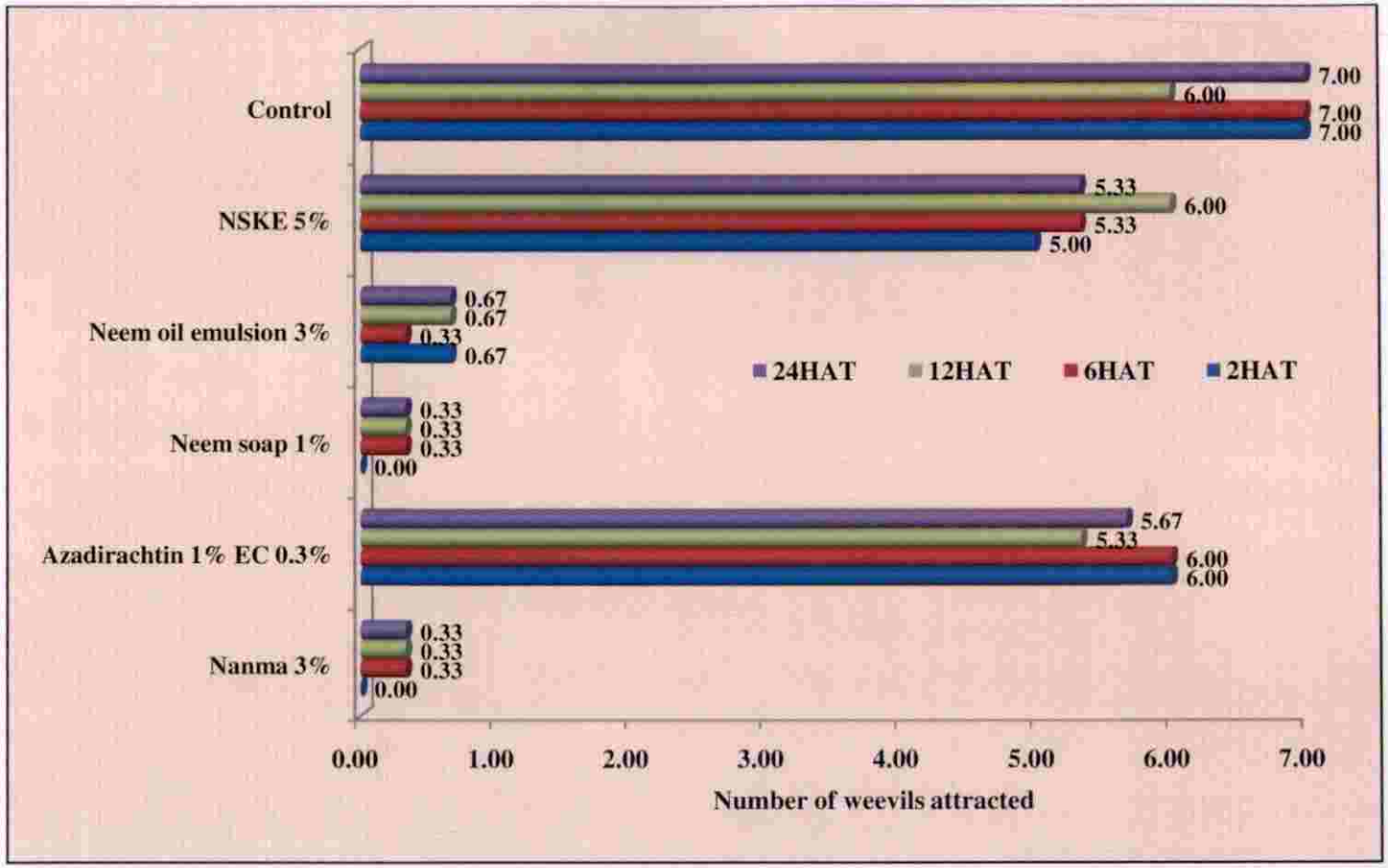


Fig. 2 Effect of botanicals as repellent against *O. longicollis* adults in multi choice test

extract 5% and azadirachtin 0.3% recorded maximum number of adult weevils during 6 HAT and 12 HAT. At twelve hours after treatment, all the treated stem pieces harboured adult weevils but varied in number.

The maximum repellency at 24 HAT was shown by 'Nanma' 3%, neem soap 1% and neem oil emulsion 3% which recorded a mean of 0.33, 0.33 and 0.67 adults, respectively. Neem seed kernel extract and azadirachtin treated stem pieces showed less repellency, as it attracted 5.33 and 5.67 adults, respectively compared to control (7.0).

4.2.6 Effect of Different Botanical Preparations on Repellency of *O. longicollis* Adults Under no Choice Method

Repellency effect of different botanical preparations on *O. longicollis* adults under no choice method is illustrated in fig. 3.

In no choice test, adults were forced to rest on the treated stem pieces or wander in the container. Repellency was observed in all treatments compared to non-treated control. Immediately after release of adults, none of the adults were found resting on stem pieces treated with 'Nanma' 3% and neem soap 1%. But in all treatments number of adult population harbouring on treated pseudostem piece showed an increase as time progressed.

'Nanma' 3% recorded no adults during 2HAT and 12 HAT, but a mean number of 0.5 and 0.25 was observed during six and 24 HAT, respectively. Neem soap 1% also showed the same trend where it recorded 0, 0.75, 1.0 and 0.75 mean numbers of adults during 2, 6, 12 and 24 HAT, respectively. Azadirachtin 0.3% treatment recorded a mean number of 1.75, 1.75, 2.5 and 2.0 adults from the observations made during 2, 6, 12 and 24 HAT, respectively.

Maximum number of adults were observed in control (8.75) followed by NSKE 5% (5).

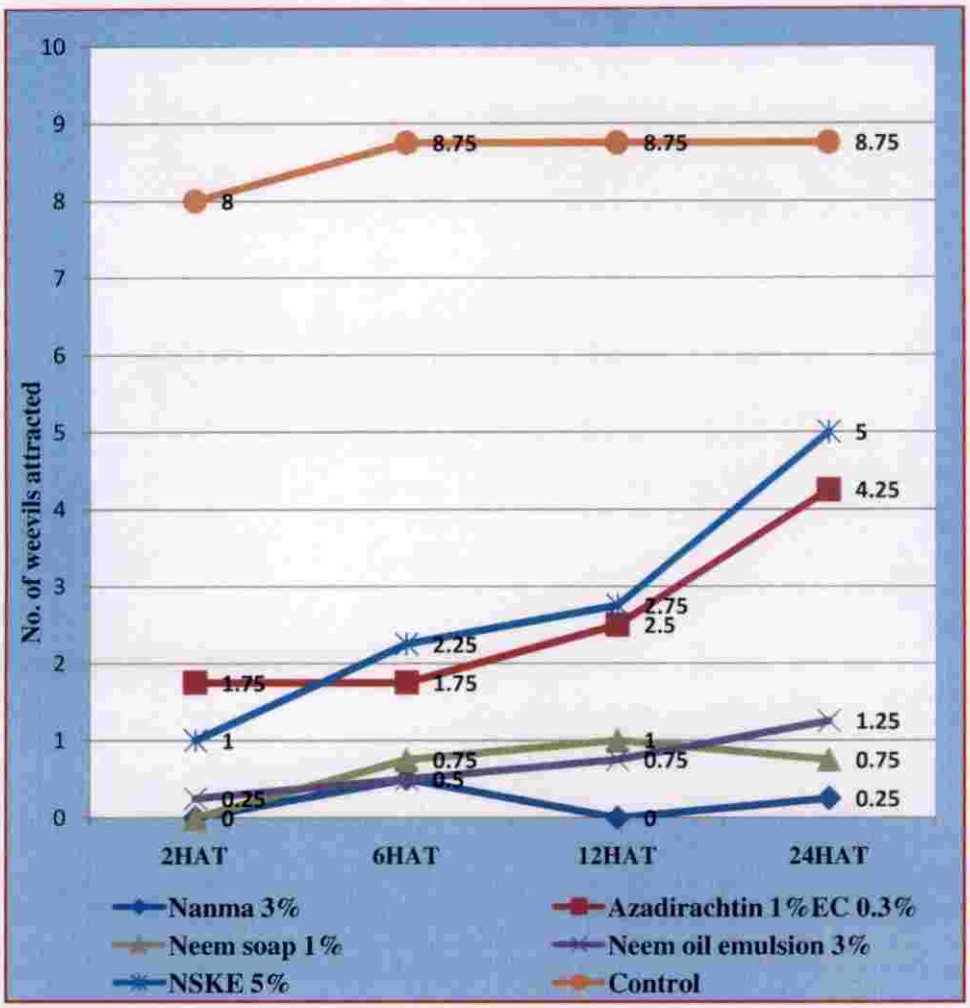


Fig. 3 Effect of botanicals as repellent against *O. longicollis* adults in no choice test

4.2.7 Effect of Different Bio agents on Mortality of *O. longicollis* Grubs

Grubs of *O. longicollis* treated with bio agents showed no mortality till fourth day after treatment (Fig. 4). But on fourth day grubs under *M. majus* treatment showed sluggish movement and stopped feeding. On fifth day *M. majus* treated grubs showed white mycelial growth on their body and found dead. Percentage mortality varied from 40 to 70 with an average of 56.67 per cent in *M. majus* treated grubs. No other bio agents affected mortality on fifth day. As days progressed, mortality of grubs treated with *M. majus* increased whereas grubs were alive in other treatments. *B. bassiana* cultures from NRCB, and Vellayani (ITCC 6063) showed no mortality of grubs of *O. longicollis* and treated grubs entered pupal stage and emerged as adults.

Maximum mortality of grubs (80 per cent) was observed with *M. majus* (2%) on seventh day and continued unchanged (Plate 9).

4.2.8 Effect of Different Bio Agents on Mortality of *O. longicollis* Adults

Mortality of adult weevils was negligible under different bio agent treatments (Fig. 5). *B. bassiana* (NRCB) and *M. majus* recorded death of adults, but less in number, on tenth day after treatment. Both the cultures recorded a mortality of 6.67 per cent only on the tenth day. None of the treatment showed any mortality up to one week. Even after ten days, *B. bassiana* culture ITCC 6063 didn't show any effect on adults.

4.3 EFFECT OF CHEMICALS ON ENTOMOPATHOGENIC FUNGUS, *M. majus* UNDER *IN VITRO* CONDITION

As per the results elaborated in 4.2.7 and 4.2.8 above, *M. majus* was proved as the most effective among the entomopathogenic fungi aganist *O. longicollis*. Hence, effect of pesticides and botanicals found effective against

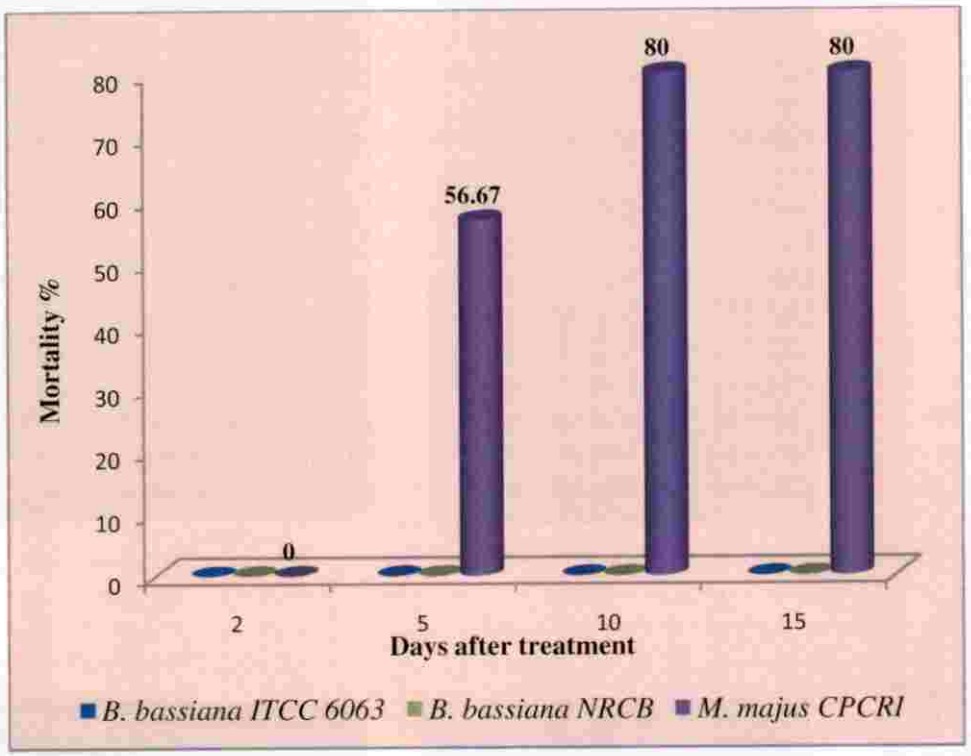


Fig. 4 Effect of different bio-agents on *O. longicollis* grubs under laboratory conditions

A- Culture of *M. majus*
B- *O. longicollis* grubs fourth day after treatment
C- *O. longicollis* grubs fifth day after treatment
D- *O. longicollis* grubs seventh day after treatment

Plate 9. Infection by *M. majus* on *O. longicollis* grubs

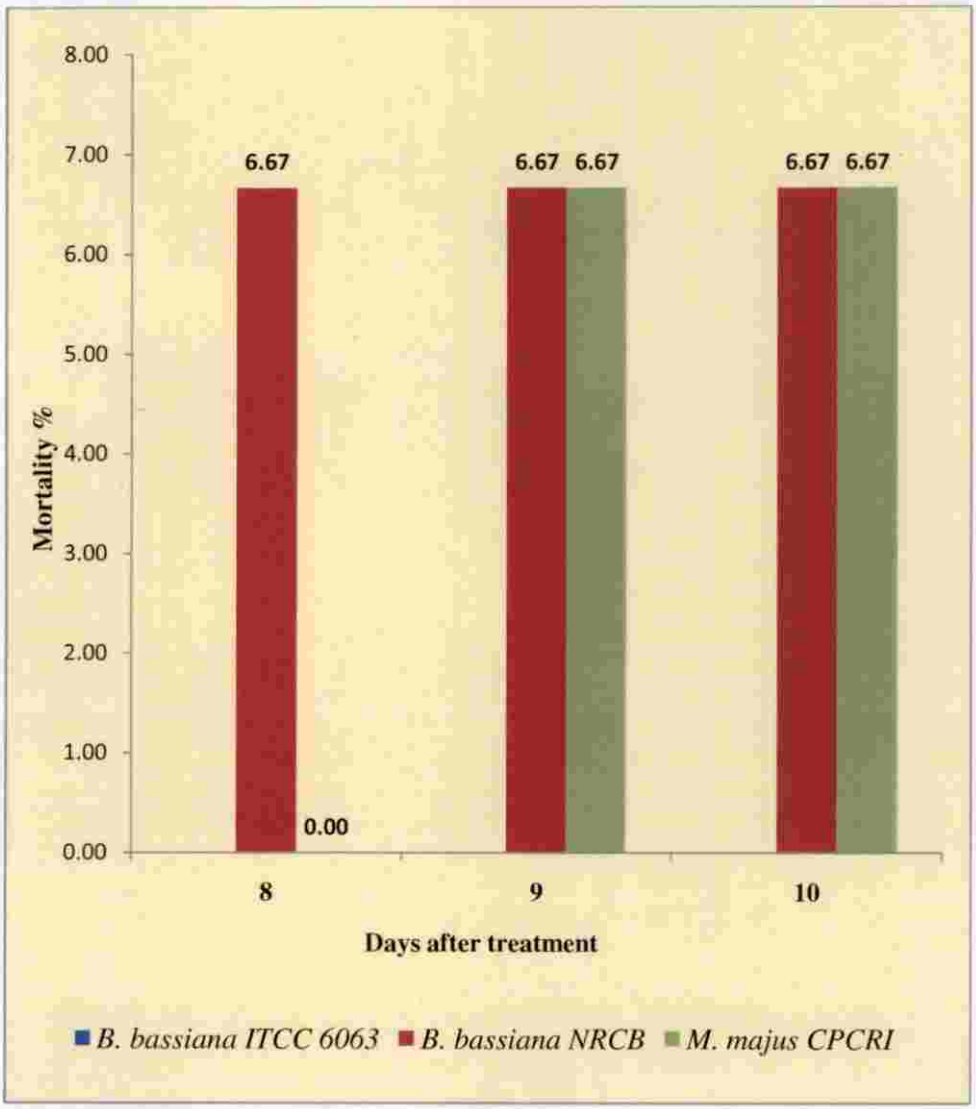


Fig. 5 Effect of different bio-agents on *O. longicollis* adults under laboratory conditions

O. longicollis in this study (4.2.1 to 4.2.6) along with fungicides used against banana diseases were tested on different growth parameters of entomopathogenic fungus, *M. majus*.

4.3.1 Effect of Chemicals on Growth of *M. majus*

Mycelial growth of *M. majus* on potato dextrose agar (PDA) media poisoned with different insecticides and botanicals are given in table 12.

Different poisoned media showed varying growth pattern of *M. majus* (Plate 10). The media poisoned with thiamethoxam 0.01 and 0.03%, 'Nanma' (cassava leaf distillate +neem oil) 5%, neem soap 1%, copperoxychloride 0.3% and non poisoned media showed growth initiation on second day of inoculation. Meanwhile, media with azoxystrobin 0.1%, mancozeb 0.3%, propiconazole 0.1%, cartap hydrochloride 0.05 %, tebuconazole 0.1% and chlorpyrifos 0.03% did not show any growth on the same day. Initiation of growth by *M. majus* was noticed only on fifth and seventh day on azoxystrobin and chlorpyrifos, respectively. Cartap hydrochloride showed delay in mycelial growth initiation in which growth was visible only on seven days after inoculation.

Initially, all treatments showed significant reduction in growth compared to control (Table 12). Growth of mycelium on different treatments on 5DAI ranged from zero to 1.77 cm. On the fifth day after inoculation, control plates recorded maximum growth of mycelia (1.77 cm) followed by neem soap 1% (1.67 cm) and two concentrations (0.01 and 0.03%) of thiamethoxam (1.62 cm each). Fungal growth on neem soap 1%, thiamethoxam 0.01% and 0.03% were on par. Among the fungicides, copperoxychloride showed maximum growth (1.0 cm), followed by azoxystrobin (0.83 cm). All other fungicides along with cartap hydrochloride and chlorpyrifos showed no growth on the fifth day after inoculation. 'Nanma' recorded 0.73 cm growth which was on par with growth on copperoxychloride.

Table 12. Effect of pesticides and botanicals on the growth of *M. majus*

Treatments	Concentration (%)	Mean radial growth *(cm)			
		5th day	10th day	20th day	30th day
Thiamethoxam	0.01	1.62 [b] (1.45)	4.03 [b] (2.13)	6.33 [a] (2.62)	7.00 [bc] (2.73)
Thiamethoxam	0.03	1.62 [b] (1.45)	4.15 [ab] (2.15)	6.82 [a] (2.71)	7.40 [b] (2.80)
Cartap hydrochloride	0.05	0.00 [f] (0.70)	0.53 [e] (0.99)	1.77 [c] (1.50)	3.00 [e] (1.86)
Cassava leaf distillate 'Nanma'	5.0	0.73 [e] (1.11)	1.27 [d] (1.32)	1.69 [c] (1.48)	2.23 [f] (1.65)
Chlorpyrifos	0.03	0.00 [f] (0.70)	1.22 [d] (1.31)	1.82 [c] (1.52)	2.20 [f] (1.65)
Neem Soap	1.0	1.67 [b] (1.48)	4.23 [ab] (2.18)	6.37 [a] (2.62)	7.77 [ab] (2.87)
Carbendazim	0.1	0.00 [f] (0.70)	0.00 [f] (0.70)	0.00 [d] (0.70)	0.00 [g] (0.70)
Mancozeb	0.3	0.00 [f] (0.70)	0.00 [f] (0.70)	0.00 [d] (0.70)	0.00 [g] (0.70)
Azoxystrobin	0.1	0.83 [d] (1.16)	2.23 [c] (1.65)	3.93 [b] (2.11)	5.33 [d] (2.42)
Propiconazole	0.1	0.00 [f] (0.70)	0.00 [f] (0.70)	0.00 [d] (0.70)	0.00 [g] (0.70)
Tebuconazole	0.1	0.00 [f] (0.70)	0.00 [f] (0.70)	0.00 [d] (0.70)	0.00 [g] (0.70)
Copperoxychloride	0.3	1.0 [c] (1.23)	2.67 [c] (1.78)	4.43 [b] (2.22)	6.10 [cd] (2.56)
Control		1.77 [a] (1.50)	4.73 [a] (2.29)	6.88 [a] (2.71)	8.43 [a] (2.99)
CD (0.05)		0.033	0.136	0.141	0.179

Treatment means with same alphabets are on par

Figures in parenthesis are $\sqrt{x+0.5}$ transformed values

* Mean of three replications

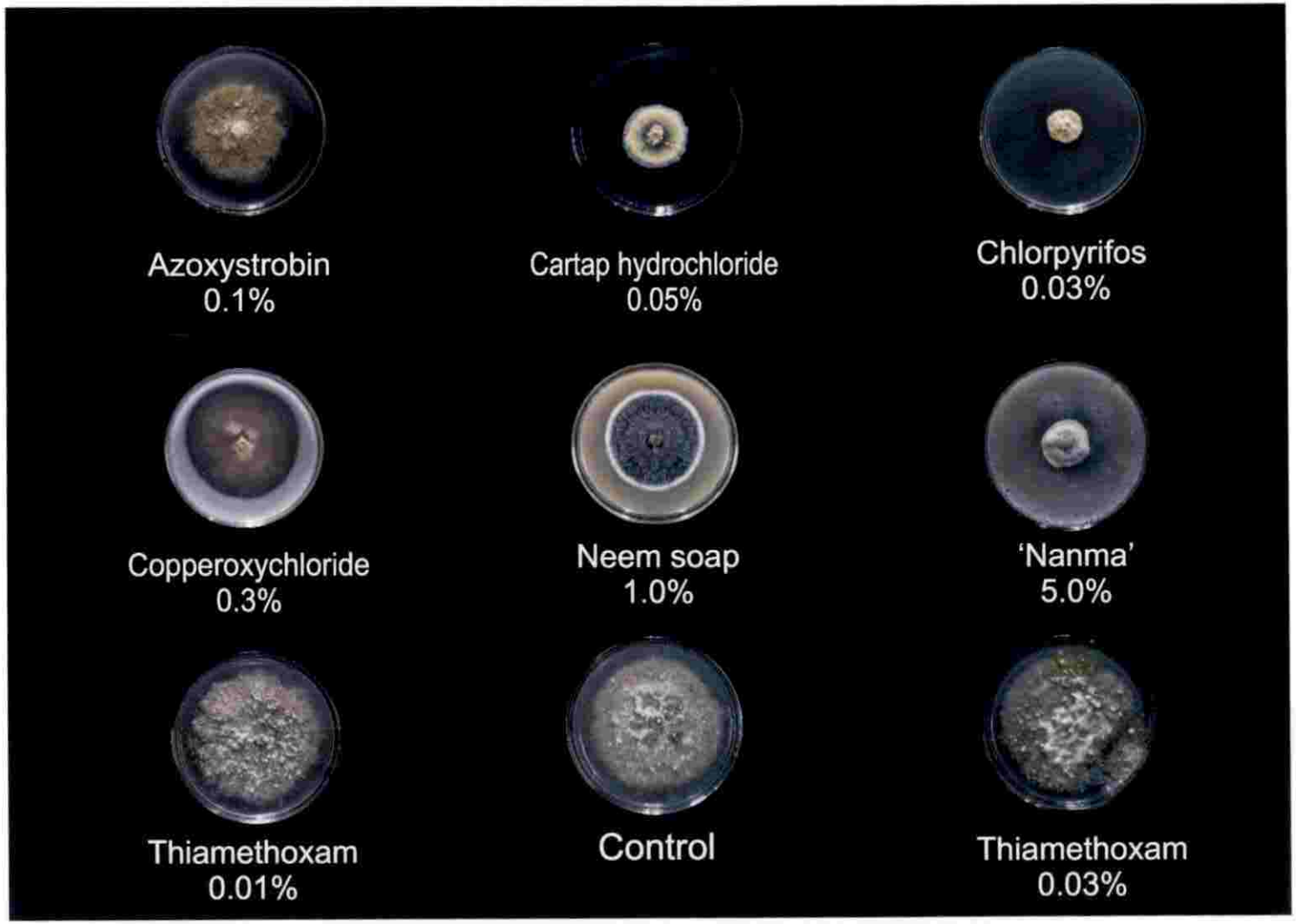


Plate 10. Growth of *M. majus* on different poisoned media

On the tenth day, treatments differed significantly with respect to the growth of mycelium. Growth on thiamethoxam 0.03% (4.15 cm) and neem soap 1% (4.23 cm) did not differ significantly with that on control (4.73 cm). Lower concentration of thiamethoxam (0.01%) was on par with its higher concentration (0.03%) in supporting fungal growth, but differed from control. Similarly, neem soap and the two concentrations of thiamethoxam had equal effect on growth of *M. majus.* Fungus on chlorpyrifos and 'Nanma' recorded growth of 1.22 and 1.27 cm, respectively which was statistically on par. At the same time cartap hydrochloride registered 0.53 cm growth, lowest among the treatments supporting growth. Growth on azoxystrobin (2.23 cm) and copperoxychloride (2.67 cm) was also on par. Maximum growth was recorded in control plates (4.73 cm) on the tenth day after inoculation. Fungicides propiconazole, tebuconazole, mancozeb and carbendazim did not support any growth.

Observations on the twentieth day clearly depicted the effect of different chemicals on the growth of *M. majus*. Vegetative growth of the fungus on the twentieth day ranged from zero to 6.88 cm. Maximum growth of 6.88 cm was observed on control plates. Growth on thiamethoxam 0.01%, 0.03% and neem soap 1.0% was statistically on par with control and recorded 6.33, 6.82, 6.37 and 6.88 cm, respectively. All other treatments were different from these four treatments. Cartap hydrochloride 0.05% (1.77 cm), chlorpyrifos 0.03% (1.82 cm) and 'Nanma' 5% (1.69 cm) were significantly inferior to control in supporting fungal growth and had same effect in inhibiting the fungal growth. Copperoxychloride 0.3% and azoxystrobin 0.1% recorded similar mean mycelia growth of 4.43 and 3.93 cm, respectively. All other fungicides did not support any growth even after twenty days of inoculation.

Growth of fungus reached maximum and covered the entire medium in control plate on the 30th day after inoculation. Growth of *M. majus* on different poisoned media ranged from zero to 8.43 cm. Maximum growth (8.43 cm) was observed in control plates while no growth was observed on fungicides propiconazole, tebuconzole, mancozeb and carbendazim. Mycelial growth on

neem soap (7.77 cm) and control (8.43 cm) was statistically on par. At the same time, growth on two concentrations of thiamethoxam (7.0 cm at 0.01% and 7.4 cm at 0.03%) showed no significant difference compared to neem soap 1% (7.77 cm). Higher concentration of thiamethoxam (0.03%) showed more mycelia growth than the lower concentration of 0.01%. Among the pesticides tested, chlorpyrifos recorded minimum growth (2.2 cm). Media poisoned with 'Nanma' recorded 2.23 cm growth of mycelium and found equivalent with chlorpyrifos in supporting growth.

Fungicides *viz.,* tebuconazole 0.1%, propiconazole 0.1%, mancozeb 0.3% and carbendazim 0.1 % recorded total inhibition of mycelia growth. Even though growth on copperoxychloride 0.3% was more than that of azoxystrobin 0.1%, statistically they were on par. Treatment with thiamethoxam 0.01% and copperoxychloride 0.3% (6.1 cm) were statistically on par with each other.

Analysis of data on growth of *M. majus* on different insecticide media revealed that maximum growth was supported by neem soap 1%, closely followed by thiamethoxam 0.03% and 0.01%.

4.3.2 Effect of Chemicals on Sporulation of *M. majus*

Total spores produced by the test fungus, *M. majus*, including dead and live were harvested and counted using Naubeur's haemocytometer to estimate the effect of different chemicals on the spore production by the fungus.

Conidia production of *M. majus* grown on different media was assessed (Table 13). On examination, conidia production by the test fungus on different poisoned media showed great variation. Average conidia production varied from zero to 1.61×10^7 spores ml^{-1}. Maximum spore production was noticed on thiamethoxam 0.03% (1.61×10^7 spores ml^{-1}) which was statistically superior to all other treatments and closely followed by neem soap 1% (1.43×10^7 spores ml^{-1}) and

Table 13. Effect of pesticides and botanicals on the sporulation of *M. majus*

Sl.No.	Treatment	Concentration (%)	Mean spore count* ($x10^7$) /ml
1	Thiamethoxam	0.01	1.01^{c} (3175.41)
2	Thiamethoxam	0.03	1.61^{a} (4008.98)
3	Cartap hydrochloride	0.05	0.80^{d} (2822.40)
4	Cassava leaf distillate 'Nanma'	5.0	0.20^{g} (1425.68)
5	Chlorpyrifos	0.03	0.43^{e} (2083.57)
6	Neem Soap	1.0	1.43^{b} (3784.79)
7	Carbendazim	0.1	0.00^{i} (0.70)
8	Mancozeb	0.3	0.00^{i} (0.70)
9	Azoxystrobin	0.1	$0.32^{7\,f}$ (1795.73)
10	Propiconazole	0.1	0.00^{i} (0.70)
11	Tebuconazole	0.1	0.00^{i} (0.70)
12	Copperoxychloride	0.3	0.06^{h} (779.92)
13	Control		0.80^{d} (2829.89)
	CD(0.05)		43.014

Treatment means with same alphabets are on par

Figures in parenthesis are $\sqrt{x+0.5}$ transformed values

* Mean of three replications

thiamethoxam 0.01% ($1.01x10^7$ spores ml^{-1}). Cartap hydrochloride (0.05%) and control yielded same quantity of spores; $0.80x10^7$ spores ml^{-1}.

Azoxystrobin supported spore production at the rate of $0.32x10^6$ spores ml^{-1} while fungus on copperoxychloride produced only $0.06x10^7$ spores ml^{-1}. The fungicides *viz.,* carbendazim, mancozeb, propiconazole and tebuconazole did not induce either spore production or mycelia growth. Cassava leaf distillate- neem oil mix, 'Nanma' also induced spore production, but at a very low rate ($0.20x10^7$ spores ml^{-1}) compared to other insecticides and neem soap.

M. majus grown on chlorpyrifos recorded the lowest sporulation among the insecticides tested with a value of $0.434x10^7$ spores ml^{-1}.

4.3.3 Effect of Chemicals on Spore Viability of *M. majus*

Total spore count will not be an accurate estimate to evaluate the effect of chemicals on sporulation of fungi, as it includes dead and inactive conidia. So viability of the spores produced was tested using spread plate method on PDA.

Thiamethoxam 0.01% recorded maximum viable spore as it had $8.33x10^6$ cfu ml^{-1}, followed by neem soap 1% ($4.11x10^6$ cfu ml^{-1}) (Table 14). Cartap hydrochloride 0.05%, thiamethoxam 0.03%, and chlorpyrifos 0.03% occupied next best positions in having viable spore production with $3.6x10^6$ cfu ml^{-1}, $1.88x10^6$ cfu ml^{-1} and $1.53x\ x10^6$ cfu ml^{-1}, respectively. 'Nanma' 5% recorded $1.06x10^6$ cfu ml^{-1} while non-chemical treatment kept as control showed $0.93x10^6$ cfu ml^{-1}.

Both the fungicides azoxystrobin 0.1% and copperoxychloride 0.3% recorded the least colony forming units which were less than the units in control.

Table 14. Effect of pesticides on the viability of spores of *M. majus*

Treatment	Log sporulation	Spore viability cfu/ml	Log cfu/ml	Spore viability (%)
Thiamethoxam 0.01%	7.00	$8.33x10^6$	6.92^a	98.82
Thiamethoxam 0.03%	7.21	$1.88 x10^6$	6.28^c	87.08
Cartap hydrochloride 0.05%	6.90	$3.60 x10^6$	6.56^b	95.00
Cassava leaf distillate 'Nanma' 5%	6.31	$1.06 x10^6$	6.02^{de}	95.52
Chlorpyrifos 0.03%	6.64	$1.53 x10^6$	6.19^{cd}	93.19
Neem Soap 1%	7.16	$4.11 x10^6$	6.61^b	92.42
Azoxystrobin 0.1%	6.51	$1.03 x10^5$	5.01^f	77.02
Copperoxychloride 0.3%	5.78	$2.00 x10^2$	2.30^g	39.78
Control	6.90	$9.30 x10^5$	5.9^e	86.46
CD (0.05)			0.161	

cfu= colony forming units
Treatment means with same alphabets are on par

Azoxystrobin and chlorpyrifos had only $1.03x10^5$ cfu ml^{-1} and $2.0x10^2$ cfu ml^{-1}, respectively. Copperoxychloride showed maximum negative effect on spore viability among the treatments.

Percentage viability of spores showed that fungus grown on thiamethoxam 0.01% produced maximum viable spores. Spores from fungus grown on thiamethoxam 0.01% had 98.82 per cent viable spores (Table 14). Higher concentration of thiamethoxam showed a negative impact on spore viability since it had only 87.08 per cent viable spore. Cartap hydrochloride 0.05% (95.0 per cent) and chlorpyrifos 0.03% (93.19 per cent) did not affect the viability of spores produced by *M. majus* grown on them. The spores produced on 'Nanma' 5% had 95.52 per cent viable spores, whereas neem soap 1% had 92.42 per cent. Only 39.78 per cent of total spores produced on copperoxychloride 0.03% were viable while 77.02 per cent spores were viable in case of azoxystrobin 0.1%. In control, 86.46 per cent spores were viable and ranked seventh among the treatments. All the insecticides, except thiamethoxam 0.03 %, could produce more than 90 per cent viable spores. Similarly, except copperoxychloride 0.1%, all other treatments produced more than 50 per cent viable spores.

4.3.4 'T' value of Chemicals on *M. majus*

Compatibility of entomopathogenic fungus, *M. majus* with insecticides and fungicides was calculated based on the 'T' value as explained in 3.3.4 and the data is presented in table 15.

'T' values of all treatments under study varied from zero to 178.13 (Table 15). Except chlorpyrifos, all other insecticide treatments were compatible with *M. majus*. The highest 'T' value was noticed with thiamethoxam 0.03% (178.13), followed by neem soap 1% (161.52) and thiamethoxam 0.01% (117.33). Cartap hydrochloride 0.05% and chlorpyrifos 0.03% recorded values of 86.69 and 48.59, respectively. According to 'T' value, chlorpyrifos 0.03% was moderately toxic to *M. majus*.

Table 15. Effect of plant protection chemicals on the growth and sporulation of *M. majus*

Sl. No.	Treatment	Concentration (%)	Mean radial growth (cm)	Percentage radial growth over control (VG)	Mean sporulation ($x10^7$)	Percentage sporulation over control (SP)	'T' value	Classification
1	Thiamethoxam	0.01	7.00	83.01	1.01	125.91	117.33	C
2	Thiamethoxam	0.03	7.40	87.75	1.61	200.73	178.13	C
3	Cartap hydrochloride	0.05	3.00	35.58	0.79	99.48	86.69	C
4	Cassava leaf distillate –'Nanma'	5.0	2.23	26.48	0.203	25.39	25.61	VT
5	Chlorpyrifos	0.03	2.20	26.09	0.43	54.21	48.59	MT
6	Neem Soap	1.0	7.77	92.10	1.43	178.88	161.52	C
7	Carbendazim	0.1	0.00	0.00	0.00	0.00	0.00	VT
8	Mancozeb	0.3	0.00	0.00	0.00	0.00	0.00	VT
9	Azoxystrobin	0.1	5.33	63.24	0.32	40.27	44.87	MT
10	Propiconazole	0.1	0.00	0.00	0.00	0.00	0.00	VT
11	Tebuconazole	0.1	0.00	0.00	0.00	0.00	0.00	VT
12	Copperoxychloride	0.3	6.10	72.34	0.06	7.59	20.54	VT
13	Control		8.43	100.00	0.80	100.00	100.00	

VG= percentage of vegetative growth compared to control
SG= percentage of sporulation compared to control
'T' value= (20xVG+80xSP)/100
C=Compatible, MT=Moderately Toxic, T=Toxic, VT=Very Toxic

The organic preparation, neem soap at 1% was not toxic (161.52) but 'Nanma' 5% with 'T' value 25.61 was very toxic to the test fungus. 'T' values of the fungicides mancozeb 0.3%, carbendazim 0.1%, propiconazole 0.1% and tebuconazole 0.1% were zero as they did not support fungal growth and sporulation. All these four insecticides were very toxic to *M. majus*. Even though copperoxychloride 0.3% supported fungal growth and sporulation, based on low 'T' value (20.54), it was also grouped as very toxic category. Meanwhile, the new generation fungicide, azoxystrobin 0.1% registered a 'T' value of 44.87 and classified as moderately toxic to the test fungus.

Results on 'T' value indicated that thiamethoxam at 0.01% and 0.03%, cartap hydrochloride 0.05% and neem soap at 1.0% were compatible with the fungus, while chlorpyrifos 0.03% and azoxystrobin 0.1% were moderately toxic to *M. majus*. All other treatments *viz*., mancozeb 0.3%, cabendazim 0.1%, propicanazole 0.1%, tebuconazole 0.1% and 'Nanma' 5% were very toxic to *M. majus in vitro*.

4.4 EVALUATION OF APPLICATION METHODS UNDER FIELD CONDITIONS

Insecticides, botanical preparations and bio agents which were found effective in laboratory experiment were tested in the field to standardise their application technique. Swabbing, spraying, leaf axil filling, injection and its combinations were tested for each successful chemical and bio agent. The insecticides, thiamethoxam and cartap hydrochloride, botanical neem soap and bio agent *M. majus* from CPCRI(RS) Kayamkulam were selected to evaluate the application method under field condition.

Twenty seven treatments including insecticides, botanicals and bio agent were tested in field conditions at Instructional Farm, College of Agriculture, Vellayani during November 2013 to August/September in 2014 (Plate 11). Data collected on various parameters are presented in Tables 16 to 18.

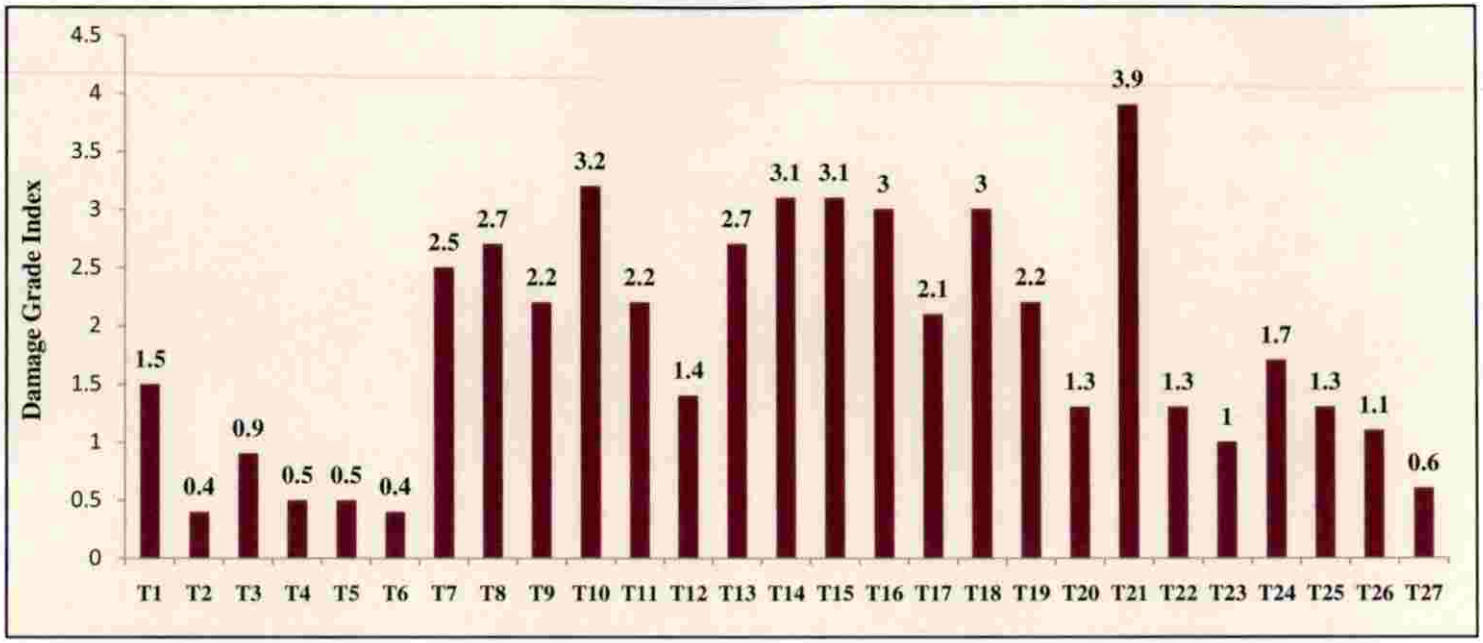
4.4.1 Crop Damage

4.4.1.1 Damage Grade Index

Crop damage grade index of treated plants was assessed at harvest or toppled down stage, whichever occurred earlier. The data on damage grade index is presented in fig.6.

The lowest damage grade indices were recorded with thiamethoxam application methods (T1-T6). Plants that received thiamethoxam 0.01% LAF (T2) and 0.01% spray +LAF (T6) showed low level of pest infestation and hence registered the lowest damage index (0.4). Different thiamethoxam application methods showed indices ranging from 0.4 to 1.5, the maximum for 0.01% swabbing (T5).

Plants under application methods of neem soap (T7-T12) and the bio agent, *M. majus* (T13-T18) recorded higher damage index when compared to



T1- Thiamethoxam 0.01% swabbing
T2- Thiamethoxam 0.01% LAF
T3- Thiamethoxam 0.01% Spray
T4- Thiamethoxam 0.03% injection
T5- Thiamethoxam 0.01% swab+LAF
T6- Thiamethoxam 0.01% spray +LAF
T7- Neem soap 1% swabbing
T8- Neem soap 1% LAF
T9- Neem soap 3% injection
T10- Neem soap 1% spray
T11- Neem soap 1% swab +LAF
T12- Neem soap 1% spray +LAF
T13- *M. majus* 2% LAF
T14- *M. majus* 2% swabbing
T15- *M. majus* 2% injection
T16- *M. majus* 2% spray
T17- *M. majus* 2% swab+LAF
T18- *M. majus* 2% spray+LAF
T19- Nanma 5%
T20- Chlorpyriphos 0.05% LAF
T21- Control
T22- Cartap hydrochloride 0.05% swabbing
T23- Cartap hydrochloride 0.05% LAF
T24- Cartap hydrochloride spray
T25- Cartap hydrochloride 0.15% injection
T26- Cartap hydrochloride 0.05% swab+LAF
T27-Cartap hydrochloride 0.05% spray+LAF

Fig. 6 Effect of different application methods on damage grade index at toppling/harvest stage of the crop

Plate 11. The experiment plot at Instructional farm, College of Agriculture, Vellayani

plants that received different insecticide application methods. Damage grade index of neem soap treated plants ranged from 1.4 to 3.2, while that of *M. majus* ranged from 2.1 to 3.1. Lowest grade index for neem soap 1% application was noted (1.4) for spray + LAF (T12), while *M. majus* had lowest index for 2% swabbing+ LAF (2.1) (T17).

Among the different application methods of cartap hydrochloride 0.05%, spraying+ LAF (T27) had lowest damage index values (0.6), but 0.05% spraying alone (T24) had the highest index (1.7).

Chlorpyrifos 0.03% and 'Nanma' 5% recorded an index of 1.3 and 2.2, respectively. Plants with no treatments recorded the highest damage grade index (3.9).

4.4.1.2. Plant Survival Rate

Crop damage in terms of number of plants survived at the time of harvest is illustrated in fig. 7. Cent per cent survival of plants was noted in LAF (T2), injection (T4), swabbing +LAF (T5) and spraying +LAF (T6) of thiamethoxam. Cartap hydrochloride LAF (T23) and spraying +LAF (T27) also recorded 100 per cent survival of plants. Among the application methods of neem soap, maximum (90 per cent) plants survived in spraying +LAF method. *M. majus* application by swabbing +LAF showed maximum (80 per cent) survival of plants. Application of chlorpyrifos (0.03%) and 'Nanma' (5%) resulted in 90 and 80 per cent survival of the plants, respectively. Lowest survival rate (30 per cent) was accounted for control plants.

4.4.1.3 Presence of Bore Holes

Table 16 describes the effect of different application techniques on the occurrence of feeding/exit holes by *O. longicollis* on pseudostem. Analysis of data revealed that minimum number of holes was with spraying + LAF (T6) of thiamethoxam 0.01% (0.4) followed closely by thiamethoxam LAF 0.01% (T2)

(0.5) and injection 0.03% (T4) (0.6) and they differed significantly from control. Four out of six different techniques tested with thiamethoxam recorded less than one hole per plant. But swabbing and spraying of thiamethoxam recorded 3.1 and 2.9 bore holes, respectively. All the thiamethoxam application methods were significantly superior to control. Cartap hydrochloride 0.05% spray+ LAF (T27) recorded 1.7 bore holes, which was on par with T2, T4, T5 and T6. Maximum number of holes (12.2) was observed in control plants.

Nereis toxin analogue, cartap hydrochloride also recorded number of holes ranging from 1.7 to 4.8. Cartap hydrochloride 0.05% spray + LAF application method recorded an average of 1.7 holes plant^{-1} and was on par with thiamethoxam LAF, injection, swabbing + LAF and spray + LAF.

Insecticide check, chlorpyrifos recorded average 4.7 holes plant^{-1} which was on par with other treatments *viz.*, thiamethoxam swabbing, spraying, neem soap injection, cartap hydrochloride swabbing, LAF, injection and swabbing + LAF. 'Nanma' recorded 6.5 holes plant^{-1} on stem and found statistically on par to cartap hydrochloride swabbing, spraying and all treatments with neem soap and *M. majus*.

Neem soap application methods recorded 4.7 to 8.9 holes plant^{-1} while *Metarhizium* application treatments recorded 6.7 to 10.5 holes plant^{-1}. Neem soap swabbing + LAF, LAF and spraying did not differ from control, the same was the case with *M. majus* LAF, injection, spraying and spray + LAF. Among different application techniques, neem soap injection recorded less number of holes (4.7) which was on par with neem soap swabbing (6.8) and spray + LAF (5.1). In the case of *M. majus* application methods, swabbing recorded least number of holes (6.7) which was on par with swabbing + LAF (7.8).

Table 16. Effect of different application techniques on bore holes made by *O. longicollis* on stem

	Treatments	No. of bore holes plant^{-1}	Transformed values *	Comparison
1.	Thiamethoxam 0.01% swabbing	3.1	1.75	cde
2.	Thiamethoxam 0.01% LAF	0.5	0.71	a
3.	Thiamethoxam 0.01% Spray	2.9	1.71	cde
4.	Thiamethoxam 0.03% injection	0.8	0.89	ab
5.	Thiamethoxam 0.01% swab+LAF	0.6	0.78	ab
6.	Thiamethoxam 0.01% spray +LAF	0.4	0.63	a
7.	Neem soap 1% swabbing	6.8	2.58	fgh
8.	Neem soap 1% LAF	8.5	2.91	ghi
9.	Neem soap 3% injection	4.7	2.11	def
10.	Neem soap 1% spray	8.9	2.98	hi
11.	Neem soap 1% swab +LAF	9	2.99	hi
12.	Neem soap 1% spray +LAF	5.1	2.26	fgh
13.	*M. majus* 2% LAF	9.8	3.13	hi
14.	*M. majus* 2% swabbing	6.7	2.57	fgh
15.	*M. majus* 2% injection	10.5	3.24	hi
16.	*M. majus* 2% spray	9.1	3.02	hi
17.	*M. majus* 2% swab+LAF	7.8	2.78	fgh
18.	*M. majus* 2% spray+LAF	10.4	3.22	hi
19.	Cassava leaf distillate- 'Nanma'5%	6.5	2.54	fgh
20.	Chlorpyrifos LAF 0.03%	4.7	2.11	def
21.	Control	12.2	3.48	i
22.	Cartap hydrochloride 0.05% swabbing	4.8	2.19	def
23.	Cartap hydrochloride 0.05% LAF	3.2	1.79	cde
24.	Cartap hydrochloride 0.05% spray	5.1	2.26	efg
25.	Cartap hydrochloride 0.15% injection	3.3	1.76	cde
26.	Cartap hydrochloride 0.05% swab+LAF	2.4	1.44	bcd
27.	Cartap hydrochloride 0.05% spray+LAF	1.7	1.25	abc
	CD (0.05)		0.694	

*Transformed values are $\sqrt{x+0.5}$ values; Treatment means with same alphabets are on par

LAF- Leaf Axil Filling

4.4.2 Pest Incidence

Effect of application techniques using different chemicals and bio agents on number of live *O. longicollis* grubs are given in table 17.

Grubs were counted when the toppling of plant occurred or the bunch was harvested. Number of live grubs present inside the stem varied from 0.5 to 7.9. Plants under every treatment invariably harboured live *O. longicollis* grubs. The least count of grubs (0.5) was observed in the plants in which thiamethoxam LAF treatment was done and it was closely followed by injection (0.6) and spray + LAF (1.0) treatments. Maximum number of grubs (7.9) was obtained from plants in control plot.

Among the different application techniques tested for the insecticides, thiamethoxam LAF was the most effective technique as it had the lowest number of grubs (0.5). But other application techniques such as injection and spray + LAF were statistically on par to LAF of thiamethoxam. Spraying of thiamethoxam recorded maximum grubs among the application techniques tested for thiamethoxam (2.3).

Treatments comprising of cartap hydrochloride also gave promising results in reducing number of grubs/plant. Spray + LAF with cartap hydrochloride, swabbing + LAF and leaf axil filling also registered lowest number of grubs (1.2,1.4 and 1.8, respectively) which had equal effect as that of thiamethoxam LAF. Spraying of cartap hydrochloride was less effective as it recorded maximum grubs (3.5) among different cartap hydrochloride application techniques.

Table 17. Effect of different application techniques on number of live grubs of *O. longicollis* in stem

	Treatments	Average no. of grubs plant^{-1}	Transformed values *	Comparison
1.	Thiamethoxam 0.01% swabbing	2.2	1.46	cdef
2.	Thiamethoxam 0.01% LAF	0.5	0.71	a
3.	Thiamethoxam 0.01% Spray	2.3	1.51	cdefg
4.	Thiamethoxam 0.03% injection	0.6	0.77	ab
5.	Thiamethoxam 0.01% swab+LAF	1.6	1.26	bcde
6.	Thiamethoxam 0.01% spray +LAF	1	0.98	abc
7.	Neem soap 1% swabbing	4.6	2.14	hijk
8.	Neem soap 1% LAF	4.2	2.04	ghijk
9.	Neem soap 3% injection	5.4	2.32	ijkl
10.	Neem soap 1% spray	5	2.23	ijk
11.	Neem soap 1% swab +LAF	4.1	2.02	ghij
12.	Neem soap 1% spray +LAF	4	1.96	fghi
13.	*M. majus* 2% LAF	6.6	2.56	jkl
14.	*M. majus* 2% swabbing	5.3	2.29	ijkl
15.	*M. majus* 2% injection	6.7	2.59	kl
16.	*M. majus* 2% spray	6.1	2.46	jkl
17.	*M. majus* 2% swab+LAF	5	2.20	ijk
18.	*M. majus* 2% spray+LAF	5.4	2.32	ijkl
19.	Cassava leaf distillate- 'Nanma'5%	3.7	1.89	fghi
20.	Chlorpyrifos LAF 0.03%	2.6	1.59	defgh
21.	Control	7.9	2.80	l
22.	Cartap hydrochloride 0.05% swabbing	2.6	1.61	efgh
23.	Cartap hydrochloride 0.05% LAF	1.3	1.13	abcde
24.	Cartap hydrochloride 0.05% spray	3.5	1.88	fghi
25.	Cartap hydrochloride 0.15% injection	1.8	1.34	cde
26.	Cartap hydrochloride 0.05% swab+LAF	1.4	1.13	abcde
27.	Cartap hydrochloride 0.05% spray+LAF	1.2	1.05	abcd
	CD (0.05)		0.546	

*Transformed values are $\sqrt{x+0.5}$ values; Treatment means with same alphabets are on par
LAF- Leaf Axil Filling

Among the different application methods tested using neem soap, there was no significant difference observed between treatments. All the application techniques using neem soap recorded a minimum of 4.0 grubs plant^{-1}. Spraying + LAF method was recorded as the best treatment among different application methods of neem soap with 4.0 grubs plant^{-1}, whereas injection had maximum number of grubs per plant (5.4). Spraying + LAF of neem soap was equally effective as other treatments *viz*., 'Nanma' 5% spraying+ LAF, chlorpyrifos 0.3% swabbing and spraying of thiamethoxam and cartap hydrochloride.

The entomopathogen, *M. majus* was also tested for finding out the best application method. Except swabbing + LAF, all other methods showed no difference compared to control. The application comprising of swabbing + LAF of *M. majus* scored least number of grubs (5.0) compared to other *M. majus* application methods.

Cassava leaf distillate 'Nanma' applied as spraying + LAF recorded a mean of 3.7 grubs plant^{-1} which was on par with insecticide check, chlorpyrifos (2.6 grubs plant^{-1}). 'Nanma' was equally effective with swabbing and spraying of cartap hydrochloride, thiamethoxam and neem soap spray + LAF.

4.4.3 Yield

Yield data from different application methods showed variation among treatments tested. The yield data is presented in table 18.

The yield from different treatments ranged from 10.98 to 1.70 kg plant^{-1}. Maximum yield of 10.98 kg was recorded with thiamethoxam LAF followed by thiamethoxam injection (10.88 kg plant^{-1}), thiamethoxam spray + LAF (10.85 kg plant^{-1}) and thiamethoxam swabbing + LAF (10.83 kg plant^{-1}). All these treatments were on par with cartap hydrochloride LAF (9.7 kg plant^{-1}), swabbing + LAF (9.23 kg plant^{-1}), spray + LAF (10.5 kg plant^{-1}), neem soap spray + LAF

Table 18. Effect of different application techniques against *O. longicollis* on yield

	Treatments	Mean yield (kg plant^{-1})	Transformed values *	Comparison
1.	Thiamethoxam 0.01% swabbing	7.38	2.72	cdef
2.	Thiamethoxam 0.01% LAF	10.98	3.32	a
3.	Thiamethoxam 0.01% Spray	8.85	2.97	abcd
4.	Thiamethoxam 0.03% injection	10.88	3.29	a
5.	Thiamethoxam 0.01% swab+LAF	10.83	3.29	ab
6.	Thiamethoxam 0.01% spray +LAF	10.85	3.29	a
7.	Neem soap 1% swabbing	4.70	2.16	ghi
8.	Neem soap 1% LAF	3.60	1.89	hijk
9.	Neem soap 3% injection	5.28	2.29	fgi
10.	Neem soap 1% spray	2.70	1.64	jkl
11.	Neem soap 1% swab +LAF	6.95	2.63	def
12.	Neem soap 1% spray +LAF	8.80	2.96	abcd
13.	*M. majus* 2% LAF	4.18	2.04	hij
14.	*M. majus* 2% swabbing	2.50	1.59	kl
15.	*M. majus* 2% injection	3.03	1.73	jk
16.	*M. majus* 2% spray	3.05	1.73	ijk
17.	*M. majus* 2% swab+LAF	6.43	2.52	efg
18.	*M. majus* 2% spray+LAF	4.15	2.04	hij
19.	Cassava leaf distillate- 'Nanma'5%	7.73	2.77	cde
20.	Chlorpyrifos LAF 0.03%	8.40	2.89	abcde
21.	Control	1.70	1.29	l
22.	Cartap hydrochloride 0.05% swabbing	7.75	2.79	cde
23.	Cartap hydrochloride 0.05% LAF	9.70	3.11	abc
24.	Cartap hydrochloride 0.05% spray	8.18	2.86	bcde
25.	Cartap hydrochloride 0.15% injection	7.70	2.77	cde
26.	Cartap hydrochloride 0.05% swab+LAF	9.23	3.04	abcd
27.	Cartap hydrochloride 0.05% spray+LAF	10.50	3.24	ab
	CD (0.05)		0.435	

*Transformed values are $\sqrt{x+0.5}$ values; Treatment means with same alphabets are on par

LAF- Leaf Axil Filling

(8.8 kg plant^{-1}) and chlorpyrifos LAF (8.4 kg plant^{-1}). So all the application methods of thiamethoxam, except swabbing were equally effective in managing *O. longicollis*. Swabbing of thiamethoxam on pseudostem registered a mean yield of 7.38 kg plant^{-1} only.

Among the different application methods tested for neem soap, maximum yield was recorded by spraying+ LAF method (8.8 kg plant^{-1}). This method had same effect as that of all other application methods of thiamethoxam. The yield obtained for neem soap spraying +LAF (8.8 kg plant^{-1}) was on par with the maximum yield obtained for thiamethoxam LAF (10.98 kg plant^{-1}) treatment. No difference had been noted between neem soap spraying + LAF (8.8 kg plant^{-1}) and swabbing+ LAF (6.95 kg plant^{-1}). Neem soap as spraying was less effective as it could record only 2.7 kg plant^{-1} which was on par with control.

The best method of application for *M. majus* was swabbing + LAF as it recorded maximum yield (6.43 kg plant^{-1}) among different methods tested for *Metarhizium.* As in the case of neem soap, *Metarhizium* swabbing was less effective with an yield of 2.5 kg plant^{-1}. Spraying (3.05 kg plant^{-1}), swabbing (6.43 kg plant^{-1}) and injection (6.43 kg plant^{-1}) of *M. majus* had same effect on yield.

Cassava distillate, 'Nanma' applied as spraying + LAF recorded an average yield of 7.73 kg plant^{-1} which was on par with thiamethoxam swabbing (7.38 kg plant^{-1}), spraying (8.85 kg plant^{-1}), neem soap spray + LAF(8.8 kg plant^{-1}), chlorpyrifos LAF (8.4 kg plant^{-1}), cartap hydrochloride LAF (9.7 kg plant^{-1}), swabbing (7.75 kg plant^{-1}), spraying (7.7 kg plant^{-1}), injection and swabbing + LAF (9.23 kg plant^{-1}).

Spraying + leaf axil filling of cartap hydrochloride was found effective (10.5 kg plant^{-1}) among the application methods tested. All except spray+ LAF of cartap hydrochloride were statistically on par.

4.4.4 Time Requirement for Different Application Methods

Time taken to cover one plant under different application methods had been recorded and presented in fig. 8.

Spraying, as it involves comparatively less skill, recorded minimum time to cover a plant (49.45 s) whereas, leaf axil filling (LAF)+ swabbing recorded maximum time (142.55 s) among different application methods tested. Stem injection required 64.8 s to cover one plant and found statistically on par with LAF (65.85 s). LAF + spraying took maximum time (101.05 s) among all the treatments.

Based on the analysis of data on various parameters obtained in the this experiment, leaf axil filling as well as injection for thiamethoxam, spraying + LAF for neem soap and swabbing + LAF for *Metarhizium* were found the best application methods. These methods were followed in the field evaluation of prophylactic and curative methods.

4.5 FIELD EVALUATION- PROPHYLACTIC METHOD

Effective treatments obtained from experiment on application methods, were further tested in farmers' field at Aruvappulam, Konny, Pathananthitta district (Plate 12).

The selected treatments were thiamethoxam 0.01% LAF and 0.03% injection, neem soap 1% spraying + LAF, *M. majus* 2% swabbing + LAF ,their different combinations and cassava leaf distillate 'Nanma' 5% spraying + LAF and chlorpyrifos 0.0% LAF. Altogether, seventeen treatments were tested in the field as prophylactic method to manage *O. longicollis* as described in 3.5. Treatments were applied on plants on fifth and sixth month after planting. The results obtained in this experiment are described below.

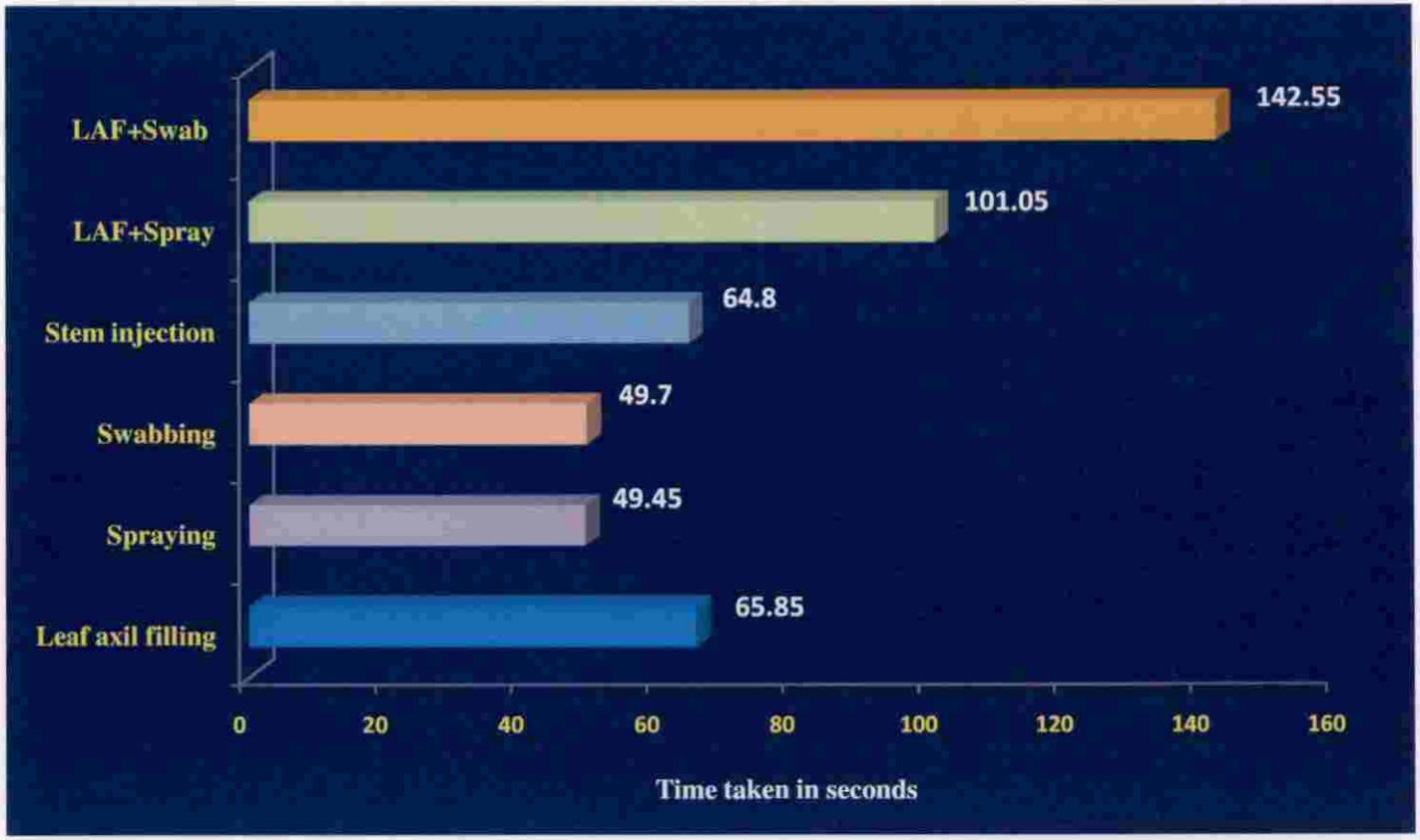


Fig. 8 Time taken for different application methods per plant

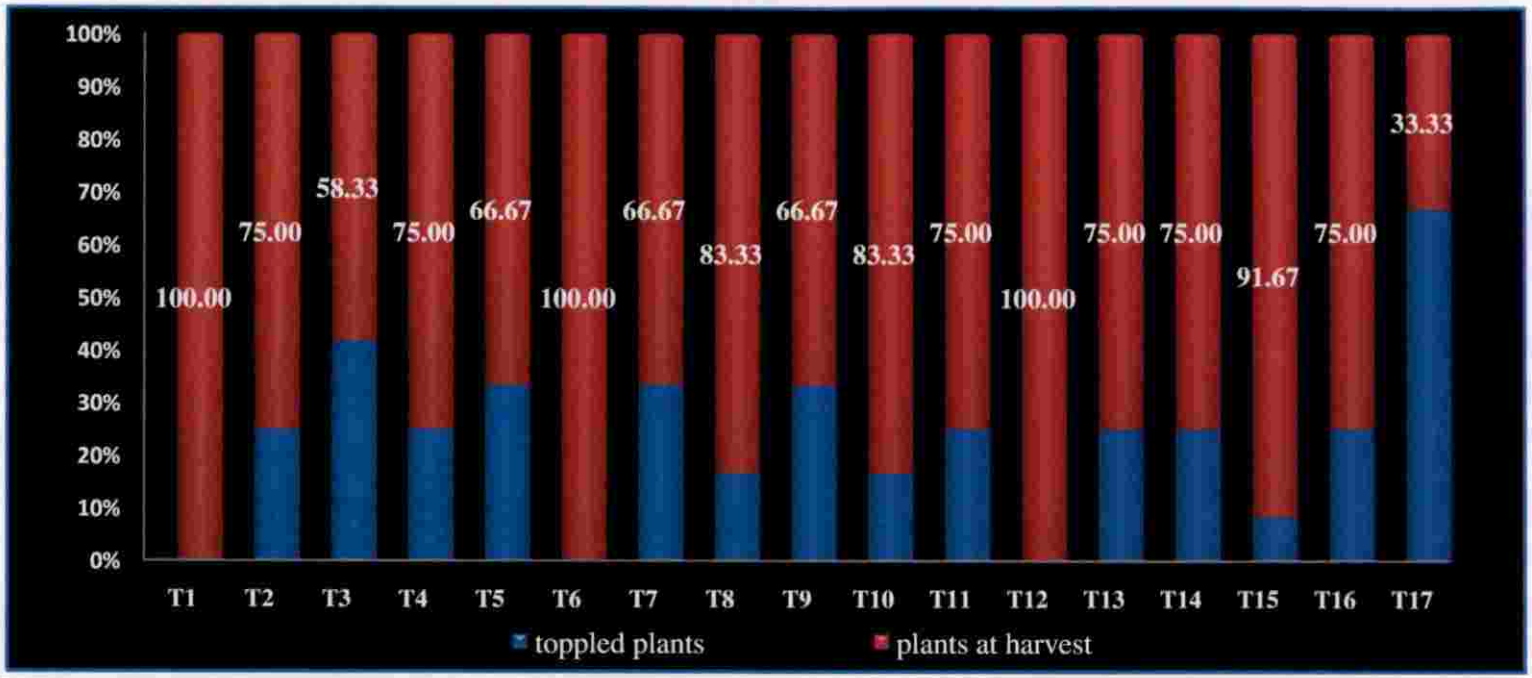
Plate 12. The field experiment plot at Aruvappulam, Pathanamthitta

4.5.1 Crop Damage

The survival rate of plants in prophylactivc method is illustrated in fig. 9. Three treatments *viz.,* thiamethoxam 0.03% injection (T1), *M. majus* swabbing + thiamethoxam 0.03% injection (T6) and thiamethoxam 0.01% LAF (T12) scored maximum survival rate (100 per cent) among the 17 treatments tested. Minimum survival rate was recorded in control (33.33 per cent). Second highest survival rate (91.67 per cent) was registered for *M. majus* + thiamethoxam 0.01 % LAF (T15). Neem soap+ thiamethoxam injection (T8) and 'Nanma' (T10) had equal effect on plant protection.

Crop damage, both pre and post treatment, was also recorded. Plants were observed for the presence of any feeding/exit holes before treatment application and the data collected is presented in the table 19. Analysis of pre treatment data of holes on pseudostem showed no significant difference among treatments.

Number of bore holes made by grubs on the pseudostem was recorded at the time of the harvest or toppling due to pest attack. The number of holes present on the stem at final stage of the crop showed significant difference among the treatments. All the sixteen treatments differed significantly from control which recorded maximum number of holes (8.67 plant^{-1}). With the exemption of thiamethoxam 0.03% injection at fifth and sixth MAP, all other treatments recorded holes on the stem ranging from 0.08 to 8.67. The treatments, T1 and T12 which involved two time application of thiamethoxam 0.03% injection and 0.01 % leaf axil filling, respectively recorded the least number of holes (0.0 and 0.08 plant^{-1}) and found superior to all other treatments. Injecting thiamethoxam 0.03% twice at five and six months after planting recorded no fresh holes at the time of harvest.



T1 Thiamethoxam 0.03% injection
T2 Neem soap 5%
T3 *M. majus* 2%
T4 Thiamethoxam injection+ *M. majus*
T5 Thiamethoxam injection + Neem soap
T6 *M. majus*+ Thiamethoxam injection
T7 *M. majus*+ Neem soap
T8 Neem soap+Thiamethoxam injection
T9 Neem soap +*M. majus*
T10 'Nanma' (5%)
T11 Chlorpyrifos (0.03%)
T12 Thiamethoxam 0.01% LAF
T13 Thiamethoxam LAF+*M. majus*
T14 Thiamethoxam LAF + Neem soap
T15 *M. majus*+ Thiamethoxam LAF
T16 Neem soap + Thiamethoxam LAF
T17 Control

Fig.9. Effect of prophylactic methods on survival rate of plants at harvest

Table 19. Effect of different prophylactic treatments for *O. longicollis* management on the pseudostem

Treatment number	Treatments	Mean number of holes plant^{-1}	
		Pre count at 5MAP	At harvest
T1	Thiamethoxam (0.03%) injection at 5&6 MAP	0.08 (0.76)	0.00 ^{h} (0.70)
T2	Neem soap (1%) spray+LAF 5&6 MAP	0.08 (0.76)	4.75 ^{bc} (2.29)
T3	*M. majus* (2%) swabbing + LAF 5&6 MAP	0.00 (0.70)	5.50 ^{b} (2.44)
T4	Thiamethoxam (0.03%) injection 5MAP + *M. majus* (2%) swabbing + LAF 6 MAP	0.00 (0.70)	2.92 ^{cde} (1.83)
T5	Thiamethoxam (0.03%) injection 5MAP + Neem soap (1%) spray 6MAP	0.17 (0.81)	3.67 ^{bcde} (2.04)
T6	*M. majus* (2%) swabbing 5MAP + Thiamethoxam (0.03%) injection 6MAP	0.17 (0.88)	0.50 ^{gh} (0.99)
T7	*M. majus* (2%) swabbing 5MAP + Neem soap (1%) spray 6MAP	0.08 (0.76)	3.83 ^{bcde} (2.05)
T8	Neem soap (1%) spray 5MAP+ Thiamethoxam (0.03%) injection 6MAP	0.00 (0.70)	2.42 ^{ef} (1.67)
T9	Neem soap (1%) spray 5MAP + *M. majus* (2%) swabbing 6MAP	0.08 (0.76)	4.42 ^{bcd} (2.20)
T10	Cassava leaf distillate - 'Nanma' (5%) 5&6 MAP	0.000 (0.70)	3.00 ^{cde} (1.84)
T11	Chlorpyrifos (0.03%) 5&6 MAP	0.17 (0.88)	2.33 ^{ef} (1.67)
T12	Thiamethoxam (0.01%) LAF 5&6 MAP	0.17 (0.81)	0.08 ^{h} (0.76)
T13	Thiamethoxam (0.01%) LAF 5MAP + *M. majus* (2%) swabbing 6MAP	0.00 (0.70)	2.75 ^{de} (1.79)
T14	Thiamethoxam (0.01%) LAF 5MAP+ Neem soap (1%) spray 6MAP	0.08 (0.76)	3.25 ^{cde} (1.92)
T15	*M. majus* (2%) swabbing 5MAP+ Thiamethoxam (0.01%) LAF 6MAP	0.00 (0.70)	1.42 ^{fg} (1.30)
T16	Neem soap (1%) spray 5MAP+ Thiamethoxam (0.01%) LAF 6MAP	0.08 (0.76)	2.08 ^{ef} (1.59)
T17	Control	0.08 (0.76)	8.67 ^{a} (3.02)
	CD (0.05)	NS	0.474

Figures in parenthesis are $\sqrt{x+0.5}$ transformed values. MAP-Months after planting
Treatment means with same alphabets are on par, NS=Not significant

While analyzing the number of holes on the stem, application of *M. majus* as swabbing and leaf axil filling on five months after planting followed by hiamethoxam injection in six months after planting (T6) (0.5 holes plant^{-1}) was also on par with treatment 1 and 12. Treatments 6 (0.5 holes plant^{-1}) and 15 (1.42 holes plant^{-1}), where thiamethoxam application on 6 MAP was done as injection and leaf axil filling, respectively were found statistically on par. All other treatments, where second application was done with thiamethoxam *i.e.*, T8, T15, T16 and chlorpyrifos (T11) showed same effect and statistically on par.

Plants received two time application of the bio agent, *M.majus* recorded maximum holes (5.5 holes plant^{-1}) among the treatments except control and this was statistically on par with two time application of neem soap 1.0% and sequential application of *M.majus* – neem soap. Insecticide check chlorpyrifos treated plants had mean number of 2.33 holes and was statistically on par with the cassava leaf distillate treatment (3 holes plant^{-1}).

4.5.2 Pest Incidence

4.5.2.1 Presence of Grubs

Different life stages of the pest *O. longicollis* present in the pseudostem at harvest or toppling is given in table 20. Number of live grubs present inside the stem under different treatments ranged from zero to 4.75. The least mean was recorded in treatments with thiamethoxam injection (T1) (0.0 grubs plant^{-1}) and leaf axil filling (T12) (0.083 grubs plant^{-1}).

Treatment (T6) with *M. majus* + thiamethoxam injection (0.5 grubs plant^{-1}) was found statistically on par with T1 (0.0 grubs plant $^{-1}$) and T12 (0.08 grubs plant^{-1}) and T15 (1.08 grubs plant^{-1}). All other treatments were found inferior to these four treatments.

The treatments with two time application of bio agent *M. majus* (T3) (3.58 grubs plant^{-1})and in combination with neem soap (T7 and T9) (3.5 grubs plant^{-1} and 4.75 grubs plant^{-1}) were not effective.

Treatment (T10) with cassava leaf distillate + neem oil ('Nanma') was found having same effect (1.83 grubs plant^{-1}) as that of T11 (2.08 grubs plant^{-1}), T13 (2.0 grubs plant^{-1}), T14 (2.0 grubs plant^{-1}), T15 (1.08 grubs plant^{-1}), T8 (2.3 grubs plant^{-1}), T4 (2.5 grubs plant^{-1}) and T2 (2.5 grubs plant^{-1}). Effect of treatments with bio agent *M. majus* alone (T3) and in combination with neem soap (T7 and T9) was not found effective.

4.5.2.2 Presence of Pupa

At the time of harvest/toppling, pupae seen inside the pseudeostem were also recorded. Mean number of pupae ranged from zero to 1.58 plant^{-1}. Pupae were seen inside a cocoon made up of chewed banana fibers, mostly on the outer sheaths of the stem. The cocoons were ovoid in shape and attached to the inner side of the outer sheaths between the air columns. Both the ends of cocoon were plugged and some of them were seen as opened indicating emergence of adult. No pupae were found in treatments with two time application of thiamethoxam injection (T1), leaf axil filling (T12) and *M. majus* + thiamethoxam injection (T6). Chlorpyrifos treated plants recorded a mean number of 0.5 pupa plant^{-1} which was statistically on par with one time application of thiamethoxam as leaf axil filling (T13, T14, T15 and T16), neem soap – thiamethoxam combination (T5 and T8) and also with 'Nanma' (T10). These treatments T1, T6 and T12 were also on par with treatments T8, T10, T14, T15 and T16. Except T10, all other treatments had thiamethoxam application at least once. Control plants recorded 1.58 pupae per plant which was similar to T3 (1.08), T7 (1.25) and T9 (0.92).

4.5.2.3 Presence of Adults

Adult weevils resting in between leaf sheaths and inside the damaged pseudostem were counted at harvest/toppling of plant. The computed data is presented in table 20.

Adult weevils were present in all the treatments and maximum number was noticed in control (3.25 plant^{-1}). All the treatments differed significantly from control. Thiamethoxam leaf axil filling (T12) and injection (T1) were superior to all other treatments and they recorded 0.08 and 0.17 adults plant^{-1}, respectively.

Cassava leaf distillate 'Nanma' treated plants also had less number of adults (0.67) which was on par with chlorpyrifos. Number of adults on plants received injection of thiamethoxam at five and six months after planting, 'Nanma' and chlorpyrifos were statistically on par. Sequential application of *M. majus* and neem soap recorded 2.25 and 2.17 adults, respectively. The treatments in which thiamethoxam was applied on six month after planting (T6, T8, T15 and T16), all except T16 were equally effective in managing adult population on treated plants. All the treatments with one time thiamethoxam leaf axil filling were also similar in action against adults. Thiamethoxam at 0.01% and 0.03%, chlorpyrifos 0.03% and 'Nanma' 5% along with *M.majus* + thiamethoxam 0.03% had less than one adult weevil per plant.

4.5.3 Yield

Data on yield from plants received different treatments in prophylactic method is elaborated in table 21. Mean yield from treated plants ranged from 10.68 kg plant^{-1} in thiamethoxam injection (T1) to 1.67 kg in control (T17). All the treatments differed significantly from control.

147

Table 20. Effect of different prophylactic treatments on different life stages of *O. longicollis*

Treatment number	Treatments	Mean number/plant		
		Grubs	Pupa	Adults
T1	Thiamethoxam (0.03%) injection at 5&6 MAP	0.00 ^{f} (0.70)	0.00 ^{g} (0.70)	0.17 ^{hi} (0.81)
T2	Neem soap (1%) spray+LAF 5&6 MAP	2.50 ^{bcd} (1.70)	0.67 ^{bcde} (1.08)	1.42 ^{cdef} (1.39)
T3	*M. majus* (2%) swabbing + LAF 5&6 MAP	3.58 ^{ab} (2.02)	1.08 ^{abc} (1.26)	1.75 ^{bcde} (1.49)
T4	Thiamethoxam (0.03%) injection 5MAP + *M. majus* (2%) swabbing + LAF 6 MAP	2.50 ^{bc} (1.71)	0.83 ^{abcd} (1.15)	1.50 ^{bcdef} (1.41)
T5	Thiamethoxam (0.03%) injection 5MAP + Neem soap (1%) spray 6MAP	2.67 ^{bc} (1.74)	0.58 ^{cdef} (1.03)	2.08 ^{bcd} (1.59)
T6	*M. majus* (2%) swabbing 5MAP + Thiamethoxam (0.03%) injection 6MAP	0.50 ^{ef} (0.99)	0.00 ^{g} (0.70)	0.92 ^{fg} (1.16)
T7	*M. majus* (2%) swabbing 5MAP + Neem soap (1%) spray 6MAP	3.50 ^{ab} (1.99)	1.25 ^{ab} (1.33)	2.25 ^{b} (1.66)
T8	Neem soap (1%) spray 5MAP+ Thiamethoxam (0.03%) injection 6MAP	2.33 ^{bcd} (1.67)	0.42 ^{defg} (0.95)	1.08 ^{efg} (1.25)
T9	Neem soap (1%) spray 5MAP + *M. majus* (2%) swabbing 6MAP	4.75 ^{a} (2.27)	0.92 ^{abcd} (1.14)	2.17 ^{bc} (1.63)
T10	Cassava leaf distillate - 'Nanma' (5%) 5&6 MAP	1.83 ^{cd} (1.46)	0.42 ^{defg} (0.95)	0.67 ^{gh} (1.07)
T11	Chlorpyrifos (0.03%) 5&6 MAP	2.08 ^{bcd} (1.59)	0.50 ^{cdef} (1.00)	0.67 ^{gh} (1.08)
T12	Thiamethoxam (0.01%) LAF 5&6 MAP	0.08 ^{f} (0.76)	0.000 ^{g} (0.70)	0.08 ^{i} (0.76)
T13	Thiamethoxam (0.01%) LAF 5MAP + *M. majus* (2%) swabbing 6MAP	2.00 ^{bcd} (1.57)	0.500 ^{cdef} (0.99)	1.33 ^{def} (1.35)
T14	Thiamethoxam (0.01%) LAF 5MAP+ Neem soap (1%) spray 6MAP	2.00 ^{bcd} (1.58)	0.25 ^{efg} (0.86)	1.75 ^{bcde} (1.49)
T15	*M. majus* (2%) swabbing 5MAP+ Thiamethoxam (0.01%) LAF 6MAP	1.08 ^{de} (1.25)	0.08 ^{fg} (0.76)	1.08 ^{efg} (1.26)
T16	Neem soap (1%) spray 5MAP+ Thiamethoxam (0.01%) LAF 6MAP	2.67 ^{bc} (1.78)	0.25 ^{efg} (0.86)	1.58 ^{bcde} (1.45)
T17	Control	4.67 ^{a} (2.27)	1.58 ^{a} (1.42)	3.25 ^{a} (1.92)
	CD (0.05)	0.455	0.285	0.262

Figures in parenthesis are $\sqrt{x+0.5}$ transformed values. MAP- Months after planting

Treatment means with same alphabets are on par

148

Table 21. Effect of different prophylactic treatments for *O. longicollis* management on yield

Treatment number	Treatments	Yield/plant (kg)
T1	Thiamethoxam (0.03%) injection at 5&6 MAP	10.68[a]
T2	Neem soap (1%) spray+LAF 5&6 MAP	5.18[gh]
T3	*M. majus* (2%) swabbing + LAF 5&6 MAP	3.65[i]
T4	Thiamethoxam (0.03%) injection 5MAP + *M. majus* (2%) swabbing + LAF 6 MAP	5.85[efg]
T5	Thiamethoxam (0.03%) injection 5MAP + Neem soap (1%) spray 6MAP	5.48[fg]
T6	*M. majus* (2%) swabbing 5MAP + Thiamethoxam (0.03%) injection 6MAP	8.82[b]
T7	*M. majus* (2%) swabbing 5MAP + Neem soap (1%) spray 6MAP	4.77[gh]
T8	Neem soap (1%) spray 5MAP+ Thiamethoxam (0.03%) injection 6MAP	6.70[de]
T9	Neem soap (1%) spray 5MAP + *M. majus* (2%) swabbing 6MAP	4.25[hi]
T10	Cassava leaf distillate - 'Nanma' (5%) 5&6 MAP	7.50[cd]
T11	Chlorpyrifos (0.03%) 5&6 MAP	6.78[de]
T12	Thiamethoxam (0.01%) LAF 5&6 MAP	10.32[a]
T13	Thiamethoxam (0.01%) LAF 5MAP + *M. majus* (2%) swabbing 6MAP	5.80[efg]
T14	Thiamethoxam (0.01%) LAF 5MAP+ Neem soap (1%) spray 6MAP	5.83[efg]
T15	*M. majus* (2%) swabbing 5MAP+ Thiamethoxam (0.01%) LAF 6MAP	8.50[bc]
T16	Neem soap (1%) spray 5MAP+ Thiamethoxam (0.01%) LAF 6MAP	6.57[def]
T17	Control	1.67[j]
	CD (0.05)	1.111

Treatment means with same alphabets are on par

MAP- Months after planting

Maximum yield of 10.68 kg plant^{-1} was recorded in two time application of thiamethoxam 0.03% injection (T1). This was followed by two time thiamethoxam leaf axil filling (T12) (10.32 kg plant^{-1}). These treatments were on par with each other and statistically superior to all other treatments.

Plants treated with *M. majus* on five months after planting and thiamethoxam injection (T6) or leaf axil filling (T15) on six months after planting recorded a yield of 8.82 and 8.50 kg plant^{-1}, respectively. Cassava leaf distillate based formulation, 'Nanma' (T10) was found equally effective (7.5 kg plant^{-1}) with T15 (8.5 kg plant^{-1}), T11 (6.78 kg plant^{-1}), T8 (6.70kg plant^{-1}) and T16 (6.57 kg plant^{-1}).

Yield from plants received thiamethoxam injection or leaf axil filling only once at five months after planting as in treatments T4 (5.85 kg plant^{-1}), T5 (5.48 kg plant^{-1}), T13 (5.80 kg plant^{-1}) and T14 (5.83 kg plant^{-1}) did not show any difference. On the contrary, thiamethoxam leaf axil or injection only once at six months after planting in combination with *M. majus* and neem soap treatments (T6, T8, T15 and T16) showed variation. But yield from plants treated with *M. majus* at five months after planting in combination with thiamethoxam at six months after planting either as injection (T6-8.82 kg plant^{-1}) or leaf axil filling (T15-8.50 kg plant^{-1}) were on par. Similarly neem soap LAF and spraying at five months after planting followed by thiamethoxam application either as injection or leaf axil filling at six months after planting also showed no difference in yield.

The insecticide check (T11) chlorpyrifos recorded mean yield of 6.78 kg plant^{-1} and this was on par with T10, T16 and T8. The lowest yield was recorded in control as many plants had toppled down before harvest. The thiamethoxam treatment either as injection or leaf axil filling at five MAP followed by application of either *M. majus* (T4 and T13) or neem soap (T5 and T14) were on par. Application of bio agent *M. majus* twice on five and six month after planting as leaf axil filling and swabbing did not significantly differ from control as yield from both the treatments were on par.

150

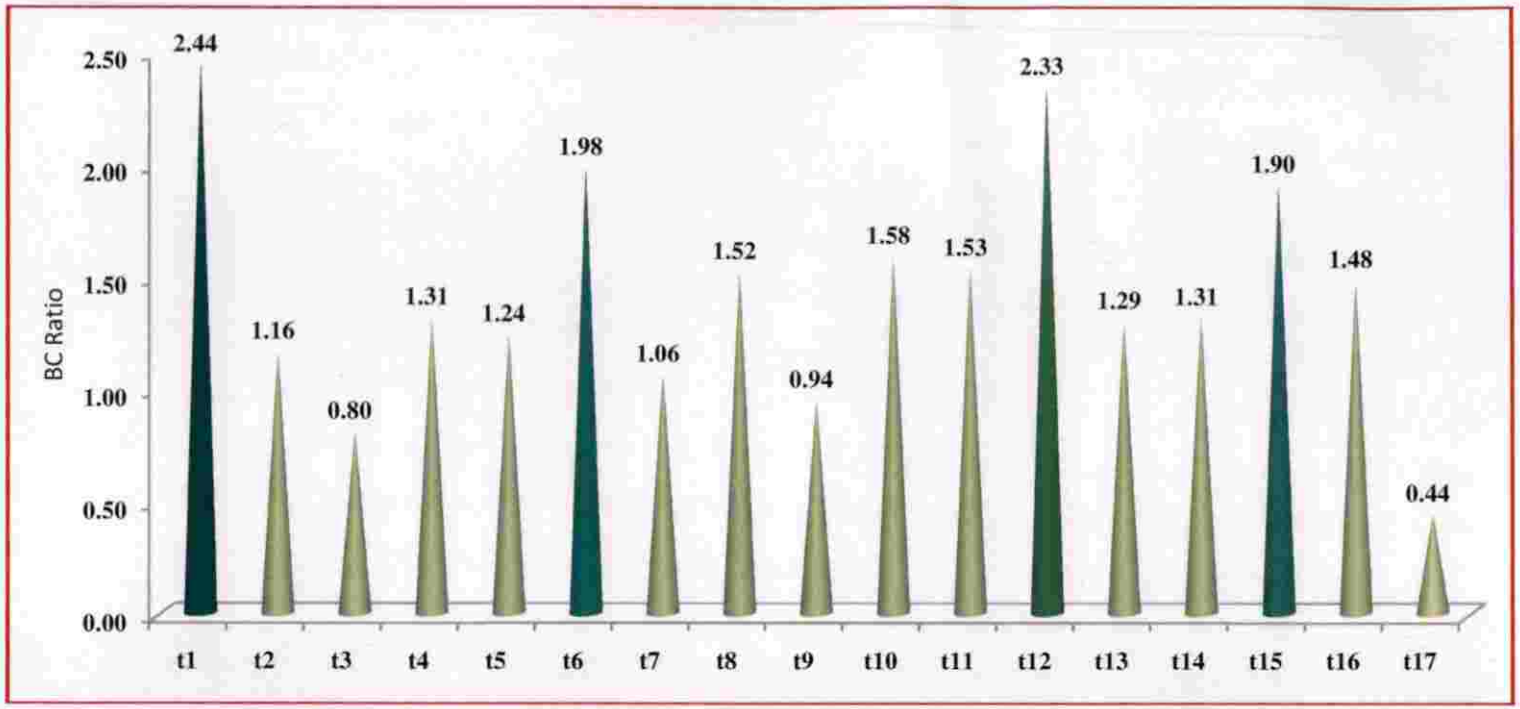
4.5.4 Benefit Cost Ratio

Benefit cost ratio was calculated for each treatment and presented in the fig. 10. Benefit was calculated by taking only the yield. It was calculated @ Rs.50 per kg fruit based on the prevailing market price.

Highest BC ratio was recorded by T1 (2.44) closely followed by T12 (2.33). The least ratio 0.44 was observed in control. Next best BC ratio was found with treatments T6 and T15 which recorded rates of 1.98 and 1.90 respectively and these two treatments were on par also. Cassava leaf distillate treatment ('Nanma'-T10) was found on par with insecticide check chlorpyrifos, T8 and T16 which registered B:C ratios 1.58, 1.53, 1.52 and 1.48 respectively. Except T3, T9 and control, all other treatments recorded a BC ratio more than one, indicating net returns. The net profit analysis (fig. 10) indicated that control plants registered a huge loss of -106.42 rupees plant^{-1} followed by T3 (-44.25 plant^{-}) and T9 (-12.36 plant^{-}).

Maximum profit was assured by T1 which recorded Rs.314.74 as net profit plant^{-1} closely followed by T12 with Rs. 294.84 plant^{-1}. Application of thiamethoxam once as LAF or injection on six months after planting recorded a BC ratio of more than 1.5 in T6, T8, T15 and T16. At the same time, thiamethoxam application at five months after planting alone could not offer a higher BC ratio. Neem soap 1% application at five and six months after planting recorded a BC ratio of only 1.16, but in all combination with thiamethoxam, it could register a higher BC ratio.

Cost of cultivation including plant protection was maximum for treatment T10 with Rs.236.83 plant^{-1} followed by T3, T7 and T9 (Fig. 11). Control plants with no plant protection treatment recorded a cost of Rs.189.75 plant^{-1}. Among the treatments other than control, T1 with injection of thiamethoxam twice had the lowest cost Rs.219.22 plant^{-1}.



T1 Thiamethoxam 0.03% injection
T2 Neem soap 5%
T3 *M. Majus 2%*
T4 Thiamethoxam injection+ *M. majus*
T5 Thiamethoxam injection + Neem soap
T6 *M. majus*+chemical injection
T7 *M. majus*+ Neem soap
T8 Neem soap +chemical injection
T9 Neem soap +*M. majus*
T10 'Nanma' 5%
T11 Chlorpyrifos
T12 Thiamethoxam 0.01% LAF
T13 Thiamethoxam LAF+*M. majus*
T14 Thiamethoxam LAF + Neem soap
T15 *M. majus*+ Thiamethoxam LAF
T16 Neem soap + Thiamethoxam LAF
T17Control

Fig.10. BC ratio of different treatments in prophylactic method

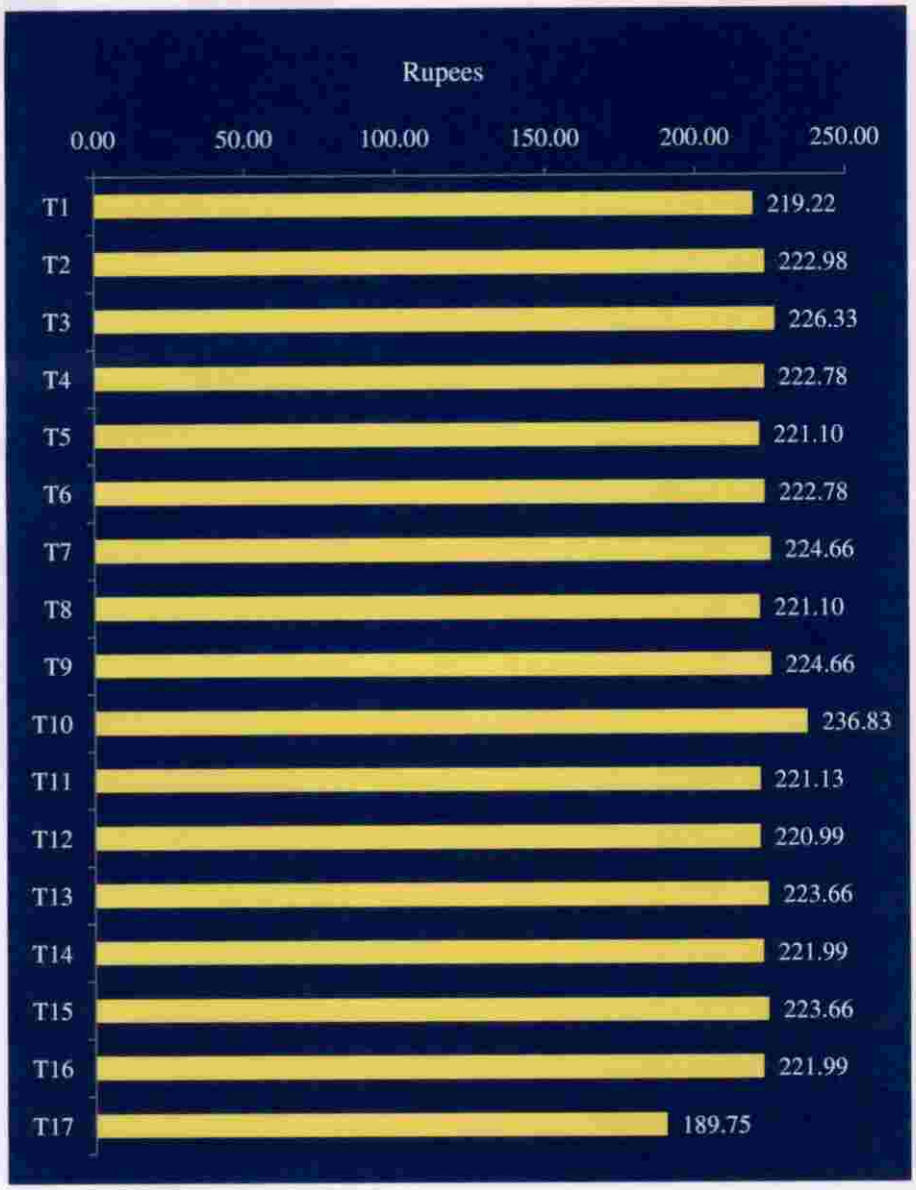


Fig. 11 Cost of cultivation for different treatments

Benefit cost analysis of the study on prophylactic method revealed that thiamethoxam 0.03% injection (T1) and thiamethoxam 0.01% LAF (T12) were superior to other treatments as it could gave maximum return, highest yield and minimum crop damage.

4.6 FIELD EVALUATION- CURATIVE METHOD.

The effect of curative method of *O. longicollis* management in banana using seven treatments was tested in farmers' plot at Konny, Pathanamthitta district. The study area was selected based on the severe infestation of the pest.

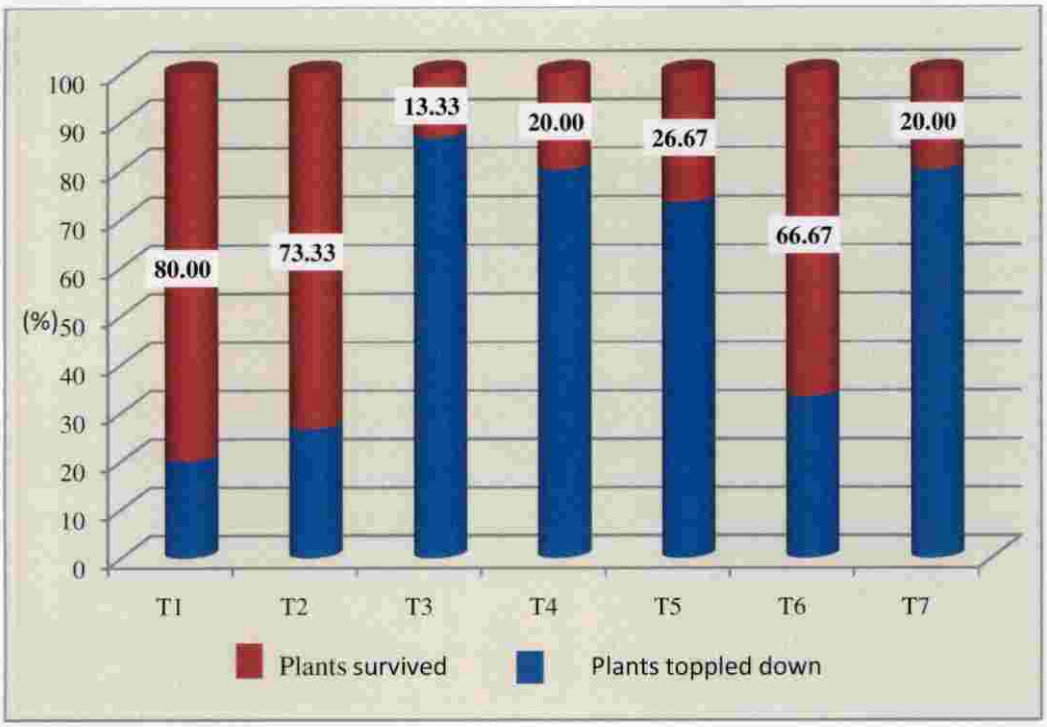
Infested plants with damage grade index 1 and 2 were uniformly selected for this study. Final damage grade index was assessed by counting the number of holes, at the time of harvest or toppled down.

4.6.1 Crop Damage

Survival rates of plants under curative method varied from 13.33 to 80.0 per cent (Fig. 12). Highest survival rate was shown by plants received thiamethoxam injection 0.03% (80.0 per cent) followed by thiamethoxam leaf axil filling 0.01 % (73.37 per cent). Lowest survival rate (13.33 per cent) was noticed among plants treated with neem soap 1.0% spray+ leaf axil filling. Plants treated curatively with chlorpyrifos 0.03% as leaf axil filling recorded 66.67 per cent survival rate. Only 26.67 per cent plants survived under 'Menma' and 20 per cent in *M. majus* treatment in curative method. The survival rate of plants which received no treatments was 20 per cent, same as that of *M. majus* treated plants.

4.6.2 Pest Incidence

Feeding/exit holes made by grubs of *O. longicollis* on pseudostem was taken as visual manifestation of pest damage. Counting of holes just before treatment application ranged from 1.67 to 1.93 and they did not differ statistically.



T1	Thiamethoxam 0.03 % injection
T2	Thiamethoxam 0.01 % LAF
T3	Neem Soap 1.0 % spray and LAF
T4	*M. majus* 2.0 % swabbing and LAF
T5	Cassava leaf distillate ('Menma') 15 ml plant^{-1} injection
T6	Chlorpyrifos 0.03 %
T7	Control

Fig. 12 Effect of curative method of treatments on survival rate of plants at harvest

Total number of holes on the stem at the time of harvest or toppled down was counted and recorded (Table 22). Lowest number of holes in post treatment was noticed in plants received thiamethoxam (0.03% and 0.01%) treatments (5.87 and 5.73). Meanwhile, highest number of holes (9.47) was recorded in plants which received no treatment. Plants injected with 'Menma' showed more holes (8.47) than thiamethoxam 0.03% injected plants (5.87). The number of holes and subsequently the damage grade index of all plants under curative method had increased from the initial value.

4.6.3 Yield

Yield obtained from plants in curative method was very low and ranged from 0.9 to 3.53kg plant^{-1} only (Table 22). The highest yield was recorded for thiamethoxam 0.03% injection (3.53 kg plant^{-1}). This was followed by yield obtained from thiamethoxam 0.01% leaf axil filling (3.10 kg plant^{-1}) and chlorpyrifos 0.03% leaf axil filling (2.75 kg plant^{-1}).

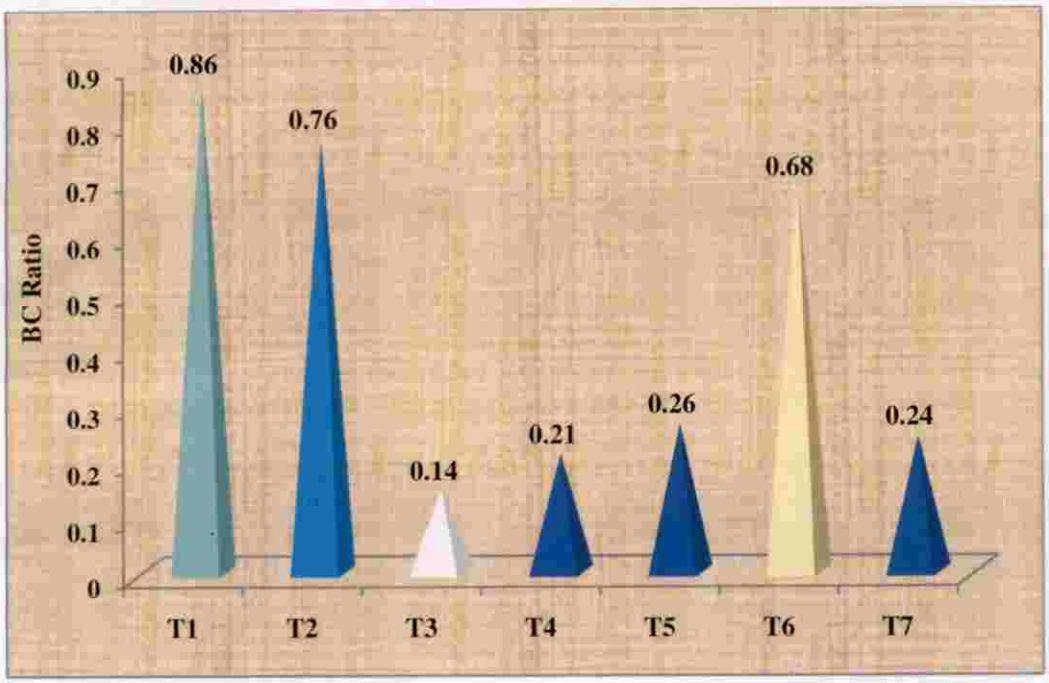
4.6.4 Benefit Cost Ratio

BC ratio obtained for different treatments under curative method is depicted in fig. 13. In curative method, maximum BC ratio (0.86) was recorded for thiamethoxam 0.03% injection, closely followed by thiamethoxam 0.01% leaf axil filling (0.76). All the treatments recorded BC ratio below 1.0, indicating the non effectiveness of curative method against *O. longicollis*. The lowest ratio (0.14) was recorded for plants received Neem soap 1% spraying + leaf axil filling. Insecticide check, chlorpyrifos 0.03% leaf axil as curative method had a BC ratio of 0.68 only.

Table 22. Effect of different curative methods for *O. longicollis* management

Treatment number	Treatments	No. of holes on stem at topple/harvest	Mean yield from survived plants (kg)	Yield/plant (kg)
T1	Thiamethoxam (0.03%) injection	5.87	4.35	3.53 [a] (2.00)
T2	Thiamethoxam (0.01%) LAF	5.73	4.21	3.10 [a] (1.89)
T3	Neem Soap (1%) spary+LAF	9.2	2.92	0.58 [b] (1.01)
T4	*M. majus* (2%) swabbing +LAF	8.67	4.25	0.85 [b] (1.16)
T5	Cassava leaf distillate – 'Menma' injection (15ml plant^{-1})	8.47	4.04	1.07 [b] (1.25)
T6	Chlorpyrifos (0.03%)	6.27	4.13	2.75 [a] (1.79)
T7	Control	9.47	3.00	0.90 [b] (1.14)
	CD (0.05)			(0.377)

Figures in parenthesis are $\sqrt{x+0.5}$ transformed values.
Treatment means with same alphabets are on par



T1	Thiamethoxam 0.03 % injection
T2	Thiamethoxam 0.01 % LAF
T3	Neem Soap 1.0 % spray and LAF
T4	*M. majus* 2.0 % swabbing and LAF
T5	Cassava leaf distillate ('Menma') 15 ml plant^{-1} injection
T6	Chlorpyrifos 0.03 %
T7	Control

Fig. 13 BC ratio of different curative methods

Cassava distillate, 'Menma' could give a BC ratio of 0.26 only in the current study. Bio-agent, *M. majus* also found not fit for curative method of treatment as it could register a ratio of 0.21 only.

Analysis of data recorded from the study on curative method indicated the ineffectiveness of treatments in resulting high yield and pest management compared to prophylactic method.

4.7 ESTIMATION OF HARVEST TIME RESIDUES IN THE DIFFERENT PRODUCE

Residues of thiamethoxam in main edible parts of banana were estimated adopting the QuEChERS procedure for fruits and vegetables. Validation of this procedure for matrices under study was done following the steps for single laboratory method validation.

4.7.1 Method Validation

Validation of pesticide residue estimation methodology by QuEChERS method was done by calculating the recovery percentage after fortification with known quantity of pesticide in the matrix. Since thiamethoxam was the only insecticide used in the field experiments recovery study was restricted to thiamethoxam alone. Recovery of thiamethoxam was done in banana green fruit, male bud and inner core of the stem which are the edible portions of the plant. Calibration curve (Appendix II) was drawn to check the linear response of the instrument to thiamethoxam concentrations.

Recovery studies of thiamethoxam in all three matrices revealed that the recovery percentage obtained was within the acceptable range of 70 to 120 per cent. Recovery percent from different matrices ranged from 80.58 to 98.24 per cent with relative standard deviation (RSD) ranging from 0.793 to 8.405.

Recovery of thiamethoxam from green fruits of banana fortified at 0.05 ppm was 95.88±1.035 per cent with RSD 1.08 (Table. 23). The higher concentrations *ie.*, 0.25 and 0.5 ppm had recovery percentage of 95.84±2.809 per cent, 98.2±1.78 per cent with RSD 2.931 and 1.812 respectively.

Experiments with male bud yielded 86.84±2.435 per cent recovery of thiamethoxam with RSD 2.804 for 0.05 ppm and 92.4±7.767 per cent, 97.8±1.086 per cent for 0.25 and 0.5 ppm respectively (Table 24). RSDs for all concentrations were well below the acceptable limit of 20. Inner core or extended peduncle of banana recorded a maximum recovery of 96.76±0.767 per cent at 0.05 ppm while at higher fortification levels of 0.5 ppm, 86.96±4.949 per cent recovery was obtained (Table 25). Values for RSD ranged from 0.793 to 5.691.

4.7.2 Pesticide Residue Estimation in Different Matrices

Samples were collected from plants treated at least once with the insecticide, thiamethoxam. No residue was detected in any of the samples from two time application of thiamethoxam as LAF and injection. Concentration or residue of thiamethoxam was well below detectable level (BDL) in fruits, male bud and peduncle treated with thiamethoxam at 5 MAP. Similarly residue was at BDL in matrices collected from plants treated with thiamethoxam even at 6 MAP. Thus in all matrices tested, irrespective of their time and method of application, thiamethoxam residue was below detectable level. Chromatograms are attached in appendix III.

Table 23. Recovery of thiamethoxam spiked in banana fruit with peel

Chemical	Fortification level (ppm)	Mean recovery (%)	Standard Deviation	RSD
Thiamethoxam	0.05	95.88	1.035	1.080
	0.25	95.84	2.809	2.931
	0.50	98.24	1.780	1.812

Table 24. Recovery of thiamethoxam spiked in banana male bud

Chemical	Fortification level (ppm)	Mean recovery (%)	Standard Deviation	RSD
Thiamethoxam	0.05	86.84	2.435	2.804
	0.25	92.40	7.767	8.405
	0.50	97.80	1.086	1.111

Table 25. Recovery of thiamethoxam spiked in banana inner core (stem)

Chemical	Fortification level (ppm)	Mean recovery (%)	Standard Deviation	RSD
Thiamethoxam	0.05	96.76	0.767	0.793
	0.25	80.58	1.078	1.337
	0.50	86.96	4.949	5.691

RSD= relative standard deviation

Pesticide residue analysis showed no detectable residue of thiamethoxam in edible parts such as male bud, peduncle and fruits collected from plants treated with thiamethoxam 0.01% and 0.03% at 5MAP and 6MAP.

5.8 MATRIX SCORING

Farmers' response on ten attributes of three different insecticide delivery devices *viz.*, conventional metal knapsack sprayer, high density polyethylene (HDPE) sprayer with extensible lance and newly designed injection assembly was recorded in a matrix format and presented in table 26. The attributes were ranked in a three point scale from 1 to 3; 1 for good and 3 for best. Maximum score (3.0) was given to injection assembly for cost, minimum spillage and safety. The device also obtained highest scores for attributes like non-wastage of chemical (2.9), availability (2.65) and easiness in handling (2.65). Farmers preferred metal knapsack sprayer to HDPE sprayer with extensible lance for its durability.

The respondents appraised HDPE sprayer and injection assembly equally for their efficacy in delivering the chemical at the correct site. They also had the opinion that number of spray fluid filling required was more for injection assembly (1.6) to cover a unit area, compared to other two devices. Injection assembly obtained a mean score of 2.49, whereas HDPE sprayer and metal knapsack sprayer were given scores, 1.995 and 1.515, respectively.

Table 26 . Comparison of different attributes for pesticide application devices in banana by farmers

	Knapsack sprayer	HDPE extensible lance sprayer	Injection using special needle
Affordable cost	1.15	1.85	3.00
Minimum spillage	1.00	2.00	3.00
Non wastage of chemical	1.00	2.10	2.90
Durability	2.90	1.70	1.40
Time taken to cover one plant	1.15	2.70	2.15
Easy availability	2.25	1.10	2.65
Safe to user	1.0	2.00	3.00
Filling frequency for unit area coverage	2.30	2.10	1.60
Accessing correct point of delivery of chemical	1.00	2.45	2.50
Easiness in handling	1.40	1.95	2.65
Mean score	1.515	1.995	2.49

1= Good; 2= Better; 3= Best

Discussion

5. DISCUSSION

Banana is an important crop of the State and its cultivation supports livelihood as well as play a vital role in providing nutritional security to man and animals. Variation in climate, flaring up of pests and diseases, volatile market and exorbitant rise in cost of inputs are the emerging problems faced by banana growers. Psuedostem borer, *O. longicollis* is a major pest of banana which could cause up to cent per cent damage; if no timely management practices were followed (Padmanaban and Sathiamoorthy, 2001). Recommended management practices against *O. longicollis* include use of chlorpyrifos 0.03 % and carbaryl 0.2 % (KAU, 2011a).

Studies conducted at various parts of the world unambiguously proved ill effects of chlorpyrifos to humans as well as environment (Alavanja *et al.*, 2003; Lee *et al.*, 2004). It is high time to excogitate for a solution to the problem and so the present study aims at evolving a management practice with safer chemicals and bio rational methods. The study comprised of documentation of pest status and farmers' pest management practices, efficacy testing of insecticides, botanical and bio agents, standardization of application methods, field evaluation of best treatments emanated out of laboratory experiments; both as prophylactic and curative methods. All the experiments were sequentially planned, as result of one experiment is taken as a lead for the succeeding experiment. The results of the study are discussed below.

5.1 DOCUMENTATION OF PEST STATUS AND FARMERS' PRACTICES

Documentation of pest intensity, different aspects of farmers' practices on pest management will help to identify technology gaps in banana production. For this, a survey was conducted in four southern districts of the state *viz.*, Thiruvananthapuram, Kollam, Patahanamthitta and Alappuzha to collect field data

regarding *O. longicollis* incidence and management strategies adopted (Plate 13 and14).

5.1.1 Intensity of *O. longicollis* Infestation

Results of the survey revealed that 'Nendran' was the most extensively cultivated banana cultivar in all the surveyed districts. This cultivar was raised on a planned crop calendar and phased manner, synchronized with market demands. In the survey, among the different varieties, Nendran showed maximum infestation (6.41 per cent) by *O. longicollis* followed by Palayankodan (5.21 per cent). This observation in the study corroborates with earlier findings of Charles *et al.*, 1996; Anitha, 2000; Lalitha *et al.,* 2002; Thippaiah *et al.*, 2010.

The first report of *O. longicollis* from Kerala was also from 'Nendran' (Visalakshi *et al.*, 1989). 'Njalipoovan' showed the lowest infestation by *O. longicollis* (2.13 per cent) among the infested cultivars in all the districts. High infestation of *O. longicollis* in AAB banana cultivars Nendran and Palayamkodan is substantiated by Padmanaban *et al.* (2001b) where they observed preference of the pest to AAB group of banana. The high susceptibility of cv. Nendran is attributed by high moisture, low crude fibre, low protein, low total and OD phenol present in them, while the resistance of cv. Njalipoovan may be due to a reverse situation in that variety (Lalitha *et al.,* 2002).

The farmers followed pest management practices against *O. longicollis* in 'Nendran', which was grown as a commercial crop. Even after practicing pest management in these varieties, farmers face a pest incidence up to 21.00 per cent. Ninety two per cent of the surveyed farmers recognized the pest attack only when they noticed ooze out or presence of exit holes on the stem (Fig.14). Lack of proper adoption of pest management practices at the early stage or prophylactic measures might have created this situation.

Plate 13. Survey locations in different districts

A- Sasthamkotta, Kollam
B- Aruvappulam, Pathanamthitta
C- Murinjakal, Pathanamthitta
D- Kunnathukal, Thiruvananthapuram
E- Venmony, Alappuzha
F- Nedumangad, Thiruvananthapuram
G- Vakayar, Pathanamthitta

Plate 14. Survey plots at different districts

5.1.2 Other Emerging Pests

The data collected in survey indicated future pest menace to banana growers. Rhizome weevil (*C. sordidus*), leaf eating caterpillar (*S. litura*), banana skipper (*Erionota* sp.), rhinoceros beetle (*O. rhinoceros*), wild boar (*S. scrofa*) and fruit fly (*B. dorsalis*) was observed as emerging pest on banana in southern districts of Kerala. *O. rhinoceros* on 'Nendran' and 'Njalipoovan' was reported earlier from Alleppey district, Kerala (Sivakumar and Mohan, 2013). Brown scale, *C. hesperidium* and small banana weevil, *P. mellerborgi* were also collected from different plots during the survey. The banana weevil, *P. mellerborgi* is reported for the first time from Kerala, which was earlier reported from Tamil Nadu (Padmanaban *et al.*, 2001c). The occurrence of *B. dorsalis* is alarming as the farmers could not easily notice the infestation. Wild boar was observed as a problem in banana cultivation in two districts *viz.*, Thiruvananthapuram and Pathanamthitta.

The attack of wild boar has been observed in plots near to forest area in Pathanamthitta and Thiruvananthapuram districts and their occurrence in the area may be due to the less availability of food in forest as suggested by Chauhan *et al.* (2009). Wild boar has been reported as a major threat to many other crops from several parts of India (Chauhan *et al.*, 2009; Vanitha *et al.*, 2011). Severe attack was experienced at planting when the animals destroy the sprouting corms. On matured plants, they push down the plant and devour the bunch.

5.1.3 Insecticides Used by Farmers in Banana

In the survey it was observed that organophosphorus (OP) insecticide, chlorpyrifos (40 per cent) and quinalphos (37 per cent) were the major insecticides used by banana growers. These two insecticides are recommended against *O. longicollis* (KAU, 2011a). Since these chemicals were recommended by the agricultural extension agencies and due to easy availability in the market, farmers used it frequently. The survey also revealed that farmers depended on State owned agencies for technology source. This justifies the use of

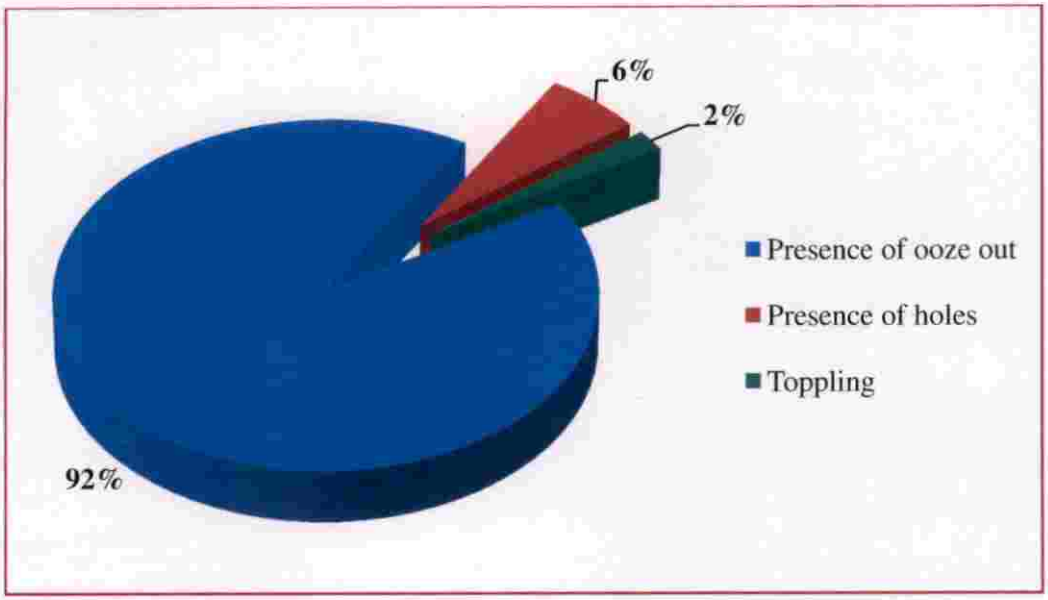


Fig. 14 Identification of *O. longicollis* infestation in banana by farmers

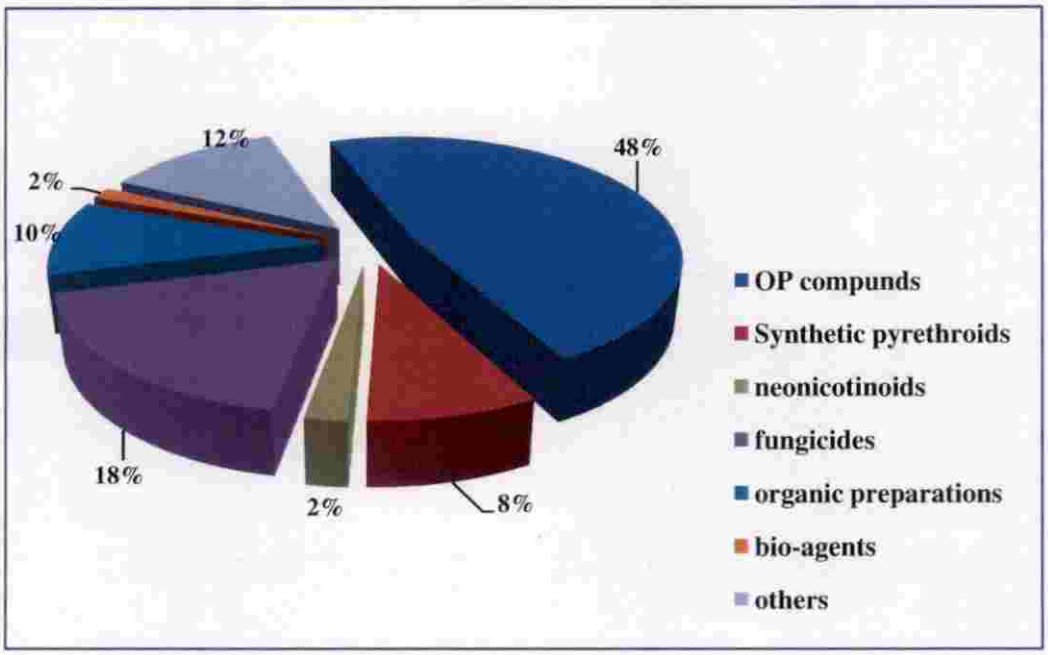


Fig. 15 Use of different chemicals and bio agents in banana ecosystem

recommended pesticides in banana. Forty eight percent of the respondents used OP insecticides; meanwhile only ten per cent used organic or botanical preparations against pest problems in banana (Fig. 15). Fipronil was used (20 per cent) as an alternative to carbofuran by farmers. They preferred this granular formulation because of the easiness in application.

Drenching the leaf axils with insecticides is one of the recommended application methods (Reghunath *et al.*, 1992; Anitha, 2000; KAU, 2011a) but it was rarely followed by the farmers and instead, they sprayed on the pseudostem. This will lead to less retention of the chemical on the target site. This indicates improper use of insecticides due to lack of awareness and knowledge in use of pesticides.

Crop residues with different stages of pest should be properly destroyed or removed from the field to reduce the pest population build up. This practice was seldom noticed in the surveyed fields. The psuedostem after harvest, was heaped in the field and was found as breeding site of *O. longicollis.* Similar situations were reported earlier as well (Padmanaban and Kandasamy, 2003). So awareness on value addition such as fibre extraction and product diversification from pseudostem has to be increased for reducing population build up of the pest.

5.1.4 Protective Gadgets Used by Farmers

Protective gadgets were used by the farmers to minimize the physical exposure to pesticide while handling. But use of gadgets varied from 2.0 per cent to 72.0 per cent (Fig. 16). Farmers had awareness about the risk of pesticide inhalation and exposure as evidenced from the use of personal protective gadgets such as mask and full sleeve shirts. Even though they were cautious in protecting upper body part, farmers paid least attention in covering lower body parts such as legs. This is evident from the lesser users (2 per cent) of boots. The use of masks among farmers was more than that of gloves or goggles. They used hand kerchiefs, cloth and readymade masks. Since gloves and goggles were to be

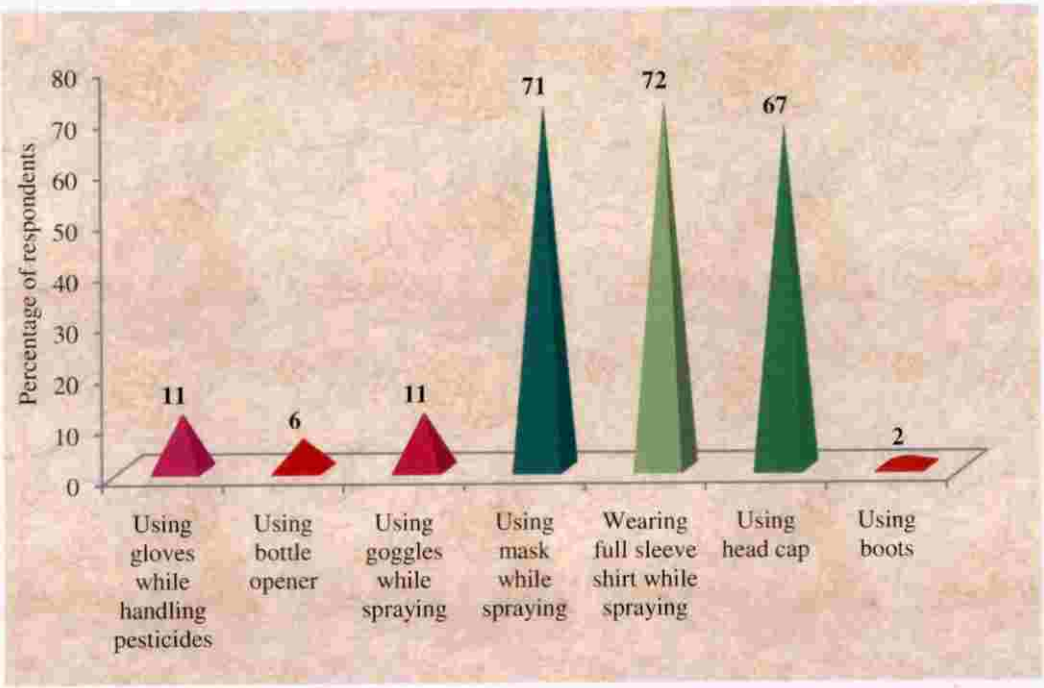


Fig. 16 Use of different personal protective gadgets by farmers while applying insecticides

purchased, they avoided it. The same trend in use of mask and gloves was observed by Warburton *et al.* (1995) among rice farmers. Use of gloves was proved effective in reducing pesticide exposure among farm workers and farmers (Damalas and Koutroubas, 2016). So awareness on using protective gadgets especially gloves and goggle has to be improved through various extension programmes.

All the farmers surveyed were well aware on the personal health and hygiene such as washing clothes and taking bath. Warburton *et al.* (1995) and Devi (2009) also observed farm workers involved in spraying operations in rice fields took bath after spraying. As the plant protection operations were undertaken on sunny days and required time, farmers consumed (16 per cent) water in between. Disposal of pesticide bottles after use was not taken care of, as only 36 per cent farmers disposed the bottles and covers promptly.

5.1.5 Source of Knowledge

Banana growers mainly depended on State owned agricultural extension services such as Krishi Bhavans (KB) and Vegetable and Fruit Promotion Kerala (VFPCK) for different queries related banana plant protection. Anitha (2000) observed low pest infestation, lack of awareness among farmers towards the pest and its management practices earlier. Establishment of strong extension network facilities facilitated by State Department of Agriculture through Krishi Bhavans, VFPCK etc. attributed to the increase in knowledge and skill of farmers in banana pest management. Even though farmers gathered information regarding type and quantity of pesticides for use, they applied these chemicals according to their experience only. Farmers judged the presence of *O. longicollis* only when external symptoms appeared and subsequently adopted plant protection measures. Extension efforts should be taken to impart knowledge and skill in identifying the pest attack and proper adoption of technology. As majority of the farmers relied

on VFPCK network for information gathering process, this channel can be exploited for information delivery.

5.1.6 Parasites and Predators

Only two predators; earwig (*Forficula* sp.) and ants (*O. smaragdina*) were identified from the fields. Aguilar *et al.* (2014) also observed earwig as natural enemy of banana pests.

5.1.7 Evaluation of Efficacy of Semiochemical

The pheromone lure bought from M/s. Chem Tica of Costa Rica to attract *O. longicollis* adult weevils failed both in laboratory and field experiments. Some earlier experiments with pheromones also failed to attract or catch *O. longicollis* adults as expected (Palanichamy *et al.*, 2011a). So the commercially available pheromone could not be effectively utilized for *O. longicollis* management or monitoring. Indigenous traps with longitudinally split pseudostem or stump trapping will be an alternate trapping method as suggested by Pinto (1928).

5.2 *IN VITRO* EVALUATION OF EFFICACY OF INSECTICIDES, BOTANICALS AND BIO AGENTS

5.2.1 Effect of Insecticides on Mortality of *O. longicollis* Grubs and Adults

The insecticides *viz.*, thiamethoxam 0.01%, indoxacarb 0.01%, emamectin benzoate 0.002% and cartap hydrochloride 0.05% registered 100.00 per cent mortality of *O. longicollis* grubs at 36 HAT, while thiamethoxam 0.01%, cartap hydrochloride 0.05%, and emamectin benzoate 0.002% were equally effective in causing 100.00 per cent adult mortality at 36 HAT (Fig. 17).

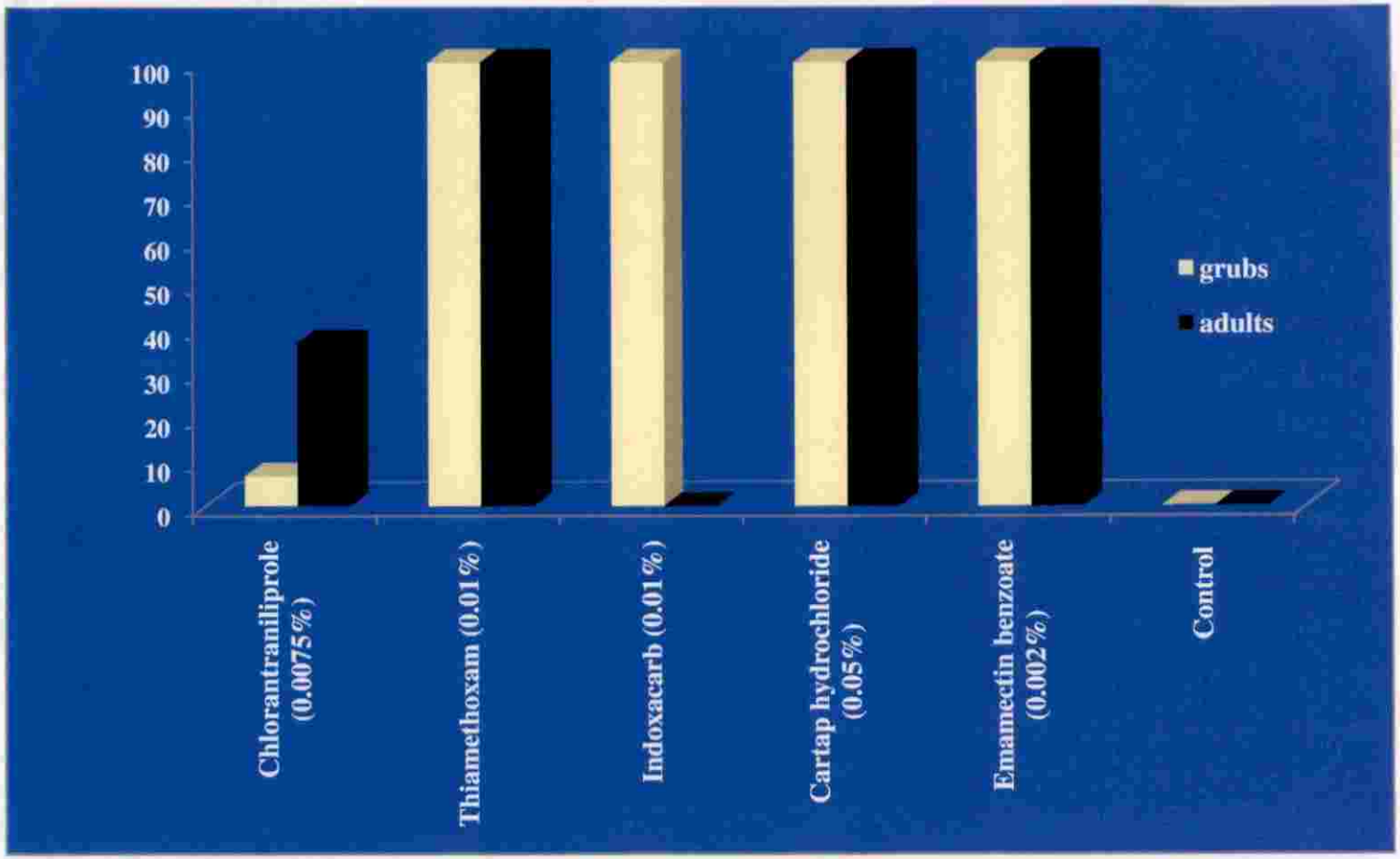


Fig.17 Mortality of adults and grubs of *O. longicollis* at 36 hours after treatment

Thiamethoxam, emamectin benzoate and cartap hydrochloride were found effective against damaging stages of *O. longicollis* at 0.01, 0.002 and 0.1%, respectively. All the three chemicals have different modes of action. Thiamethoxam act as agonist to nicotinic acetylcholine receptor site, emamectin benzoate activates chloride channels in nerve cells and nereis toxin analogue, cartap hydrochloride blocks the nicotinic acetylcholine receptor on the nerve cells (IRAC, 2015). These results are in corroboration with laboratory and field studies conducted on other insects and crops with thiamethoxam (Maienfisch *et al.*, 2001a; Vastrad, 2003; Karibasavaraja *et al.*, 2005; Sujay *et al.*, 2013 and Patel *et al.*, 2016). Efficacy of emamectin benzoate against borer pests on vegetables in laboratory has already been reported (Vijayasree, 2013).

Calculating the cost of required chemicals showed that thiamethoxam 0.01% had advantageous over other chemicals (Fig. 18). Thiamethoxam 0.01% was more cost effective (Rs. 16 for making 10 l of spray solution) when compared to cartap hydrochloride 0.05% and emamectin benzoate 0.002%. The insecticides cartap hydrochloride 0.05% and emamectin benzoate 0.002% incurred a cost of 11.55 and 46.20 rupees, respectively. Considering the mammalian toxicity, thiamethoxam has low mammalian toxicity (Maienfisch *et al.*, 2001b). All except thiamethoxam have yellow label and coming under toxic category of insecticides. Blue label of thiamethoxam makes it fit for a good choice against *O. longicollis* with low toxic effects on man and environment. Indoxacarb was more toxic to grubs than adults as it registered hundred percent mortality of grubs within 36 HAT. Indoxacarb is a broad spectrum insecticide acting as sodium channel blockers in nerve cells. Indoxacarb is a pro insecticide and the rate of bio-activation may differ in different species or life stages as proposed (Gour and Sridevi, 2012) may be the reason.

As thiamethoxam 0.01% proved effective against both grubs and adults of *O. longicollis in vitro* and economically viable, it was chosen as best insecticide against *O. longicollis*. Cartap hydrochloride 0.05% also showed its efficacy

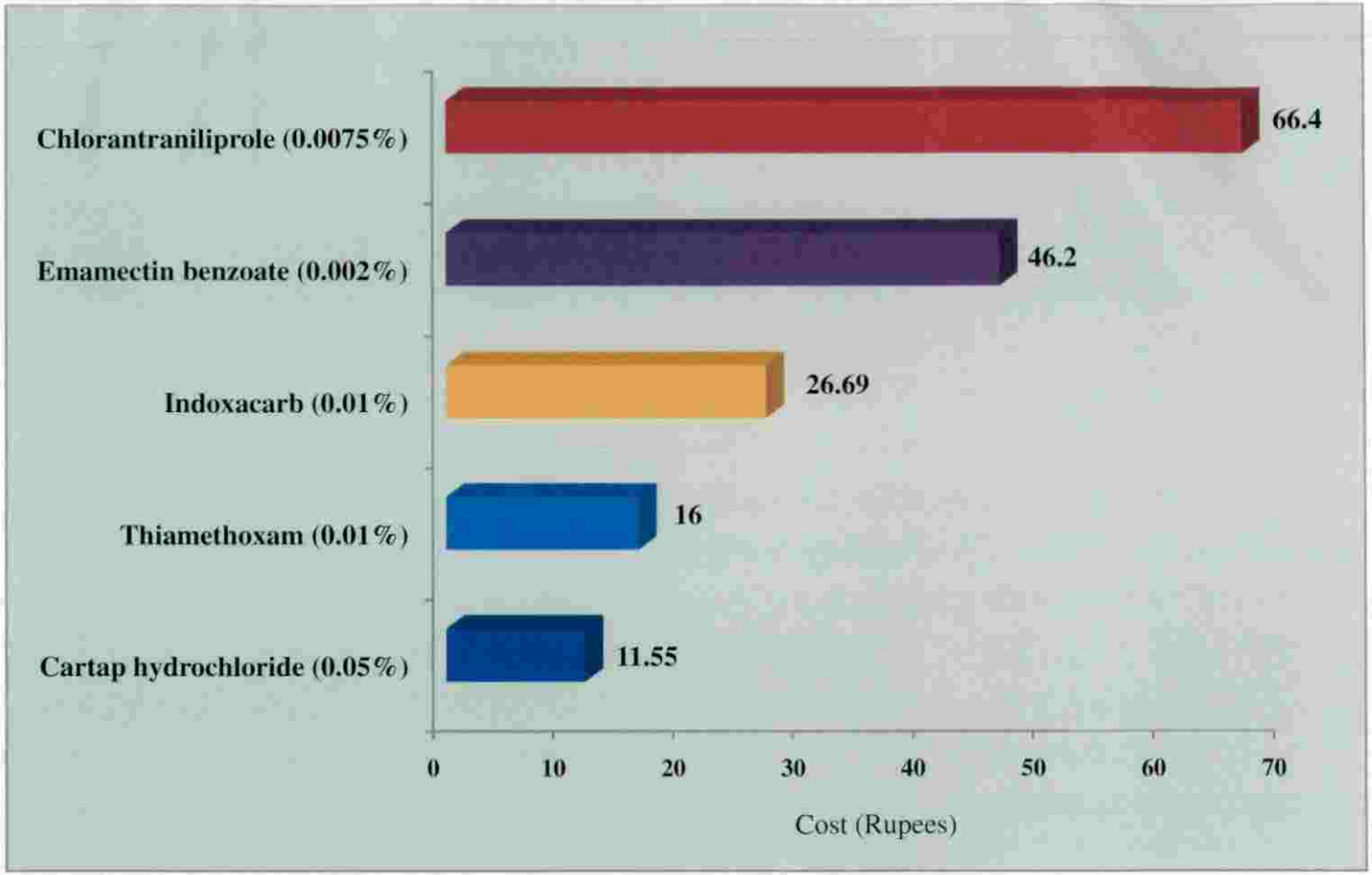


Fig.18 Cost of effective insecticides against *O. longicollis* for making 10.0 litre spray solution

against the pest and stood second in cost incurred. So both these chemicals were taken to test different application techniques in the field.

5.2.2 Effect of Different Botanical Preparations on *O. longicollis* Grubs and Adults

Effect of five botanical preparations *viz*., cassava leaf distillate 'Nanma' (3%), azadirachtin 1%EC (0.3%), neem soap (1%), neem oil emulsion (3%), NSKE (5%) was tested on *O. longicollis* grubs and adults. The results proved that only one preparation, 'Nanma' 3% had deleterious effect on *O. longicollis* grubs. This formulation caused 26.67 per cent and 36.67 per cent mortality of grubs at 10 and15 DAT, respectively. All other treatments did not differ significantly from control on fifteen days after treatment.

Adult weevils showed 36.67 per cent mortality both in 'Nanma' 3% and neem soap 1% at 10 DAT. Azadirachtin 1%EC 0.3% and neem oil emulsion 3% were equally effective in causing mortality in adults (16.67 and 13.33per cent, respectively) but differed from control. Sivasubramanian *et al*. (2009) observed a high mortality rate (43.74 per cent) of *O. longicollis* in higher concentration (4%) of azadirachtin 1.2EC. Bhagawati *et al.* (2009) observed similar results at a lower concentration of these botanicals. Zabel *et al*. (2002) observed a direct relation between neem concentration and mortality of insects. Thus low mortality percentage may be due to low concentration of neem in the formulations used. It is also supported by the observations of Messiaen *et al*. (1998) cited by Okolle *et al.* (2009) where they opined the mortality of insects depended on the concentration of neem or dose. These botanicals were very slow in effecting mortality of grubs and adults compared to the insecticides tested.

5.2.2.1 Repellent Effect of Different Botanicals on O. longicollis Adults in Multi Choice Method and No-Choice Method

Observations in this study established the repellency effect of neem based preparations like neem soap (1%), 'Nanma' (5%) and neem oil emulsion (3%). All these preparations were effective in repelling *O. longicollis* weevils from alighting on it in both multi and no choice tests. But, NSKE 5% and azadirachtin 1%EC 0.3% did not show promising results in repellency on *O. longicollis* adults in this study as against the earlier observations (Sivasubramanian *et al.*, 2009 and Irulandi *et al.*, 2012). The number of weevils alighting on the treated pseudostem pieces increased as time progressed in no choice method. Bhagavathi *et al.* (2009) also observed the same trend in their experiment also.

5.2.3 Effect of Different Bio Agents on *O. longicollis* Grubs and Adults

Three entomopathogenic fungi, *B. bassiana* (ITCC 6063), *B. bassiana* (NRCB, Trichy) and *M. majus* [ICAR-CPCRI(RS) Kayamkulam] were tested on both grubs and adults of *O. longicollis*. Among these, *M. majus* was the only bio agent found effective against *O. longicollis*. *M. majus* caused 80 per cent mortality of grubs within ten days after treatment. The result on grub mortality by *M. majus* is validated by earlier studies on *M. anisopliae* (Anitha *et al.*, 1998 and Beegum, 2005). Earlier, *Metarhizium* was reported to cause mortality in other coleopteran pests also (Nirula *et al.*, 1955; Kabaluk *et al.,* 2005; Makaka, 2008). All the bio agents caused same mortality (6.67 per cent) on adults.

5.3 EFFECT OF CHEMICALS ON ENTOMOPATHOGENIC FUNGUS, *M. majus* UNDER *IN VITRO* CONDITION

5.3.1 Effect of Chemicals on Growth of *M. majus*

In vitro studies were done to test the effect of promising pesticides and fungicides on *M. majus*. Insecticides and botanicals were selected based on the results in the experiment 4.2. Mycelial growth of the fungi on different poisoned media with the test pesticides differed significantly. Neem soap 1% recorded growth (7.77 cm) on par with control (8.43 cm). Growth of the fungus on thiamethoxam (0.01% and 0.03%) was the highest among insecticides (7.0 and 7.40, respectively) and was also on par with neem soap 1%. Filho *et al.* (2001); Neves *et al.* (2001) and Oliveira *et al.* (2003) also had similar observations for thiamethoxam. Fungal growth initiated only two days after inoculation in all insecticide treatments whereas in cartap hydrochloride and chlorpyrifos growth was visible only after a week. Even after the slow growth initiation, fungal growth in cartap hydrochloride plates surpassed chlorpyrifos plates in growth and on 30th day it showed significantly higher hyphal growth (3.0 cm) than chlorphyrifos (2.23 cm). This type of growth pattern was observed for *M. anisopliae* with carbaryl (0.01%) by Soman and Mohan (2011). They observed low growth rate at 10DAI, but on par with control on 30th day after inoculation.

The fungicides, *viz.*, carbendazim 0.1%, mancozeb 0.3%, propiconazole 0.1% and tebuconazole 0.1% did not produce any growth of *M. majus*. Earlier studies by Beegum (2005) and Rachappa *et al.* (2007) support this result. Azoxystrobin caused initial growth inhibition and took five days to show any visible sign of mycelial growth. Observations by Li and Holdom (1994), indicated *M. anisopliae* isolates were more tolerant towards insecticides and herbicides than fungicides. Fungal growth on copperoxychloride showed a peculiar clear zone as a halo around the mycelia growth (Plate 15).

Growth of the fungus on different poisoned media was different and unique. The two neem oil based formulations, Neem soap 1% and 'Nanma' 5% showed

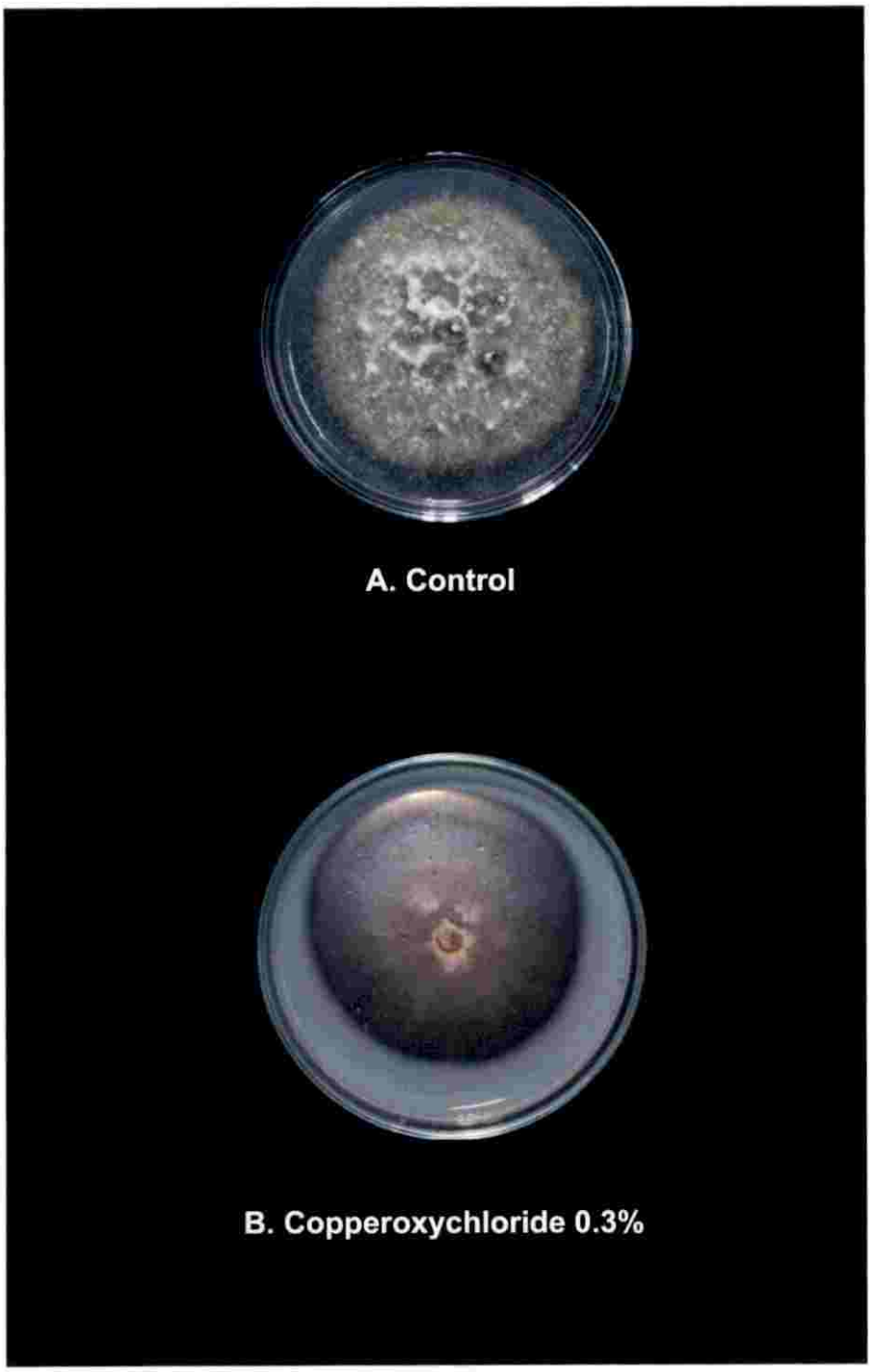


Plate 15. Clear zone formed by growth of *M. majus* on copperoxychloride

obvious difference in supporting fungal growth and sporulation of *M.majus in vitro*. Initial growth of the fungus on media with 'Nanma' restricted radially while mycelial growth was seen as vertical on the entire disc area. This may be due to the poison effect of cassava distillate, 'Nanma' in the surrounding medium and fungus might have utilized the free area of the original fungal disc. *M. majus* grown on neem soap treated medium did not exhibit such abnormal growth pattern. This change may be attributed to the lower concentration of neem soap (1%) compared to 'Nanma' (5%) and the presence of additional cyanogen compounds present in 'Nanma'. Inverse relation between concentration of neem oil and fungal growth as observed earlier by Aguda (1986); Gupta *et al.* (1999) and Isaiah *et al.* (2005) may be the reason for difference in growth of *M. majus* on 'Nanma' and neem soap. Both the concentrations of thiamethoxam supported a mat like horizontally and evenly spreading growth patterns as in control plates.

5.3.2 Effect of Chemicals on *M. majus* Sporulation and Viability

Maximum sporulation by *M. majus* was noticed in thiamethoxam 0.03%, meanwhile sporulation in both the concentrations of thiamethoxam (0.1% and 0.03%) were significantly higher than control. It is observed that spore production by *M. majus* increased with increase in thiamethoxam concentration. Filho *et al.* (2001) also observed the same trend in sporulation with imidacloprid and thiamethoxam. Neem soap which ranked first among the chemicals to support growth of the test fungus attained second best position after thiamethoxam 0.03% in sporulation.

Among the fungicides tested, azoxystrobin 0.1% recorded the highest sporulation. Other fungicides *viz.*, mancozeb, carbendazim, tebuconazole and propiconazole completely inhibited fungal growth as well as sporulation (Plate 16). No sporulation and colony growth of *M. anisopliae* was observed with carbendazim even at a very low concentration 0.0001% by Li and Holdom (1994). Manocozeb at 0.19% and 0.0959% totally inhibited spore germination of entomopathogenic

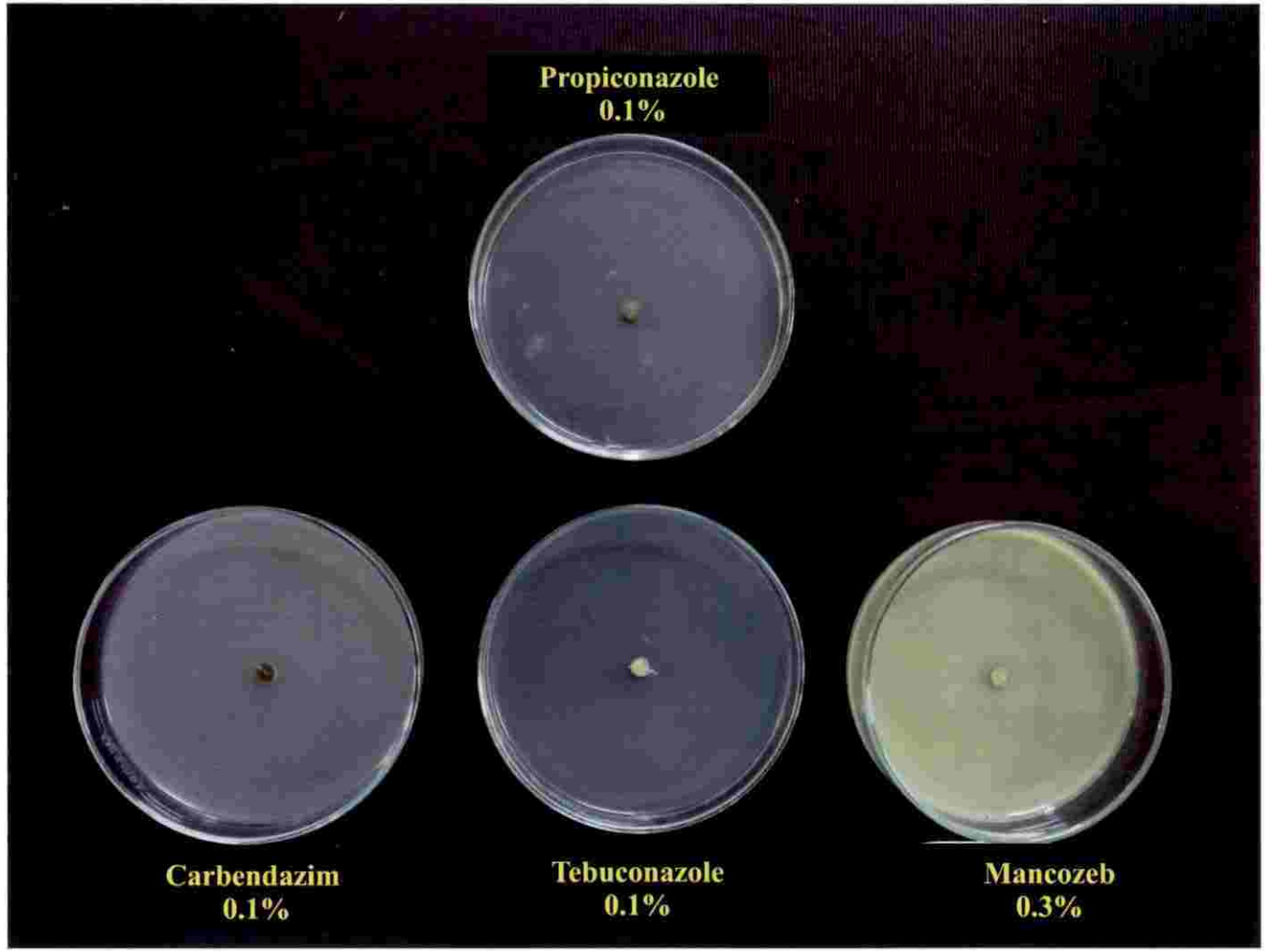


Plate 16. Growth inhibition of *M. majus* on different poisoned media

fungus *B. bassiana* in earlier studies by Loria *et al.*, (1983) and the incompatibility of mancozeb with *B. bassiana* was also reported by Todorova *et al.*, (1998). Total inhibition of sporulation of *M. anisopliae* by carbendazim, propioconazole, hexaconazole and chlorothalonil was reported by Rachappa *et al.*, (2007). These studies support results of the present study. Azoxystrobin yielded more conidia ($0.32x10^7$ spores ml^{-1}) compared to copperoxychloride ($0.06x10^7$ spores ml^{-1}). Growth on these fungicides treated media was very flimsy and thin. Rachappa *et al.*, (2007) observed mycelia growth of *M. anisopliae* (12.6mm) in copperoxychloride with a growth inhibition of 67.53 per cent concur the findings of the study. But in the current study the sporulation ($0.06x10^7$ spores ml^{-1}) on copperoxychloride was less than they observed ($0.17x10^7$ spores ml^{-1}).

Spore viability of fungus grown on pesticides is an important indication of compatibility of the bio agent with the chemical. Perusal of data on percentage viability of spores produced in different poisoned media showed that thiamethoxam did not affect the viability of spores compared to control and other treatments. Thiamethoxam at 0.01% yielded 98.82 per cent viable spores as against 86.46 per cent in control. The order of other chemicals supporting viability was 'Nanma' 5% (95.52 per cent), cartap hydrochloride 0.05% (95.0 per cent), chlorpyrifos 0.03% (93.19 per cent), neem soap 1% (92.42 per cent), thiamethoxam 0.03% (87.08 per cent), azoxystrobin 0.1% (77.02 per cent) and copperoxychloride 0.1% (39.78 per cent). This observation further strengthens the concept that neonicotinoid insecticide thiamethoxam is compatible with *M. majus* and cause minimum damage to the fungus (Filho *et al.*, 2001; Silva *et al.*, 2013).

5.3.3 Compatibility of Chemicals Using 'T' Value

Neves *et al.*, (2001) used 'T' value for computing compatibility of various chemicals to bio agents, based on fungal growth and sporulation. A pesticide with 'T' value higher than 60 is compatible. In this study, three treatments, *viz.*,

thiamethoxam 0.01%, thiamethoxam 0.03%, cartap hydrochloride 0.05% and neem soap 1.0% recorded 'T' value higher than 60. At both lower (0.01%) and higher concentrations (0.03%), thiamethoxam neither affected fungal growth nor spore production. Hence these pesticides are found compatible with *M. majus*. This observation is validated by earlier reports by Filho *et al.,* (2001); Neves *et al.,* (2001) and Silva *et al.,* (2013). Thiamethoxam at higher concentration (0.03%) tested in stem injection enhanced spore production compared to control. This concentration also recorded minimum growth inhibition. Spores harvested from thiamethoxam showed maximum viable spores also. It is evident from the results obtained from the current study that higher concentration of thiamethoxam enhances the growth and sporulation of *M. majus in vitro* and this is supported by earlier work of Filho *et al*., (2001) on *M. anisopliae*. It can be explained that the concentration of thiamethoxam used in stem injection will not affect the action of *M. majus* and thus can be used in combination, against *O. longicollis*.

Compatibility calculation using radial growth and sporulation revealed that all fungicides except azoxystrobin 0.1% were very toxic to *M. majus*. The new generation fungicide under methoxy acrylate group, azoxystrobin at 0.1% was moderately toxic to *M. majus* as it supported radial growth and spore production. *M. majus* on azoxystrobin showed 63.24 per cent growth and 40 per cent sporulation compared to control. Earlier, azoxystrobin was found compatible with bio agents, *Pseudomonas fluorescens, Bacillus subtilis* (Ehrenberg)and *Trichoderma harzianum* Rifai (Pandey *et al*., 2006; Devi and Prakasam, 2013). Fungicides are widely used in various disease management of banana (KAU, 2011a). When these are applied on aerial parts such as leaves for controlling leaf diseases, chance of getting contact with *M. majus* applied on stem is more. In such cases, sufficient time interval should be observed between the fungicide and bioagent applications. The strobilurin fungicide, azoxystrobin can be preferred over other conventional fungicides in emergency situations as it was found less toxic to *M. majus*, compared to other common fungicides used in banana.

Compatibility study of the entomopathogenic fungus, *M. majus* with several pesticides depicted that the most innocuous of the treatments tested were neonicotinoid insecticide thiamethoxam at concentrations of 0.01% and 0.03% and neem soap at 1.0%.

5.4 EVALUATION OF APPLICATION METHODS UNDER FIELD CONDITIONS

In this experiment, LAF, injection, swabbing+ LAF and spraying+ LAF methods of thiamethoxam application were found equally effective in containing the pest incidence and resulting in higher yield (Table 19). So among these superior treatments, LAF and injection were selected for further study because these methods required less time and had less chemical load compared to other methods. Being a systemic insecticide with translaminar action and acropetal distribution through xylem vessels (Elbert *et al.*, 2008), thiamethoxam will be readily reaching every part of the plant. Ring structure of thiamethoxam facilitates its hydrophilic nature. Banana pseudostem holds 96 per cent water (Li *et al.*, 2010) and this further enhances the solubility and ready absorption of thiamethoxam in banana. Thus it can offer protection to even young parts of the plant. These properties of thiamethoxam attribute its efficacy against *O. longicollis* in field application. Systemic insecticides like monocrotophos and dimethoate were proved effective as injection in banana to manage *O. longicollis* by early workers (Janakiraman and Rao, 2001; Justin *et al.* 2006; Irulandi *et al.* 2012; Shanmugam *et al.* 2013).

Cartap hydrochloride 0.15% injection caused blackening of tissues around the point of injection which sometimes extended further, but no discoloration on leaf axils was noticed in LAF using cartap hydrochloride 0.05%. In the case of thiamethoxam 0.03% injection, such tissue discoloration was not noticed. The stem of thiamethoxam injected plants was smooth and devoid of any oviposition punctures or exit /feeding holes or marks. Thiamethoxam leaf axil filled plants

showed infestation on the upper portion of the plant at 9 to 10 months stage, close to harvest. This may be due to the low or no pesticide residue left because of long gap of 3 to 4 months after last application of pesticide.

Among the application methods tested for neem soap, spraying+ LAF recorded higher plant survival rate and recorded higher yield. Spraying of neem soap and LAF might act as an oviposition deterrent and repellent for adults who seek shelter between leaf sheaths. Repellent and antifeedant action of neem based formulations are reported on many coleopterans by many workers (Musabyimana *et al.*, 2001; Zabel *et al.*, 2002; Inyang and Emosairue, 2005; Tinzaara *et al.*, 2006; Echereobia *et al.*, 2010; Sahayaraj and Kombiah, 2010). The injection of neem soap was not effective. The observation of Justin *et al.* (2006) on the ineffectiveness of injection of neem based formulation against *O. longicollis* further supported the current study.

Because of the waxy nature of banana pseudostem, when test chemicals and botanical are applied on stem as swabbing or spraying, results in low retention of chemicals on the stem (Abraham and Thomas, 1995). Due to rain this can easily be washed off. On the contrary, leaf axil filling will be effective as it will allow the chemical to percolate down slowly (Reghunath *et al.,* 1992). Being contact in action, cartap hydrochloride injection was not that effective as thiamethoxam. But cartap hydrochloride offered good results when applied as spraying + LAF. The residual contact action of cartap hydrochloride was due to its persistence as evidenced by low infestation of pest in plants received spray + LAF. Similar results were observed earlier when other conventional contact insecticides were used (Reghunath *et al.*, 1992; Mathew *et al.*, 1997; Anitha, 2000).

Application of *M. majus* using different methods was not promising for managing the pest. Swabbing +LAF was the only treatment which could give a higher yield and less number of pest stages. *M. majus* when applied as LAF will remain within leaf sheath and when adults shelter between the sheaths, fungal spores adhere onto the insect body and infection starts. Because of the occluded habitat,

chance of fungal spore getting direct contact with grubs is very meager. Earlier studies proved that half life of fungal spores was adversely affected by sunlight. Ignoffo (1992) observed *M. anisopliae* had only a half life of 1.3-4 h under stimulated sunlight. This may be the reason for reduced effect of *M. majus* in field compared to *in vitro*. Meanwhile, swabbing of *M. majus* will uniformly place fungal spores on the surface of pseudostem leading to direct contact with the pest. These findings are supported by earlier workwrs (Anitha, 2000; Beegum, 2005) on *M. anisopliae*. Swabbing as a method of pesticide application along with soil was advocated earlier (Abraham and Thomas, 1995; Mathew *et al.*, 1997; ICAR-NRCB, 2015) in banana against *O. longicollis*. Prabhavathi and Ghosh (2014) succeeded in early establishment of *B. bassiana* inside the banana pseudostem as an endophyte. However, no observation was made in this study to establish endophytic nature of *M. majus*.

All the treatments in evaluation of application method produced more yield compared to control (Fig. 19). Maximum yield was recorded by different methods of thiamethoxam application. Four treatments of this recorded more than six times yield than control. This was achieved since plants under thiamethoxam treatments recorded less toppling. From this experiment on application methods it is apparent that thiamethoxam injection, LAF and LAF + spray are equally effective in controlling *O. longicollis*. While considering drudgery, time and quantity of chemical; either LAF or injection will be effective and economically viable option for thiamethoxam application in banana. Injection of systemic insecticides like monocrotophos and dimethoate was found effective against *O. longicollis* (Janakiraman and Rao, 2001; Justin *et al.*, 2006; Vijayalalitha and Kannan, 2006; Shanmugam *et al.*, 2013) but failure of contact insecticides as injection was also reported (Anitha, 2000). For neem soap, almost all application methods except spray +LAF were found not effective. Likewise in case of the bioagent, *M. majus* swabbing + LAF was the most effective among the tested methods. Cartap hydrochloride spray + LAF can be used in the field to manage

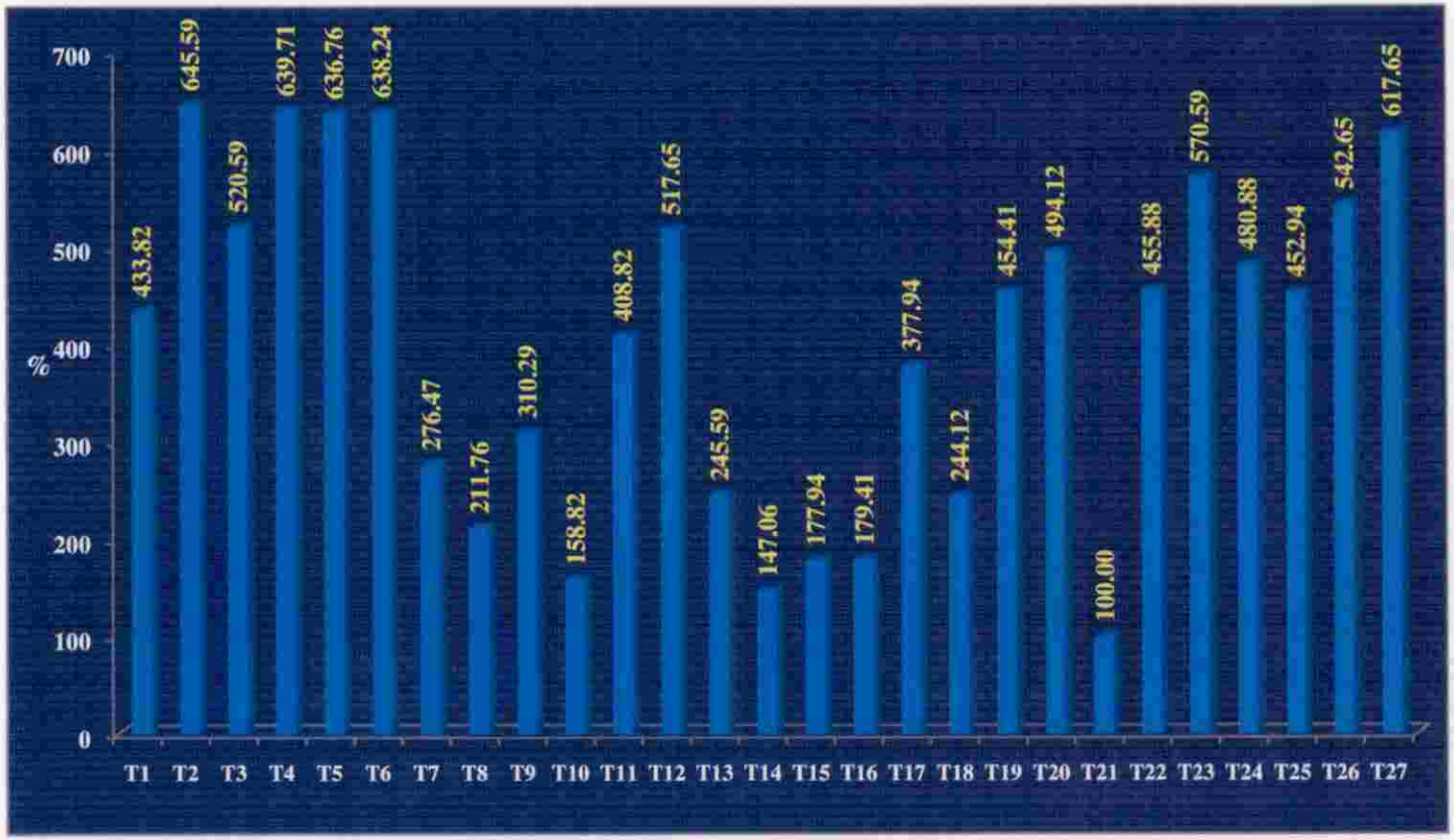


Fig. 19 Effect of different application methods on the yield of banana

O. longicollis infestation. The LD_{50} of cartap hydrochloride is lower than thiamethoxam and hence the latter is preferred for field application.

Time required for different application method, was recorded and means are presented in fig.8. It is obvious from the observation that spraying as well as swabbing requires less time when compared to injection or leaf axil filling. Leaf axil filling took more time (65.85 s) as more precision is needed to bring the nozzle at each axil and had to move around the plant to cover the targeted axils. Time for injection also recorded an average of 64.80 s, very similar to LAF. Injecting the chemical to the stem required more attention. Injection could be done slowly to avoid any overflow of chemical. Meanwhile spraying or swabbing operations were rather simple and less skill involved. Obviously more time was needed when two application methods were combined. Leaf axil filling and swabbing are two methods requiring different application devices and equipments. Change over from one device to other requires a time gap and hence more time was required for swabbing + LAF (142.55 s).

5.5 FIELD EVALUATION- PROPHYLACTIC METHOD

On analysis of data on different life stages of *O. longicollis* obtained from plants received different treatments in prophylactic method revealed that thiamethoxam 25WG 0.03% injection (T1) and 0.01% leaf axil filling (T12) were found as the most effective treatments in managing all stages of the pest. These treatments also recorded 100 per cent survival rate of plants and the yield were on par. *M. majus* application at 5 MAP and thiamethoxam 0.03% injection at 6 MAP (T6) also recorded 100 per cent survival of the plants. Cassava leaf distillate preparation, 'Nanma' (T10) was better in repelling adults and equally effective as existing chemical recommendation, chlorpyrifos.

One time application of *M. majus* at 5MAP followed by thiamethoxam 0.01% LAF (T15) or 0.03% injection (T6) was found promising, next best to two

time application of thiamethoxam treatments. Fresh infestation at top portion near the base of last leaf at the time of harvest was observed in certain plants which received one time application of thiamethoxam leaf axil filling at 5MAP. This indicates later infestation because of the time gap of four to five months between last application and harvest.

The botanical formulation, neem soap, when used alone (T2) was not effective in managing pest damage. This may be attributed to the lower concentration (1%) of neem soap coupled with high temperature and heat in the field. Insecticidal activity of neem based preparations was found reduced under higher temperature and sunlight in earlier studies (Sundaram, 1996; Radwan and Shiekh, 2012). Neem based formulations were found less effective for pests like fruit flies (Singh and Naik, 2006), but was used effectively to manage external feeders and sap feeders (Gundappa *et al.*, 2013; Sivakumar *et al.*, 2013; Prasannakumar *et al.*, 2014). When a comparison between neem soap 1% and 'Nanma' 5% was made based on the present study, 'Nanma' was found superior to neem soap in *O. longicollis* management. It may be attributed to the higher concentration (5%) and cassava leaf distillate in it.

The combined effect of *M. majus* and thiamethoxam in the field is quite evident from the results obtained in this study. *M. majus* possibly prevented early infestation, followed by the continued protection offered by the succeeding application of thiamethoxam. Thiamethoxam will promote the growth and sporulation of *M. majus* as evidenced from early studies (Filho *et al.,* 2001; Neves *et al.,* 2001 and Silva *et al.,* 2013) and studies conducted as part of this study. Meanwhile application of *M. majus* alone was not effective in *O. longicollis* management. Presence of late and early stages of the pest in plants previously treated with *M. majus* alone indicated continuous infestation. Low field persistence under adverse climate coupled with morphological features of the plant made it difficult for the bio agent to impart desired results when it was used alone. This observation is in contradiction to earlier reports of successful use of *M. anisopliae* against *O. longicollis* (Anitha, 2000 and Beegum, 2005)

Results from experiment on prophylactic method clearly depicted that two time application of thiamethoxam 25WG either as injection or LAF at five and six months after planting was the most effective treatment. Injection of thiamethoxam at 0.03% is more viable and eco friendly method as the total active ingredient used per plant is less (0.012 g plant^{-1}) compared to leaf axil filling (0.12 g plant^{-1}). Moreover, through injection, active principle enters the plant directly and chance of environmental contamination is the least. Injection method involves less drudgery and offer more safety. The farmers encountered maximum *O. longicollis* infestation during rainy season. Injection may be the only suitable application method during rainy season. Injection is also advisable for plants where intercrop such as diascorea is twined on the pesudostem.

The treatments T1 involving two time application of thiamethoxam 0.03% injection recorded the highest net return per plant (Rs.314.74) followed by T12 (Rs. 294.84) (Fig. 20). So the treatments, T1 and T12 can be recommended in commercial as well as small scale cultivation. The treatment T6, where only one time application of chemical preceded by *M. majus* could gave a net profit of Rs.217.849 plant^{-1} and ranked third among treatments in terms of returns. The intention of reducing pesticide can be achieved by adopting this sequential application of bio agents and insecticides. The cassava distillate, 'Nanma' (T10) registered a net profit of Rs. 138.78 plant^{-1}. In organic homestead cultivation and wherever there is assurance of higher price for pure organic produce, 'Nanma' can be used for the management of the pest.

The result of this study is agreeable with the findings of earlier works on thiamethoxam in different agro ecosystems. Banana Board of Jamaica recommends thiamethoxam 25WDG @ 5g 19 l^{-1} as an effective treatment against rhizome weevil, *C. sordidus* (Anon., 2011). Thiamethoxam was found effective in managing many coleopteran pests like wire worms, cereal ground weevil and cotton weevil (Maienfisch *et al.*, 2001b), leaf weevil of peas (Carcamo *et al.*, 2012), grapes flea beetle (Kulkarni and Patil, 2012), rice water weevil (Lanka *et al.*, 2013), alfalfa weevil (Vajargah *et al.*, 2013).

Thiamethoxam injection (T1) and LAF (T12) at 5 and 6 MAP against *O. longicollis* gave maximum economic benefit as evidenced from BC ratio. The yield from these treatments was significantly higher as well as their cost of application was the lowest among the treatments (Fig. 21). The treatment T6 could not give BC ratio higher than 1.98 as its cost (Rs.222.78) was above than that of T1 (Rs.219.22) and T12 (Rs.220.99). Low net profit for organic treatments is due to the high cost incurred for the inputs. Moreover, thiamethoxam was used at a low concentration of 0.01% in LAF and 0.03% in stem injection whereas 'Nanma' was used at a higher concentration of five percent. If the farmers had sold the produce treated with *M. majus* and neem soap at the market rate, they could have got only Rs.13.678 plant^{-1} as net return, reducing their profit considerably. This calls for organic produce branding and establishing markets exclusively for organic produce.

5.6 FIELD EVALUATION- CURATIVE METHOD

In curative method, thiamethoxam 0.03% injection recorded the highest survival rate (80 per cent) and highest yield. Previous studies by Janakiraman and Rao, 2001 and Justice *et al*., 2006 also confirmed the effectiveness of insecticide injection for curative method against *O. longicollis*. But, none of the curative methods either with chemicals or botanicals proved effective in controlling *O. longicollis* incidence in banana compared to prophylactic method. In field, farmers detect the damage by the feeding/exit holes made on the pseudostem by the pest. But the symptoms expressed externally by the plants may not be true to the actual damage caused by the pest internally. By the time symptoms are expressed, the internal damage might have reached the maximum. Thus, even though curative method is adopted, recovery of the plant may not be possible. The yield of plants under curative method was low which led to the lower value of BC ratio. Treatments with thiamethoxam 0.03% injection (T1), 0.01% leaf axil filling (T2) and chlorpyrifos 0.03% leaf axil filling (T6) was found equally

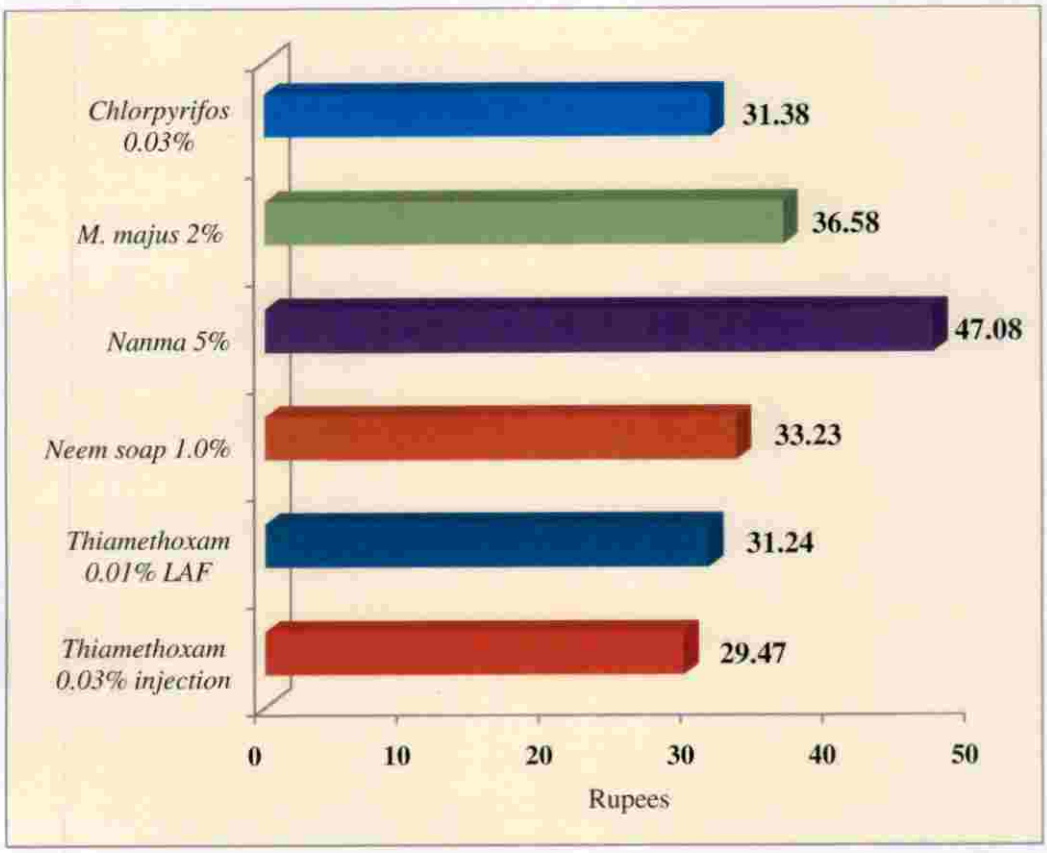


Fig. 21 Cost of different treatments for plant protection under prophylactic method

effective as curative method, but with very low yield compared to the corresponding yields obtained in prophylactic method. The survived plants bore small bunches only and this may be due to the internal damage already made by the pest on the pseudostem , making it unable to support the weight of bigger bunches. The BC ratio recorded for different treatments in curative method ranged from 0.14 to 0.86 only. The low value of BC ratio was due to the poor yield of plants in this method. When Reghunath *et al.* (1992) tried monocrotophos 0.1% as curative treatment to heavily infested plant, it failed. Because of the cryptic habitat of the pest, Abraham and Thomas (1995) also preferred prophylactic method to curative. The present study with newer pesticide molecules further reinforces these observations. From the observations made in this study it can be concluded that curative method of pest control of *O. longicollis* is not effective compared to prophylactic method.

5.7 ESTIMATION OF HARVEST TIME RESIDUES IN THE DIFFERENT PRODUCE

The data obtained from validation of QuEChERS method for estimation of residues of thiamethoxam on different matrices of banana revealed the suitability of QuEChERS. The mean recovery percentage ranged from 80.58 (in pseudostem at 0.5 ppm fortification level) to 98.24 (in fruit at 0.5 ppm fortification level). This range is well fitted into the acceptance criteria, recovery percentage 70-110 with relative standard deviation values below 20 (SANCO, 2011). As the QuEChERS method complies the validation requirements for the estimation of thiamethoxam residues in male bud, fruits and stem of banana, it was adopted for all analytical procedures of the study.

None of the matrices tested was found positive for thiamethoxam residue. Irrespective of the time of application and method, thiamethoxam left no detectable residues in the final edible portions of treated plants. Thiamethoxam residues could not be detected in male bud which was taken just two months after

last application. Plants received higher concentration of thiamethoxam (0.03%) through injection could avoid pest attack and at the same time left no residue on any edible portions. High water content of banana pseudostem might have facilitated the dilution of chemical lethal to pest but leaving no residue in the final product. The long pre harvest interval allows the chemical to dissipate into other metabolites or fall below detection limit. The result obtained from the present study corroborates the findings of Kumar *et al.* (2014), wherein no residues of thiamethoxam was detected in potato tubers after 90 days of application. Correspondingly fast dissipation of thiamethoxam was reported by Sharma and Mohapatra (2005) in okra and found no residues after 7-10 days after the last application. Earlier studies proved that half life of thiamethoxam in different soils is only 11 to 26 days (Karmarkar *et al.*, 2006). These earlier observations obviously shore up the results of the current study. Leaving no detectable residue at harvest or any other edible parts of the treated banana plants even at higher concentration justifies thiamethoxam as a good safe candidate molecule for including in the management of *O. longicollis* in banana.

5.8 MATRIX SCORING

Farmers preferred the newly tested injection assembly kit over the conventional sprayers as evidenced from matrix scoring. Application of insecticide against pseudostem borer during rainy season is cumbersome and injection is an alternate solution to this problem. The requirement for more number of refilling was pointed out as a disadvantage. So an attempt is needed to improve the current assembly to hold more volume of the injection fluid.

From various experiments and survey conducted as part of this study proved efficacy of thiamethoxam 0.03% injection and 0.01% LAF at 5 and 6 MAP as prophylactic method against *O. longicollis*. This insecticide application was found safe as it left no detectable residue in any of the edible plant part such as male bud, fruit and peduncle. Thiamethoxam 0.03% injection was able to record

the highest survival of plants, yield and BC ratio. Thiamethoxam 0.01% and 0.03% were found compatible with the entomopathogenic fungus, *M. majus.*

Results of the study on *O. longicollis* management lead to the following recommendations;

Regular crop/pest surveillance is necessary for early detection pests in banana

Knowledge and skill upgradation for banana farmers should be planned by extension service agencies in mutually exclusive manner

Thiamethoxam 0.03% given as injection @ 10 ml plant^{-1} at 60, 90, 120 and 150 cm height during fifth and sixth month after planting is an economically viable method for the management of pseudostem borer.

Thiamethoxam 0.01% leaf axil filling at fifth and sixth month after planting is also equally effective in controlling the pest

Bio agent, *M. majus* can be applied at fifth month followed by either thiamethoxam 0.01% LAF or 0.03% injection can be adopted as a semi organic method of pest control.

Summary

6. SUMMARY

Banana, one of the most popular fruit crops of Kerala is affected by a slew of pests which attack from root to the pipe leaf. Pseudostem borer of banana (*O. longicollis*) is a major pest, causing serious economic loss. Farmers use various pesticides to manage the pest. However, many of these are not recommended for the crop. The organophosphorus insecticide, chlorpyrifos, hazardous to health and environment, is extensively used. Hence, it is imperative to find alternate management strategies against the pest, using new and safe insecticides and organic measures. The present study was undertaken with an objective to evolve a management practice against *O. longicollis* using safe chemicals, botanicals and bio agents. The study was divided into seven experiments and carried out during 2012-2016 at the College of Agriculture, Vellayani and farmer's field at Konny, Pathanamthitta.

A detailed survey was conducted in four Southern districts of Kerala to document pest incidence, parasites, predators, farmers' practice for pest management and the safety measures adopted. From each district, twenty five farmers having at least fifty plants of the banana variety Nendran were selected. The data were collected using a proforma. Farmers from all the surveyed districts reported pseudostem borer, *O. longicollis* as a major problem in banana cultivation. Nendran recorded maximum infestation of *O. longicollis* (6.41per cent), followed by another popular variety, Palayankodan (5.21 per cent). However, 'Robusta' did not show any infestation by *O. longicollis*. Among the four districts surveyed, maximum and minimum infestation in Nendran was observed in Pathanamthitta district (7.64 per cent) and Kollam district (5.36 per cent), respectively.

Rhizome weevil (*C. sordidus*), leaf eating caterpillar (*S. litura*), banana skipper (*Erionota* sp.), Rhinoceros beetle (*O. rhinoceros*) and fruit fly (*B. dorsalis*) were observed as emerging pests on banana in the southern districts of Kerala. Brown scale (*C. hesperidium*) and small banana weevil (*P. mellerborgi*) were also collected from different plots during the survey. Occurrence of *P. mellerborgi* was the first report from Kerala. Wild boar (*S. scrofa*) attack was observed as a

problem in banana cultivation in two districts *viz.*, Thiruvananthapuram and Pathanamthitta. Organophosphorus (OP) insecticides *viz.*, chlorpyrifos and quinalphos were the major insecticides used by banana growers. Use of the banned insecticide, carbofuran was observed among four respondents in Thiruvananthapuram and one in Alappuzha. Organic preparations like neem oil, 'Nanma', Panchagavya, tobacco decoction and cow's urine + pepper were also used by farmers to manage pest problems in banana. All the farmers were observed to take proper precautionary measures while applying pesticides.

No specific parasites or predators were encountered during the survey. The semiochemical from M/s. Chem Tica International for *O. longicollis* was not effective in attracting weevils both under laboratory and field conditions. The results of the survey emphasized the importance of improving knowledge and awareness among the farmers on plant protection in banana. VFPCK and Krishi Bhavans served as knowledge centers for providing recent advances in banana cultivation and protection.

New generation insecticides were evaluated for their efficacy against *O. longicollis* grubs and adults under laboratory conditions. Among the new generation insecticides tested on *O. longicollis* grubs and adults under laboratory, thiamethoxam 0.01%, indoxacarb 0.01%, emamectin benzoate 0.002% and cartap hydrochloride 0.05% registered 100 per cent mortality of grubs at 36HAT. Chlorantraniliprole 0.0075% showed only 6.67 per cent mortality of grubs at 36HAT whereas, all control grubs were alive. In case of adults, at the end of 72HAT, thiamethoxam 0.01%, cartap hydrochloride 0.05% and emamectin benzoate 0.002% treatments showed maximum mortality rate (100 per cent), followed by chlorantraniliprole 0.0075% (36.67 per cent). Control treatment and indoxacarb 0.01% did not record any mortality on adults during this period. These were significantly different from all other treatments.

Five botanical preparations *viz.*, neem seed kernel extract (5%), neem soap (1%), cassava leaf distillate, 'Nanma' (3%), neem oil (3%) and azadirachtin formulation

1% EC (0.3%) were tested for their effect on mortality of grubs and adult weevils. These botanical formulations were found not effective as insecticides. Among these formulations, cassava leaf distillate, 'Nanma' caused 36.67 per cent mortality of grubs at 15 DAT only. In adults, both 'Nanma' (36.67 per cent) and neem soap (36.67 per cent) effected mortality and were superior to other treatments on 10DAT.

Repellency of botanical formulations on adult weevils was tested in multi choice and no choice method. In no choice method, all treatments showed an increase in number of adult population harbouring on treated pseudostem piece as time progressed. 'Nanma'(3%) and neem soap (1.0%) recorded less number of adults compared to other treatments.

In multi choice method, treated pseudostem pieces were placed at equidistance towards the edge of round plastic basin. The maximum repellency at 24 HAT was shown by 'Nanma', neem soap and neem oil emulsion which recorded a mean of 0.33, 0.33 and 0.67 adults, respectively. Neem seed kernel extract and azadirachtin treated stem pieces showed less repellency, as it attracted 5.33 and 5.67 adults, respectively.

Entomopathogenic fungi *viz.*, *M. majus*, *B. bassiana* (NRCB) and *B. bassiana* (ITCC 6063) were tested on *O. longicollis* grubs and adults under laboratory. All the pathogens were tested using talc based formulation @ 2%. Only *M. majus* caused mortality of both grubs (80 per cent) and adults (6.67 per cent). Maximum mortality of grubs (80 per cent) was observed with *M. majus* on seventh day. No other treatment caused any mortality of grubs. In adults, *M. majus* and *B. bassiana* (NRCB) induced only 6.67 per cent mortality on tenth day after treatment.

Laboratory experiments clearly proved that thiamethoxam 25WG @ 0.01%, emamectin benzoate 5G @ 0.002% and cartap hydrochloride 50SP @ 0.05% were equally effective against grubs and adults of *O. longicollis*. The cassava leaf distillate neem oil preparation, 'Nanma' and neem soap had better repellency than

other botanicals tested. *M. majus* was the effective entomopathogenic fungi against *O. longicollis* grubs.

As *M. majus* was found effective against *O. longicollis*, its compatibility with insecticides and botanicals under study and recommended fungicides were evaluated under *in vitro* conditions using poisoned food technique. On thirtieth day after inoculation, fungal growth on control plate and neem soap 1% treated plates were statistically similar. It was closely followed by growth on thiamethoxam 0.01 and 0.03%. No growth of *M. majus* was observed on fungicides *viz*., tebuconazole 0.1%, propiconazole 0.1%, mancozeb 0.3% and carbendazim 0.1%. Maximum spore production was noticed on thiamethoxam 0.03% ($1.61x10^7$ spores ml^{-1}) which was statistically superior to all other treatments and closely followed by neem soap 1% ($1.43x10^7$ spores ml^{-1}) and thiamethoxam 0.01% ($1.01x10^7$ spores ml^{-1}). Meanwhile, thiamethoxam 0.01% recorded maximum viable spore as it had $8.33x10^6$ cfu ml^{-1}, followed by neem soap ($4.11x10^6$ cfu ml^{-1}). 'T' value, calculated based on the effect of chemical on growth and sporulation, indicated that thiamethoxam at 0.01% and 0.03%, cartap hydrochloride 0.05% and neem soap at 1% were compatible with *M. majus* , while chlorpyrifos 0.03% and azoxystrobin 0.1% were moderately toxic. But, all other treatments *viz*., mancozeb 0.3%, carbendazim 0.1%, propiconazole 0.1%, tebuconazole 0.1% and 'Nanma' 5% were very toxic to *M. majus.*

Based on the effectiveness against *O. longicollis* and economic viability, the treatments *viz*., thiamethoxam, cartap hydrochloride, neem soap and *M. majus* were selected for further studies. Six different application methods *i.e*., spraying, swabbing, leaf axil filling, injection, spray + LAF, swabbing + LAF were evaluated for each selected treatments. Injection was done at 60, 90, 120 and 150 cm above the ground on the pseudostem with special needle. Ten ml of the treatment solution was applied in one plant @ 2.5 ml per injection point. Spraying and leaf axil filling was done using HDPE sprayer with extensible lance. The cassava leaf distillate based 'Nanma' and chlorpyrifos were taken as checks. The experiment was conducted at Instructional Farm, College of Agriculture,

Vellayani during November 2013 to August/September in 2014. The treatments were given at five and six months after planting.

Among the treatments, maximum yield (10.98 kg plant^{-1}) was recorded with thiamethoxam LAF and were on par with thiamethoxam injection (10.88 kg plant^{-1}), thiamethoxam spray + LAF (10.85 kg plant^{-1}) and thiamethoxam swabbing + LAF (10.83 kg plant^{-1}), cartap hydrochloride LAF (9.7 kg plant^{-1}), swabbing + LAF (9.23 kg plant^{-1}), spray + LAF (10.5 kg plant^{-1}), neem soap spray + LAF (8.8 kg plant^{-1}) and chlorpyrifos LAF (8.4 kg plant^{-1}). Considering the yield, pest incidence and crop damage, thiamethoxam LAF, thiamethoxam injection, neem soap spraying + LAF, *M. majus* swabbing + LAF were found as effective application methods for each.

The promising application method for insecticide, botanical and bio agent was selected for further study. Field experiments were conducted in an endemic farmers' plot at Konny, Pathanamthitta district. Both prophylactic and curative methods were tested in the field against *O. longicollis.* Experiment on prophylactic method was conducted with 17 treatments and the treatments were applied on fifth and sixth month after planting. Thiamethoxam 0.1% LAF, 0.03% injection, neem soap 1%, *M. majus* 2% were applied singly and in combination. 'Nanma' (5%) and chlorpyrifos (0.03%) were applied as check. Crop damage was the minimum in plants treated with thiamethoxam 0.03% injection at fifth and sixth month after planting as it recorded no holes and it was on par with thiamethoxam 0.1% LAF and *M. majus* at 5 MAP + thiamethoxam injection 6MAP. No live grubs were also found in plants treated with thiamethoxam 0.03% injection at fifth and sixth month after planting. Yield was the highest (10.68 kg plant^{-1}) for two time application of thiamethoxam injection, but on par with two time application of thiamethoxam 0.01% leaf axil filling. Application of bio agent, *M. majus* at 5MAP+thiamethoxam injection or LAF at 6MAP was also found as best treatment, next to two time application of thiamethoxam. Thiamethoxam 0.03% injection at fifth and sixth MAP registered a BC ratio of 2.44, the highest among the treatments tested as prophylactic method.

In curative method, the treatments were applied based on the ooze out and holes formed on the stem by the attack of *O. longicollis* and according to the damage score. Thiamethoxam 0.1% LAF, 0.03% injection, neem soap 1% spray+LAF, *M. majus* 2% as swabbing+ LAF, cassava leaf distillate, 'Menma' @ 15 ml l^{-1} as injection were tested in curative method. The yield of plants under curative method was low when compared to prophylactic method. Thiamethoxam 0.03% injection gave the highest yield (3.53 kg $plant^{-1}$) which was on par with thiamethoxam 0.01% LAF (3.10 kg $plant^{-1}$) and chlorpyrifos 0.03% (2.75 kg $plant^{-1}$). The highest survival rate of plants (80 per cent) was also recorded by thiamethoxam injection. All the treatments in curative method recorded BC ratio of less than one. It indicated that curative method is effective in managing *O. longicollis* attack.

Harvest time residues from all the edible parts such as male bud, peduncle and green unpeeled fruits were estimated. The extraction and clean-up was done following the QuEChERS method and quantified using UPLC-MS/MS under optimized conditions. In all matrices tested, irrespective of their time and method of application, thiamethoxam residue was below detectable level.

Evaluation of different pesticide application devices such as conventional metal sprayer, HDPE sprayer with extensible lance and syringe with modified needle was carried out among selected twenty farmers. Scores from 1 to 3 was given according to their perception as bad, good and best for each device with respect to corresponding attribute. Injection assembly obtained a mean score of 2.49, whereas HDPE sprayer and metal knapsack sprayer were given scores, 1.995 and 1.515, respectively.

So from the current study it can be concluded that,

- Banana growers have to be empowered on plant protection aspects with special emphasis to handling and application of pesticides.

- Thiamethoxam 0.01%, cartap hydrochloride 0.05% and emamectin benzoate 0.002% were found effective against both grubs and adults of *O. longicollis* in the laboratory studies
- Among the application methods, injection and LAF for thiamethoxam, swabbing + LAF for *M. majus* and spraying + LAF for neem soap were found effective
- In field conditions, prophylactic application of thiamethoxam 0.03% as injection at 5 and 6 MAP could effectively manage *O. longicollis* with economic returns
- The injection can be applied at 2.5 ml l^{-1} per injection point at four diagonally opposite points on the pseudostem; 60, 90, 120 and 150 cm above from the ground
- *M. majus* is compatible with thiamethoxam 0.01 and 0.03%, cartap hydrochloride 0.05% and neem soap 1%
- Thiamethoxam application at 0.01 and 0.03% concentration during 5^{th} and 6^{th} months after planting did not leave any residue in edible parts such as male bud, peduncle and fruits.

References

7. REFERENCE

Abbott, W. S. 1925. A method of computing the effectiveness of an insecticide. *J. Econ. Entomol.* 18: 265-267

Abera, K. A. M., Hasyim, A., Gold, C. S. and Driesche, R. V. 2006. Field surveys in Indonesia for natural enemies of the banana weevil, *Cosmopolites sordidus* (Germar). *Biological Control*. 37: 16-24

Abraham, C. C. and Thomas, J. 1995. Mud slurry as a base carrier of insecticides for swabbing of banana pseudostem against the weevil *Odoiporus longicollis* Oliv.. *Insect Environ.* 1(2): 14

Aguda, R. M. 1986. Effect of neem oil on germination and sporulation of the entomogenous fungus *Metarhizium anisopliae. Int. Rice Res. Newsl.* 11(4): 34-35

Aguilar, C. H., Zapico, F. L., Namocatcat, J., Fortich, A. and Bojadores, R. M. 2014. Farmers' perceptions about banana insect pests and integrated pest management (IPM) systems in SocSarGen, Mindanao, Philippines. *Int. Proc. of Chem. Biol. Environ. Engng.* 63: 22-27. Available: http://www.ipcbee.com/list-91-1.html [02 Dec.2015]

Akbar, S., Freed, S., Hameed, A., Gul, H. T., Akmal, M., Malik, M. N., Naeem, M. and Khan, M. B. 2012. Compatibility of *Metarhizium anisopliae* with different insecticides and fungicides. *Afr. J. Microbiol. Res.* 6(17): 3956-3962

Akiyama, Y., Matsuoka, T., Yoshioka, N., Akamatsu, S. and Mitsuhashi, T. 2011. Pesticide residues in domestic agricultural products monitored in Hyogo prefecture, Japan, FY 1995-2009. *J. Pestic. Sci.* 36(1): 66-72

Alavanja, M. C. R., Samanic, C., Dosemeci, M., Lubin, J., Tarone, R., Lynch, C. F., Knott, C., Thomas, K., Hoppin, J. A., Barker, J., Coble, J., Sandler, D. P. and Blair, A. 2003. Use of Agricultural Pesticides and Prostate Cancer Risk in the Agricultural Health Study Cohort. *Am. J. Epidemiol.* 157(9): 800–814

Ali, A., Samih, M. A., Khezri, M. and Riseh, R. S. 2007. Compatibility of *Beauveria bassiana* (Bals.) Vuill. with Several Pesticides. *Int. J. Agric. Biol.* 9(1): 31-34

Amutha, M. and Banu, G. J. 2012. Compatability of *Metarhizium anisopliae* and *Pochonia lecanii* with insecticides. *Ann. Pl. Protec. Sci.* 20 (2) : 354-357

Anastassiades, M., Lehotay, S. J, Stajnbaher, D. and Schenck, F. J. 2003. Fast and easy multiresidue method employing acetonitrile extraction/partitioning and dispersive solid-phase extractionfor the determination of pesticide residues in produce. *J. AOAC Int.* 86(2): 412–431

Anderson, T. E. and Roberts, D. W. 1983. Compatibility of *Beauveria bassiana* Isolates with Insecticide Formulations Used in Colorado Potato Beetle (Coleoptera: Chrysomelidae) Control. *J. Econ. Entomol.* 76: 1437-1441

Anderson, T. E., Hajek, A. E., Roberts, D. W., Priesler, H. K. and Robertson, J. L. 1989. Colorado Potato Beetle (Coleoptera: Chrysomelidae): Effects of Combinations of *Beauveria basiana* with Insecticides. *J. Econ. Entomol.* 82(1): 83-89

Anis, J. R. 2014. Evaluation of entomopathogenic fungi for the management of coleopteran pests and characterization of pesticide tolerant strains. Ph.D thesis, Kerala Agricultural University, Thrissur, 335p.

Anitha, N. 2000. Bioecology and integrated management of banana pseudostem weevil, *Odoiporus longicollis* Oliv. Ph.D. thesis, Kerala Agricultural University, Thrissur, 178p.

Anitha, N. 2004. Clonal susceptibility and age preference of banana pseudostem weevil, *Odoiporus longicollis* Oliv. *Insect Environ.* 10(3): 132-133

Anitha, N. and Nair, G.M. 2004. Life table and intrinsic rate of increase of pseudostem weevil *Odoiporus longicollis* Oliv. on popular banana clones of Kerala. *Entomon.* 29(4): 345-350

Anitha, N., Nair, G. M and Mathai, S. 1998. *Metarhizium anisopliae* (Met.) Sorokin as a biocontrol agent of *Odoiporus longicollis* (Oliv.) (Coleoptera: Curculionidae). *Insect Environ.* 4(3): 96-97

Anitha, N., Nair, G. M and Mathai, S. 1999a. *Mucor heimalis f. heimalis* A new fungal pathogen of banana pseudostem borer, *Odoiporus longicollis* (Oliv.) (Coleoptera: Curculionidae). *Insect Environ.* 5(2): 80-81

Anitha, N., Nair, G. M., Mathai, S. and Rejirani, O. P. 1999b. A new fungal pathogen of banana pseudostem borer, *Odoiporus longicollis* (Oliv.) (Coleoptera: Curculionidae). *Insect Environ.* 5(2): 80

[Anonymous]. 2011. The management of banana borer (*Cosmopolites sordidus*) using Actara insecticide [on line]. The Banana Board, Kingston. Available: http://www.thebananaboard.org/pdf/ACTARA.pdf [05 June 2014]

Anwar, T., Ahmad, I. and Tahir, S. 2011. Determination of pesticide residues in fruits of Nawabshah district, Sindh, Pakistan. *Pak. J. Bot.*, 43(2): 1133-1139

Arun, W. A., Bohra, P. and Ranganath, K. G. 2012. Preliminary report on pseudostem weevil, *Odoiporus longicollis* Oliver infestation in Silk Banana-'*Nanjanagud Rasabale'. Pest Manage. Hort. Ecosyst.* 18(2): 217-218

Asi, M. R., Bashir, M.H., Afzal, M., Ashfaq, M. and Sahi, S.T. 2010. Compatibility of entomopathogenic fungi, *Metarhizium anisopliae* and *Paecilomyces fumosoroseus* with selective insecticides. *Pak. J. Bot.*, 42(6): 4207-4214

Azam, M., Tara, J. S., Ayri, S., Feroz, M. and Ramamurthy, V. V. 2010. Bionomics of *Odoiporus longicollis* Oliver (Coleoptera: Rhynchophoridae) on banana plant (*Musa paradisica*). *Munis Ent. Zool.*, 5(2): 627-635.

Bakirici, G. T, Acay, D. B. Y, Bakirci, F. and Otles, S. 2014. Pesticide residues in fruits and vegetables from the Aegean region, Turkey. *Food Chem.* 160: 379–392

Banu, G. J. and Rajendran, G. 2002. Host records of entomopathogenic nematode, *Heterorhabditis indica*. *Insect Environ.* 8(2): 61-62

Basheer, P. P. M. and Thomas, S. K. 2012. Indian Treepie *Dendrocitta vagabunda parvula* (Latham, 1790) (Passeriformes: Corvidae) as a natural enemy of the pests of coconut and areca palm plantations. *J. Biopesticides*. 5: 205-208

Batra, H. N. 1952. Occurrence of three banana pests at Delhi. *Ind. J. Ent.* 14: 60

Beegum, S. M. K. 2005. Management of banana pseudostem weevil *Odoiporus longicollis* Oliv. using entomopathogenic fungi. MSc (Ag) thesis, Kerala Agricultural University, Thrissur, 82p

Beegum, S. M. K. and Anitha, N. 2006. *Beauveria bassiana* (Bals.) Vuillemin a potential biocontrol agent for banana pseudostem weevil, *Odoiporus longicollis* Oliv. *Insect Environ.* 12(3): 106-107

Bhagawathi, B., Deka, M. K. and Patgiri, P. 2009. Bio-efficacy of botanicals against banana pseudostem borer, *Odoiporus longicollis*. *Ann. Pl. Protec. Sci.* 17 (2): 366-369

Biswas,D., Banerjee, A. and Bandyopadhyay, B. 2015. Studies on incidence pattern of pseudo stem weevil (*Odoiporus longicollis* Oliv.) under Gangetic tracts of West Bengal. *J. Crop and Weed.* 11(1):161-164

Borges, J. H., Cabrera, J.C., Delgado, M. A. R., Suarez, E. M. H. and Sauco, V. G. 2009. Analysis of pesticide residues in bananas harvested in the Canary Islands (Spain). *Food Chemistry*. 113: 313-319

Bruck, D. J. 2009. Impact of fungicides on *Metarhizium anisopliae* in the rhizosphere, bulk soil and in vitro. *Bio Control*. 54:597–606

Carcamo, H., Herle, C. and Hervet, V. 2012. Greenhouse studies of thiamethoxam effects on the pea leaf weevil, *Sitona lineatus. J. Insect Sci.* 12: 151. Available online: http://www.insectscience.org/12.151.

Carneiro, R. P., Oliveira, F. A. S., Madureira, F. D., Silva, G., Souza, W. R. and Lopes, R. P. 2013. Development and method validation for determination of 128 pesticides in bananas by modified QuEChERS and UHPLCeMS/MS analysis. *Food Control*. 33: 413-423

Castillo, L. E., Martínez, E., Ruepert , C., Savage, C., Gilek, M., Pinnock, M. and Solis, E. 2006. Water quality and macroinvertebrate community response following pesticide applications in a banana plantation, Limon, Costa Rica. *Sci. Total Environ.* 367: 418–432

Charles, J. S. K., Thomas, M. J., Menon, R., Premalatha, T. and Pillai, S. J. 1996. Field susceptibility of banana to pseudostem borer *Odoiporus longicollis* Oliver. [abstract]. In *Abstracts, Symposium on technological advancement in banana/plantain production and processing - India – International*; 20-24, August, 1996, Thrissur, Kerala, India

Chevrolat, L. A. A. 1885. Calandrides-Nouveaux genres et nouvelles especes, observations, synonymiqes, doubles emplois de noms de genres et d'especes, etc. 3e partie. *Annales de la Societe Entomologique de France.* 6 : 288

Chauhan, N. P. S., Barwal, K. S. and Kumar, D. 2009. Human–Wild Pig Conflict in Selected States in India and Mitigation Strategies. *Acta Silv. Lign. Hung.* 5: 189-197

Chiang, J. J. 1965. Studies on the inheritable variability of radiation of insects and the biological control of sterilized insects. *J. Agric. For.* 14: 255-269

China, W. E. 1935. Hemipterous predators of the weevils *Cosmopolites* and *Odoiporus*. *Bull. Entomol. Res.* 26(4): 497-498

Curbelo, M. A. G., Borges, J. H., Perez, L. M. R. and Delgado, M. A. R. 2011. Insecticides extraction from banana leaves using a modified QuEChERS method. *Food Chem.* 125: 1083–1090

Damalas, C. A. and Koutroubas, S. D. 2016. Farmers' exposure to pesticides: toxicity types and ways of prevention. *Toxics*. 4: 1-10

Devasia, M. J., Mathew, G. and Madhu, G. 2011. Analysis of the carbofuran pesticide residue in the water from banana plantation in Wayanad district, Kerala, India. *Asian J. Chem.* 23(10): 4325-4327

Devi, L. L., Ghosal, A., Kadam, V. and Bandyopadhyay. 2015. Banana pseudostem weevil, *Odoiporus longicollis* (Olivier) and its Population dynamics. *Ind. J. Entomol.* 77(1): 18-20

Devi, P. A. and Prakasam, V. 2013. Compatibility nature of Azoxystrobin 25 SC with *Pseudomonas fluorescens* and *Bacillus subtilis* on chilli plants. *Wld. J. Agric. Sci.* 1(8): 258-264

Devi, P. I. 2009. Health risk perceptions, awareness and handling behavior of pesticides by farm workers. *Agric. Econ. Res. Rev.* 22. 263-268

Dhar, P. and Kaur, G. 2009. Compatibility of the entomopathogenic fungi, *Beauveria bassiana* and *Metarhizium anisopliae* with neonicotinoid insecticide, Acetamiprid. *J. Entomol. Res.*, 33(3): 195-202

Dutt, N. and Maiti, B. B. 1971. Occurrence of non-sex-limited variation in conspecific sypatric phena of banana pseudostem weevil, *Odoiporus longicollis* Oliv. (Col., Curculionidae). *Sci. Cul.* 37(12): 572-574

Dutt, N. and Maiti, B. B. 1972. Bionomics of banana pseudostem weevil, *Odoiporus longicollis* Oliv. (Coleoptera: Curculionidae). *Ind. J. Entomol.* 34(1): 20-30

Dutt, N. and Maiti, B. B. 1979. Ovipositor lenghth in *Odoiporus longicollis* Oliv. (Coleoptera: Curculionidae) as a criterion for selection of site for oviposition in cultivated species of banana. *J. Entomol. Res.* 3(1): 91-95

Echereobia, C. O., Okerere, C. S. and Emeaso, K. C. 2010. Determination of repellence potentials of some aqueous plant extracts against okra flea beetles *Podagrica uniforma*. *J. Biopesticides*. 3(2): 505-507

Edward, J. C., Tripathi, S. C. and Singh, K. P. 1973. Observations on a 'tip over' disease of banana in Allahabad. *Curr. Sci.* 42(19):696-697

Elbert, A. Haas, M., Springer, B., Thielert, W. and Nauen, R. 2008. Applied aspects of neonicotinoid uses in crop protection. *Pest Manage. Sci.* 64: 1099-1105

FAO [Food and Agricultural Organisation]. 2013. FAO Codex Alimentarius standard page [on line]. Available: http://www.fao.org/fao-who-codexalimentarius/standards/pestres/commodities-detail/en/?lang=en&c_id=131

FAOSTAT [Food and Agricultural Organisation]. 2014. FAOSTAT home page [on line]. Available: http://www.faostat3.fao.org. [01August 2016]

FIB [Farm Information Bureau]. 2014. *Farm Guide 2014*. Farm Information Bureau, Thiruvananthapuram, 213p.

Filho, A. B., Almeida, J. E. M and Lamas,C. 2001. Effect of thiamethoxam on entomopathogenic microorganisms. *Neotropical Entomol.* 30(3): 437-447

Fletcher, T. B. 1917. *Report of the proceedings of the second entomological meeting*. Superintendent Government printing, India, Calcutta. p.238

Froggatt, J. L. 1928. The banana weevil borer in Java, with notes on other crop pests. *Queensl. Agric. J.* 530-541

Gold, C. S., Pinese, B. and Pena, J. E. 2002. Pests of banana. In: Pena, J. E., Sharp, J. L. and Wysoki, M. (eds.), *Tropical Fruit Pests and Pollinators*. CAB International, London, pp. 21-64

Gour,T. B. and Sridevi, D. 2012. *Chemistry, Toxicity and Mode of Action of Insecticides*. Kalyani Pub., Jalandhar, India, 316 p

Guang, L. M., Xiu, L. F., Qiang, P. Z., Dong, L. W., Wei, X. and Jian, W. X. 2009. Survey and identification of pest insects on banana crop in Hainan. *South China J. Agric. Sci.* 22(6): 1619-1622

Gunavathy, N. and Murugavel, S. C. 2014. *Musa acuminate* bract extract as corrosion inhibitor for mild steel. *Chem. Sci. Rev. Lett.* 3(11S): 70-79

Gunawardena, N. E. and Dissanayake, S. 2000. Host attractants for the banana stem borer, *Odoiporus longicollis* (Coleoptera: Curculionidae): identification, electrophysiological activity and behavioural bioassay. *J. Natl. Sci. Foundation Sri Lanka*. 28(4): 231-242

Gundappa, Jayanthi, P. D. K. and Verghese, A. 2013. Management of spiraling whitefly, *Aleurodicus dispersus* (Russel) in guava, *Psidium guajava* L. *Pest Manage. Hort. Ecosyst*. 19(1): 102-105

Gupta, P., Paul, M. S. and Sharma, S. N. 1999. Studies on compatibility of white muscardine fungus *Beauveria bassiana* with some neem products. *Ind. Phytopath.* 52 (3): 278-280

Gupta, S. R. 1927. *Entomology*. Department of Agriculture, Shillong, Assam. p. 31-32

Haseeb, M. 2009. Compatibility of *Beauveria bassiana* (Bals.) Vuill. with pesticides. *Ann. Pl. Protec. Sci.* 17 (1): 127-129

Hasyim, A., Azwana and Syafril. 2009. Evaluation of natural enemies in controlling of the banana weevil borer *Cosmopolites sordidus* Germar in West Sumatra. *Indonesian J. Agric. Sci*. 10(2): 43-53

Hemalatha, S. Ramaraju, K. and Jeyarani, S. 2015. Effect of insecticides on the white muscardine fungus, *Beauveria bassiana*. *Ind. J. Ent*. 77(2): 134-137

Hoffmann, W.E. 1933. Observations on a weevil injurious to banana. *The Hong Kong Naturalist*. 4(1): 48-54

Hutson, J.C. 1921. Report of the division of Entomology. *Trop. Agric*. 57(3): 194

ICAR-NRCB. 2014. *Annual Report 2013-2014*. National Research Centre for banana, Thiruchirapalli, Tamil Nadu. 104p.

ICAR-NRCB. 2015. *Annual Report 2014-2015*. National Research Centre for banana, Thiruchirapalli, Tamil Nadu. 92p.

Ignoffo, C. M. 1992. Environmental factors affecting persistence of entomopathogens. *Fla. Entomol.* 75(4): 516-525

Inyang, U. E. and Emosairue, S. O. 2005. Laboratory assessment of the repellent and anti-feedant properties of aqueous extracts of 13plants against the banana weevil *Cosmopolites sordidus* Germar (Coleoptera: Curculionidae). *Trop. Subtropical Agroecosystems* 5: 33-44

IRAC [Insecticide Resistance Action Committee]. 2015. IRAC home page [on line]. Available: http://www.irac-online.org. [02 January 2016]

Irulandi, S., Aiyanathan, E. A. K. and Bhuvaneswari, S. B. S. 2012. Assessment of biopesticides and insecticide against pseudostem weevil *Odoiporus longicollis* Oliver in red banana. *J. Biopest.* 5: 68-71

Isahaque, N. M. M. 1978. A note on the incidence of *Odoiporus longicollis* (Oliv.) on banana in Assam. *Pesticides*. 12(6): 22-24

Isaiah, A., Jain, A. and Paul, M. S. 2005. Compatibility of *Beauveria bassiana* with Multineem and chemical pesticides. *Ann. Pl. Protec. Sci.* 13 (1): 213-269

James, R. R. and Elzen, G. W. 2001. Antagonism between *Beauveria bassiana* and imidacloprid when combined for *Bemisia argentifolii* (Homoptera: Aleyrodidae) control. *J. Econ. Entomol*. 94(2): 357-361

Janakiraman, S. and Rao, P. V. S. 2001. Effect of injection of insecticides against banana pseudostem borer, *Odoiporus longicollis* (Coleoptera: Curculionidae). *Ann. Pl. Prot. Sci*., 9: 124-126.

Jardim, A. N. O. and Caldas, E. D. 2012. Brazilian monitoring programs for pesticide residues in food - Results from 2001 to 2010. *Food Control*. 25: 607-616

Jayanthi, K. P. D. and Verghese, A. 1999. Report of the occurrence of banana weevils in Bangalore. *Insect Environ.* 4(4): 153

Jayanthi, K. P. D. and Verghese, A. 2000. Evidence of Cannibalism in grubs of *Odoiporus logivollis* (Oliver). *Insect Environ.* 5(4): 148.

Jayasree, T. V. 1992. Biology of banana pseudostem weevil. MSc(Ag) thesis, Kerala Agricultural University, Thrissur.

Jiong, Y., Wang, Y. J., Gao, J. L. and Zhao, D. X. 2012. Survey on occurrence and damage of banana weevils in Hainan province, China. *Biolife*. 3(3): 662-664

Justin, G. L. C., Rajakumar. D., Nirmalatha, J. D., Joshua, J. P. and Jayasekhar, M. 2006. Dose optimisation of insecticides for the management of the pseudostem weevil *Odoiporus longicollis* (Oliv.) (Curculionidae: Coleoptera) on banana. *Agric. Sci. Digest*. 26 (2): 117 - 119

Kabaluk, J. T., Goettel, M., Erlandson, M., Ericsson, J., Duke, G. and Vernon, R. 2005. *Metarhizium anisopliae* as a biological control for wire worms and a report of some other naturally-occuring parasites. *IOBC/WPRS Bull.* 28: 109-115

Kannaujia, R. K., Gupta, C., Wani, F. and Verma, R. 2012. Analysis of pesticide residues in winter fruits. *Curr. Wld. Environ.* 7910: 145-150

Kapoor, U., Srivastava, M. K., Srivastava, A. R., Patel, D. K., Garg, V. and Srivastava, L. P. 2013. Analysis of imidacloprid residues in fruits, vegetables, cereals, fruit juices, and baby foods, and daily intake

estimation in and around Lucknow, India. *Environ. Toxicology and Chem.* 32(3): 723–727

Karibasavaraja, L.R., Balikai, R.A. and Deshpande, V.P. 2005. Thiamethoxam 70 WS, A New Promising Seed Dress for the Suppression of Sorghum Shootfly. *Ann. Pl. Prot. Sci.* 13(1): 85-87

Karmakar, R., Singh, S. B. and Kulshrestha. 2006. Persistence and transformation of thiamethoxam, a neonicotinoid insecticide, in soil of different agroclimatic zones of India. *Bull. Environ. Contam. Toxicol.* 76: 400–406

Kassab, S. O., Loureiro, E. S., Rossoni, C., Pereira, F. F., Barbosa, R. H., Costa, D. P. and Zanuncio, J. C. 2014. Combinations of *Metarhizium anisopliae* with chemical insecticides and their effectiveness in *Mahanarva fimbriolata* (Hemiptera: Cercopidae) control on sugarcane. *Fla. Entomol.* 97(1): 146-154

KAU [Kerala Agricultural University]. 2011a. *Package of practices recommendations: Crops* (14th Ed.). Kerala Agricultural University, Thrissur, 360p

KAU [Kerala Agricultural University]. 2011b. *Research report (2006-2011).* Directorate of research, Kerala Agricultural University, Thrissur. 200p.

Kavitha, K. J., Murugan, K. and Evans, D. A. 2015. Allelopathic interactions of certain *Musa* cultivars against *Odoiporus longicollis* (Olivier). *Entomon.* 40(4): 209-220

Keswani, S. and Vankhede, G. 2014. Diversity, population and habitat used by spiders in banana agro-ecosystem. *Ind. J. Arachnology.* 3(1): 12-27

Khairmode, P. V., Sathe, T. V. and Desai, A. S. 2015. Biology, Ecology and control of weevils (Coleoptera: Curculionidae) on banana from Kolhapur region, India. *Biolife.* 3(1):16-20

Kojima, H. and Kaga, Y. 2011. Record of some weevils new to the fauna of Tokunoshima Island, Southwest Japan. *Elytra*. 1(1): 159-161

Koppenhofer, A. M. and Schutterer, H. 1993. *Dactylosternum abdominal* (F.) (Coleoptera: Hydrophilidae): A predator of the banana weevil. *Biocontrol Sci. Technol.* 3: 141-147

Koppenhofer, A. M. Reddy, K. V. S., Madel, G. and Lubega, M. C. 1992. Predators of the banana weevil, *Cosmopolites sordidus* (Germar) (Col., Curculionidae) in western Kenya. *J. Appl. Ent.* 114: 530-533

Krishnakumar, R., Cherian, S. S. and Rini, C. R. 2006. Occurrence of *Fusarium oxysporum* Schlecht. on pseudostem weevil, *Odoiporus longicollis* Oliv. of banana. *Insect Environ.* 11(4): 151

Krishnan, J.U., Jayaprakas, C.A., Lekshmi, N. R., Jithine, J. R. and Ajesh, G. 2015. Effective Range of Cassava Biopesticides on Pest Management in the Banana Farms at three districts of Kerala-Thiruvananthapuram, Eranakulam and Kasaragode. In: Pandiyan, M. (ed.), Proceedings of 27th Kerala Sci. Congress; 27-29 January, 2015; Kerala State Committee on Science, Technology and Environment, Government of Kerala, pp.13-14

Krishnan, J.U., 2013. Effect of cassava based biopesticide and tactic suggestion for the control of banana pseudostem weevil, *Odoiporus longicollis* (Oliver). In: Pillai, V.N.R (ed.), Proceedings of 25th Kerala Sci. Congress; 29 January – 1 February, 2013; Kerala State Committee on Science, Technology and Environment, Government of Kerala, p.297

Kulkarni, N. S. and Patil, A. B. 2012. Field efficacy of thiamethoxam 25 WG (Actara 25 WG) against flea beetle, jassids and thrips in grapes. *Karnataka J. Agric. Sci.* 25(1): 146-147

Kumar, M. and Tiwary. S. K. 2009. Effect of celphos as fumigant on the mortality of larva, pupa and adult of *Odoiporus longicollis*- a serious pest of banana in Bihar. *Proc. Zool. Soc. Ind.* 8(2): 31-35

Kumar, N., Srivastava, A., Chauhan, S. S. and Srivastava, P. C. 2014. Studies on dissipation of thiamethoxam insecticidein two different soils and its residue in potato crop. *Plant Soil Environ.* 60(7): 332–335

Kung, K. S. 1955. The banana stem borer weevil *Odoiporus longicollis* Oliv. In Taiwan. *J. Agric. For., Taichung*. 4: 80-113

Kung, K. S. 1962. Ecological studies on the banana stem borer weevil (*Odoiporus longicollis* Oliv.). *J. Agric. For., Taichung*. 11: 137-160

Lalitha, N. and Ranjith, A. M. 2000a. Colour morphs of Pseudostem Weevil *Odoiporus longicollis* Olivier. *Insect Environ.* 6(1):6.

Lalitha,N. and Ranjith, A. M. 2000b. Susceptibility of Nendran banana to *Odoiporus logicollis* Olivier at various growth stages. *Insect Environ.* 6(3): 115

Lalitha,N. and Ranjith, A. M. 2001. A modified rating technique for *Odoiporus longicollis* Olivier damage in *Musa* plantations. *Insect Environ.* 7(2): 85-86.

Lalitha, N., Ranjith, A. M. and Augustine, A. 2002. Studies on polyphenol oxidase activity and banding pattern in relation to resistance of *Musa* spp. to pseudostem weevil, *Odoiporus longicollis* Olivier (Coleoptera: Curculionidae). *Pest Manage. Hort. Ecosyst.* 8(2):97-102

Lanka, S. K., Ottea, J. A., Davis, J. A., Hernandez, A. B. and Stout, M. J. 2013. Systemic effects of thiamethoxam and chlorantraniliprole seed treatments on adult *Lissorhoptrus oryzophilus* (Coleoptera: Curculionidae) in rice. *Pest Manage. Sci.* 69: 250-256

Lee, W. J., Blair, A., Hoppin, J. A., Lubin, J. H., Rusiecki, J. A., Sandler, D. P., Dosemeci, M. and Alavanja, M. C. R. 2004. Cancer Incidence Among Pesticide Applicators Exposed to Chlorpyrifos in the Agricultural Health Study. *J. Natl. Cancer Inst.* 96(23): 1781-1789

Lefroy, H. M. 1909. *Indian insect life. A manual of the insects of the plains.* (Tropical India). Thacker, Spink & Co., Calcutta. pp.382-390

Li, D. P. and Holdom, D. G. 1994. Effects of Pesticides on Growth and Sporulation of *Metarhizium anisopliae* (Deuteromycotina: Hyphomycetes). *J. Invertebrate Path.* 63: 209-211

Li, K., Fu, S., Zhan, H., Zhan, Y. and Lucia, L. A. 2010. Analysis of the chemical composition and morphological structure of banana pseudostem. *Bioresources.* 5(2): 576-585

Loria, R., Galaini, S. and Roberts, D. W. 1983. Survival of inoculum of the entomopathogenic fungus *Beauveria bassiana* as influenced by fungicides. *Environ. Entomol.* 12: 1724-1726

Lu, Y., Liang, G. and Zeng, L. 2002 b. Application technology of *Steinernema carpocapsae* to control the banana pseudostem weevil *Odoiporus longicollis* Oliver in banana plantation. *J. S. China Agric. Univ.* 21(6): 517-520

Lu, Y., Liang, G. and Zeng, L. 2002a. Study on the life table of natural population of the banana pseudostem weevil (*Odoiporus longicollis* Oliver). *J. S. China Agric. Univ.* 23(3): 36-39

Luo, L. Y., Luo, Q. C., Yao, X. and Liu, Z. L. 1985. Weevils injurious to banana in Guizhou and their biological features. *Insect Knowledge.* 22(6): 265-267

Madureira, F. D., Oliveira, F. A. S., Souza, W. R., Pontelo, A. P., Oliveira, M. L. G. and Silva, G. 2012. A multi-residue method for the determination of 90 pesticides in matrices with a high water content by LC–MS/MS without clean-up. *Food Additives and Contaminants*. 29(4): 665–678

Maienfisch, P., Angst, M., Brandl, F., Fischer, W., Hofer, D., Kayser, H., Kobel, W., Rindlisbacher, A., Senn, R., Steinemann, A and Widmer, H. 2001a. Chemistry and biology of thiamethoxam: a second generation neonicotinoid. *Pest Manage. Sci.* 57: 906-913

Maienfisch, P., Huerlimann, H., Rindlisbacher, A., Gsell, L., Dettwiler, H., Haettenschwiler, J., Sieger, E. and Walti, M. 2001b. The discovery of thiamethoxam: a second-generation neonicotinoid. *Pest Manage. Sci.* 57: 165-176

Makaka, C. 2008. The efficacy of two isolates of *Metarhizium anisopliae* (Metschin) Sorokin (Deuteromycotina: Hyphomycetes) against the adults of the black maize beetle *Heteronychus licas* Klug (Coleoptera: Scarabidae) under laboratory conditions. *Afr. J. Agric. Res.* 3(4): 259-265

Marshall, G. 1930. New Curculionidae, with notes on synonymy. *Ann. Mag. Nat. Hist*. 6(35): 551-577

Mathew, M. P., Nair, S. R. and Sivaraman, S. 1997. Management of pseudostem borer of banana *Odoiporus longicollis*. *Ind. J. Entomol*. 59(3): 269-273

McSwiney, J. 1920. Report of the agricultural department, Assam, for the year ending 31st March 1920. pp.6-7

Menon, R., Cherian, A. K., Nair, S. and Suma, A. 2004. Evaluation of improved hybrids in Kerala, India [abstract]. In: *Abstracts, International congress on Musa: Harnessing research to improve livelihoods*; 6-9, July, 2004, Penang, Malaysia. p.11

Mochi, D.A., Monterio, A. C. and Barbosa, J. C. 2005. Action of pesticides to *Metarhizium anisopliae* in soil. *Neotropical Entomol.* 34(6): 961-971

Musabyimana, T., Saxena, R. C., Kairu, E. W., Ogol, C. P. K. O. and Khan, Z. R. 2001. Effects of neem seed derivatives on behavioral and physiological responses of the *Cosmopolites sordidus* (Coleoptera: Curculionidae). *J. Econ. Entomol.* 94(2): 449-454

Nahif, A. A., Padmanaban, B., Sundararaju, P., and Sathiamoorthy, S. 2003. Ultrastructre of mouth parts, elytra and tarsus of the banana stem weevil, *Odoiporus longicollis* (Coleoptera: Curculionidae). *Entomon.* 28(1): 45-49

Nair, S. A. Suma, K. Cherian, A. and Menon, R. 2004. Effectiveness of traps to control the pseudostem borer of banana [abstracts]. In: *Abstracts, International congress on Musa: Harnessing research to improve livelihoods*; 6-9, July, 2004, Penang, Malaysia. p.155

Nene, Y. L. and Thapliyal, P.N. 1993. Fungicides in plant disease control (3rd Ed.). Oxford and IBH Pub. Company, New Delhi, pp. 531-532

Neves, P. M. O. J, Hirose, E., Tchujo, P. T. and Moina A. 2001. Compatibility of Entomopathogenic Fungi with Neonicotinoid Insecticides. *Neotropical Entomol.* 30(2): 263-268

NHB [National Horticultural Board]. 2015. *Indian Horticulture Database-2014.* National horticultural board, Ministry of Agriculture, Government of India, 286p

Nirula, K. K., Radha, K. and Menon, K. P. V. 1955. The green muscardine disease of *Oryctes rhinoceros* L., symptomatology, epizootology and economic importance. *Ind. Coconut J.* 9: 3-10

Okolle, J. N., Fansi, G. H., Lombi, F. M., Lang, P. S. and Loubana, P. M. 2009. Banana entomological research in Cameroon: how far and what next? *The Afr. J. Pl. Sci. Biotech.* 3(1): 1-19

Oliveira, C. N. D., Neves, P. M. O. J and Kawazoe, L. S. 2003.Compatibility between the entomopathogenic fungus *Beauveria bassiana* and Insecticides Used in Coffee Plantations. *Scientia Agricola.* 6(4): 663-667

Olivier, A. G. 1807. *Entomologie Historie naturelle des insects.* Chez Desray, Paris, 612p

Ostmark, H. E. 1974. Economic pests of banana. *Ann. Rev. Entomol.* 19: 161-176

Padmanaban, B. and Kandasamy, M. 2003. Survival of banana weevil borers in banana plant residues. *Ind. J. Entomol.* 65(3): 424-425

Padmanaban, B. and Sundararaju, P. 1999. Occurence of banana weevil borers (Curculionidae: Coleoptera) in Tamil Nadu. *Insect Environ.* 5: 135

Padmanaban, B. and Sathiamoorthy, S. 2001. *The banana stem weevil Odoiporus longicollis. Musa pest fact sheet No.5* . Inibap, Montpellier, France. 4p.

Padmanaban, B., and Sathiamoorthy, S. 2004. Integrated pest management of banana stem weevil *Odoiporus longicollis* [abstract]. In: *Abstracts, International congress on Musa: Harnessing research to improve livelihoods*; 6-9, July, 2004, Penang, Malaysia. p.138.

Padmanaban, B., Bakthavatsalam, N., Ravindra, K. V and Alagesan, A. 2014. Identification of weevil active volatiles from a susceptible cv. Poovan leaf sheath by GC-EAD [abstract]. In: *Abstracts, National Symposium on Emerging Trends in Eco-friendly Insect Pest Management*; 22-24, January, 2014, Coimbatore, Tamil Nadu. p.248. Abstract No. CHE.PO.18

Padmanaban, B., Selvarajan, R., Kandasamy, M., and Balasubramanian, V. 2002a. Occurrence of fungi *Scopularisis brevicaulis* (Saccardo) Bainer

and *Aspergillus flavus* Link as entomopathogens of banana stem weevil, *Odoiporus longicollis* Oliver (Curculionidae : Coleoptera). *Entomon.* 27(4): 411-413

Padmanaban, B., Kandasamy, M. and Sathiamoorthy, S. 2001a. New pests of banana reported in Tamil Nadu, India. *Infomusa.* 10(2): 43-44

Padmanaban, B., Sundararaju, P., and Sathiamoorthy, S. 2001b. Incidence of banana pseudostem borer, *Odoiporus longicollis* (Oliv.) (Curculionidae: Coleoptera) in banana peduncle. *Ind. J. Entomol.* 63(2): 204-205

Padmanaban, B., Sundararaju,P., Velayudhan,K,C. and Sathiamoorthy, S. 2001c. Evaluation of Musa germplasm against banana weevil borers. *Infomusa.*10(1):26-28

Padmanaban, B., Uma, S. and Sathiamoorthy, S. 2004. Susceptibility of *Musa* germplasm to the banana stem weevil, *Odoiporus longicollis* [abstract]. In: *Abstracts, International congress on Musa: Harnessing research to improve livelihoods*; 6-9, July, 2004, Penang, Malaysia. p.149

Padmanaban, B., Sundararaju, P., Cannayane, I. and Hussaini, S.S. 2002 b. Effect of Entomopathogenic Nematode, *Heterohabditis indica* (PDBC EN 13.3) on Banana Stem Weevil, *Odoiporus longicollis* Olivier *in vitro*. *Ind. J. Nematol.* 32(2): 183-233

Palanichamy, S., Padmanaban, B., Fazal M. M. I. and Mustaffa, M. M. 2011a. A simple and low cost semiochemical based trapping method for the management of banana pseudostem weevil, *Odoiporus longicollis* Olivier (Coleoptera: Cuculionidae). *Adv. Appl. Sci. Res.*, 2(3): 69-73

Palanichamy, S., Padmanaban, B., Fazal M. M. I. and Mustaffa, M. M. 2011b. Microwave Oven Assisted Extraction of Banana pseudostem kairomones as attractant of *Odoiporus longicollis* Olivier (Coleoptera:Curculionidae): Electroantennogram investigations. *Arch. Appl. Sci. Res.*, 3 (3): 213-216

Pallavi, S., Kulkarni, V. M. and Kumar, L. S. 2015. Male biased gene flow in banana pseudostem weevil (*Odoiporus longicollis* Oliver) as revealed by analysis of the COI-tRNA^{Leu} COII region. *Genetica.* 142(6). DOI 10.1007/s10709-015-9817-6

Pandey, K.K., Pandey, P.K. and Mishra, K.K. 2006. Bio-efficacy of fungicides against different fungal bio agents for tolerance level and fungistatic behavior. *Ind. Phytopath.* 59(1): 68-71

Paranthaman, R., Sudha, A. and Kumaravel, S. 2012. Determination of pesticide residues in banana by using high performance liquid chromatography and gas chromatography-mass spectrometry. *Am. J. Biochem. Biotech.* 8 (1): 1-6

Patel, L. C., Konar, A. and Sarkar, A. 2016. Field evaluation of various treatment-schedules for the control of epilachna beetle, *Henosepilachna vigintioctopunctata* (Fab.), on Brinjal. *Appl. Biol. Res.* 18(2): 139-145

Patel, Z. P. and Jagadale, V. S. 2003. Two curculionids on banana in Gujarat. *Insect Environ.* 9(3):120-121

Paul, A., Beevi, N. S., Mathew, T. B., George, T., Ravi, R., Neethu, S. K. and Mithra, I. V. 2015. Pesticide residues in soils of banana in Kerala. *J. Insect Sci.* 28(1): 68-71

Pinto, M. P. D. 1928. The teo weevil pests of plantains (Musa sapientum L.) *Cosmopolites sordidus* Germ. and *O. longicollis* Oliv. *The Tropical Agriculturist: J. Ceylon Agric. Soc.* 70(4): 216-224

Ploetz, R. C., Kema, G. H. J. and Ma, L. J. 2015. Impact of diseases on export and smallholder production of banana. *Ann. Rev. Phytopathol.* 53: 269-288

Prabhavathi, M. K. and Ghosh, S. K. 2014. Studies on the interaction between *Odoiporous longicollis* and endophytic *Beauveria bassiana* by

establishing fungal infection to bsw in the plant system. *Int. J. Pl. Prot.* 7(2): 312-317

Prasad, B. and Singh, O. L. 1987. Insect pests of banana and their incidence in Manipur. *Ind. J. Hill Fmg.* 1(1): 71-73

Prasannakumar, N.R., Kumar, G.M.S. and Mukesh, M. 2014. Efficacy of botanicals and synthetic insecticides on major insect pests of cabbage in Kullu valley, Himachal Pradesh. *Curr. Biotica.* 19(4): 231-233

Prasuna, A. L., Jyothi, K. N., Prasad, A. R., Yadav, J. S. and Padmanaban, B. 2008. Olfactory responses of banana pseudostem weevil, *Odoiporus longicollis* Olivier (Coleoptera:Curculionidae) to semiochemicals from conspecifics and host plant. *Curr. Sci.*, 94(7): 896-900.

Priyadarshini, G. I., Mukherjee, U., Nagendrakumar., Jha, P. K. and Rai, B. 2014. Seasonal incidence of banana pseudostem weevil, *Odoiporus longicollis* (Olivier) (Coleoptera : Curculionidae). *Curr. Biotica.* 8(1): 66-71

Project Coordinating Cell. 2009. Monitoring of pesticide residues at national level Annual Progress Report (April, 2008- March, 2009). All India Network Project on Pesticide Residues, IARI, New Delhi. p.13

Project Coordinating Cell. 2014. Monitoring of pesticide residues at national level Annual Progress Report (April, 2013- March, 2014). All India Network Project on Pesticide Residues, IARI, New Delhi. p.120

Rachappa, V., Lingappa, S. and Patil, R. K. 2007. Effect of Agrochemicals on Growth and Sporulation of *Metarhizium anisopliae* (Metschnikoff) Sorokin. *Karnataka J. Agric. Sci.* 20(2): 410-413

Radwan, O. A. and Shiekh, Y. W. A. 2012. Degradation of neem oil 90% EC (Azadirachtin) under storage conditions and its insecticidal activity against cotton leafworm *S. littoralis*. *Researcher*. 4(3): 77-83

Raj. A. G., Janarthanan, S., Samuel, S. D, Baskar, K and Vincent, S. 2011. Compatibility of entomopathogenic fungus *Beauveria bassiana* (Balsamo) Vuillemin isolated from Pulney hills,Western Ghats of Tamil Nadu with insecticides and fungicides. *Elixir Agric.* 40: 5563-5567

Ram, S. and Pathak, K. A. 1987. Occurrence and distribution of pest complex of some tropical and temperate fruits in Manipur. *Bull. Entomol.* 28(1); 12-18

Rashid, M., Baghdadi, A., Sheikhi, A., Pourian, H. R. and Gazavi, M. 2010. Compatibility of *Metarhizium anisopliae* (Ascomycota: Hypocreales) with several insecticides. *J. Pl. Prot. Res.* 50(1): 22-27

Ravi, G. and Palaniswamy, M. S. 2002. Evidence for a female-produced sex pheromone in the banana pseudostem weevil, *Odoiporus longicollis* Olivier. *Curr. Sci.*, 83(7):893-898.

Reddy, S. D., Madhumathi, C., Naveena, H. and Chowdary, R. L. 2015. Field evaluation of *Musa* germplasm for resistance against banana stem weevil, *Odoiporus longicollis* (Oliver) (Curculionidae: Coleoptera) in Kadapa district of Andhra Pradesh. *J. Appl. Nat. Sci.* 7 (1): 1- 4

Reghunath, P., Visalakshi, A., Mathew, T. B., Mohandas, N., Beevi, S. N. and Remamoni, K. S. 1992. Insecticidal management of the pseudostem borer *Odoiporus longicollis* Oliver (Coleoptera: Curculionidae) in banana. *Entomon*, 17(1;2):113-115

Remya, K. R. 2007. Potential of entomopathogenic nematodes for the management of weevil pests of banana (*Musa* sp.). MSc(Ag) thesis, Kerala Agricultural University, Thrissur, 178p.

Robinson, J. C. and Sauco, V. G. 2010. *Bananas and Plantains* (2nd Ed.). CAB International, 312p.

Sahayaraj, K. and Kombiah, P. 2009. Olfactory responses of the banana weevil, *Odoiporus longicollis* (Olivier) (Coleoptera: Curculionidae) against pseudostem and its crude extract. *J. Biopesticides*. 2(2): 173-176

Sahayaraj, K. and Kombiah, P. 2010. Insecticidal activites of neem gold on banana rhizome weeil (BRW), *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae). *J. Biopesticides*. 31(1 Special issue): 304-308

Sahayaraj, K., Kombiah, P., Dikshit, A. K. and Rathi, J. M. 2015. Chemical constituents of the essential oils of *Tephrosia purpurea* and *Ipomoea carnea* and their repellent activity against *Odoiporus longicollis. J. Serb. Chem. Soc.* 80 (4): 465–473

SANCO. 2011. *Method Validation and Quality Control Procedures for Pesticide Residue Analysis in Food and Feed, Guidelines for Residues Monitoring in the European Union*. Document No. SANCO/12495/2011. Central Science Laboratory,York, UK.

Sanghi, R. and Tewari, V. 2001. Monitoring of pesticide residues in summer fruits and vegetables from Kanpur, India. *Bull. Environ. Contam. Toxicol.* 67: 587–593

Shanmugam, P. S., Indhumathi, K. and Tamilselvan, N. 2013. Suitability of semiochemical and chemical methods for the management of banana pseudostem weevil, *Odoiporus longicollis* Oliver (Coleoptera: Curculionidae). *J. Entomol. Res.*, 37(1): 1-3

Sharma, B and Mohapatra, S. 2005. Dissipation pattern of indoxacarb and thiamethoxam residues in vegetables. *Veg. Sci.* 32(2): 166-168

Sharma, D., Nagpal, A., Pakade, Y. B. and Katnoria, J. K. 2010. Analytical methods for estimation of organophosphorus pesticide residues in fruits and vegetables: a review. *Talanta* 82: 1077–1089

Sharma, D. R. 2010. Current scenario of management of fruit pests in Punjab. *Haryana J. Hort. Sci.* 39(1&2): 110-120

Shukla, G.S. and Kumar,K. 1969. A new record of *Odoiporus longicollis* (Ol.) (Coleoptera : Curculionidae) from Uttar Pradesh. *Sci. Cul.* 35(9): 481-482

Shukla, G.S. and Kumar,K. 1970. A note on the biology of *Odoiporus longicollis* Olivier (Coleoptera :Curculionidae:) *Sci. Cul.* 36(9): 515-516

Shukla, G. S. and Tripathi, A. K. 1978. Effect of temperature on longevity of *Odoiporus longicollis* (Oliv.) (Coleoptera: Curculionidae). *Entomol. News.* 89(9&10): 249

Silva, R. A., Quintela, E. D., Mascarin, G. M., Barrigossi, J. A. F. and Liao, L. M. 2013. Compatibility of conventional agrochemicals used in rice crops with the entomopathogenic fungus *Metarhizium anisopliae. Sci. Agric.* 70(3): 152-160

Singh, H. S. and Naik, G. 2006. Seasonal dynamics and management of pumpkin caterpillar, *Diaphania indica* Saunders and fruit fly, *Bactrocera cucurbitae* Conq. in bitter gourd. *Veg. Sci.* 33(2): 203-205

Singh, R.K., Vats, S., Singh, B. and Singh, R.K. 2014. Compatibility analysis of entomopathogenic fungi *Beauveria bassiana* (NCIM No-1300) with several pesticides. *Res. J. Pharmaceutical Biol. Chem. Sci.* 5(1): 837-844

Singh, S.S. 1966. Observations on *Odoiporus longicollis* (Coleoptera: Curculionidae) in Kathmandu valley and its suburbs. *Ind. J. Entomol.* 28:410

Sivakumar, T. and Mohan, C. 2013. Occurrence of rhinoceros beetle, *Oryctes rhinoceros* (L.), on banana cultivars in Kerala. *Pest Manage. Hort. Ecosyst.* 19(1): 99-101

Sivakumar, T., Mohan, C. and Babu, M. 2013. Incidence and management of the leaf hopper, *Busoniomimus manjunathi*, on Malabar Tamarind, *Garcinia cambogia. Afr. J. Agric. Res.* 8(1): 145-147

Sivasubramanian, S., Kavitharaghavan, Z., Jayaprabhavathi, S. and Samiayyan, K. 2009. Efficacy of Neem Azal 1.2EC in the management of banana pseudostem weevil, *Odoiporus longicollis* Olivier. *Karnataka J. Agric. Sci.* 22(3): 561-563

Soman, S. and Mohan, C. 2011. Compatibility of *Metarhizium anisopliae* (Metsch.) Sorokin with some chemical and botanical pesticides used in coconut pest management. *J. Plantn. Crops.* 39(1): 196- 200

Sujay, A. G. K., Sharma, R. K, Shankarganesh, K., Sinha, S. R. and Sharma, K. 2013. Efficacy of newer insecticides against sucking insect pests of okra. *Ind. J. Pl. Prot.* 41(2): 113-115

Sundaram, K. M. S. 1996. Azadirachtin biopesticide: A review of studies conducted on its analytical chemistry, environmental behaviour and biological effects, *J. Environ. Sci. Hlth., Part B.* 31(4): 913-948

Tara, J. S. Sharma, S. and Kour, R. 2010. A record of weevil (coleoptera: curculionoidea) diversity from district Samba (J & K). *The Bioscan.* 5(3): 391-394

Tayade, S., Patel, Z. P., Singh, S. and Phapale, A. D. 2014. Effect of weather parameters on pest complex of banana under heavy rainfall zone of South Gujarat. *J. Agrometeorology.* 16(2): 222-226

Thakur, A. N. S., Firake, D. M., Behere, G. T., Firake, P. D. and Saikia, K. 2014. Biodiversity of Agriculturally Important Insects in North Eastern Himalaya: An Overview. *Ind. J. Hill Fmg.* 25(2): 37-40

Thippaiah, M., Kumar, A. C. T., Shivaraju, C. and Chakravarthy, A. K. 2010. Incidence of banana pseudostem weevil, *Odoiporus longicollis* (Olivier) in South Karnataka. *Pest Manage. Hort. Ecosyst.* 16(1): 50-53

Thippaiah, M., Kumar, A. C. T., Shivaraju, C., Sudhirkumar, S. and Naveena, N. I. 2011. Study of biology of banana pseudostem weevil, *Odoiporus longicollis* Olivier. *Int. J. Entomol.* 2(1): 1-5

Tinzaara, W., Tushemereirwe, W., Nankinga, C. K., Gold C. S. and Kashaija, I. 2006. The potential of using botanical insecticides for the control of the banana weevil, *Cosmopolites sordidus* (Coleoptera: Curculionidae). *Afr. J. Biotech.* 5(20): 1994-1998

Tiwary, M. 1971. Integrated control of banana stem borer *Odoiporus longicollis* Olivier. *Proc. 58th Ind. Sc. Cong. Part III Abstracts*. p.771

Todorova, S. I., Coderre, D., Duchesne, R. M. and Cote, J. C. 1998. Compatibility of *Beauveria bassiana* With Selected Fungicides and Herbicides. *Environ. Entomol.* 27(2): 427-433

Tripathi, A.K. and Chaturvedi, M.L. 1978. Adult *Odoiporus longicollis* Oliver (Coleoptera: Curculionidae) feed on own larvae. *Entomol. News*. 89(3&4): 88

Tripathi, N. K. and Pallavi, J. 2009. Occurrence of polyploidy in the weevil *Odoiporous longicollis* Olivier (Coleoptera: Curculionidae). *The Asian J. Anim. Sci.* 4(2): 149-154

Uichanco, L. B. 1936. Miscellaneous notes on locusts, agriculture and people in Mindanao. *Philippine Agriculturist*. 25(7): 565-588

Uma, S. 2007. Crop improvement strategies for pest and disease management in banana [abstract]. In: *Abstracts, Recent Advances in Banana Crop*

Protection for sustainable production and improved livelihoods; 10-14, September, 2007, White River, South Africa. p.42

Vajargah, M. M., Dastjerdi, H. R., Golizadeh, A., Hassanpour, M. and Naseri, B. 2013. Laboratory toxicity and field efficacy of lufenuron, dinotefuran and thiamethoxam against *Hypera Postica* (Gyllenhal, 1813) (Coleoptera: Curculionidae). *Mun. Ent. Zool.* 8(1): 448-457

Vanitha, K. P., Karuppuchamy and Sivasubramanian, P. 2011. Pests of Vanilla (*Vanilla planifolia* Andrews) and their natural enemies in Tamil Nadu, India. *Int. J. Biodiversity Conser.* 3(4): 116-120

Vastrad, A. S. 2003. Neonicotinoids- current success and future outlook. *Pestology*. 27(7): 60-63

Vevai, E. J. 1971. Know your crop, its pest problems and control. *Pesticides*. 5(6): 38-56

Vijayalalitha, S. J. and Kannan, S. V. 2006. Comparative study on the different control measures of pseudostem weevil in banana variety Nendran. *Int. J. Agric. Sci.* 2 (1):146-147

Vijayasree, V. 2013. Efficacy and bio safety of new generation insecticides for the management of fruit borers of cowpea, brinjal and okra. PhD thesis, Kerala Agricultural University, Thrissur, 220p.

Visalakshi, A., Nair, G. M., Beevi, S. N. and Amma, A. M. K. 1989. Occurrence of *Odoiporus longicollis* Oliver (Coleoptera: Curculionidae) as a pest of banana in Kerala. *Entomon.* 14(3&4): 367-368

Wang, X. 2013. Determination of pesticides in banana by AOAC QuEChERS and LC–MS–MS detection. *LCGC Asia Pacific*. 16(3). Available: http://www.chromatographyonline.com/determination-pesticides-banana-

aoac-quechers-and-lc%E2%80%93ms%E2%80%93ms-detection [02 Aug. 2014]

Warburton, H. Palis, F. G. and Pingali, P. L. 1995. Farmer perceptions, knowledge and pesticide use practices. In: Pingali, P. L. and Roger, P. A. (eds.), *Impact of pesticides on farmer health and the rice environment.* Kluwer Academic Publishers, Massachusetts, pp. 59-95

Waterhouse, D. F. 1993 *The major arthropod pests and weeds of agriculture in Southeast Asia.* Australian Centre for International Agricultural Research, Canberra, 141 p.

Wijesekara, G. A. W. and Menike, J. I. 1991. Management of banana root and pseudostem weevils (*Cosmopolites sordidus* and *Odoiporus longicollis*) Coleoptera; Curculionidae. *Q. Newsl. Asia Pacif. Pl. Prot. Commn.* 34(2): 10-15

Yanez, M. and France, A. 2010. Effects of fungicides on the development of the entomopathogenic fungus *Metarhizium anisopliae* var. *anisopliae*. *Chilean J. Agric. Res.* 70(3): 390-398

Zabel, A., Manojlovic, B., Rajkovic, S., Stankovic, S. and Kostic, M. 2002. Effect of neem extract on *Lymantra dispar* L. (Lepidoptera: Lymantridae) and *Leptinotarsa decemlineata* Say. (Coleoptera: Chrysomelidae). *J. Pest. Sci.* 75: 19-25

Zhou, S.F. and Wu, X.Z. 1986. Monitoring and control of the banana borer, *Odoiporus longicollis* (Olivier). *Acta Phytophylactica Sinica.* 13(3): 195-199

MANAGEMENT OF BANANA PSEUDOSTEM WEEVIL, *Odoiporus longicollis* (Olivier), USING SAFE CHEMICALS AND BIO-RATIONAL METHODS

by

SIVAKUMAR,T.

(2012-21-111)

Abstract of the thesis

Submitted in partial fulfillment of the

requirement for the degree of

DOCTOR OF PHILOSOPHY IN AGRICULTURE

Faculty of Agriculture

Kerala Agricultural University

DEPARTMENT OF AGRICULTURAL ENTOMOLOGY

COLLEGE OF AGRICULTURE

VELLAYANI, THIRUVANANTHAPURAM-695522

KERALA, INDIA

2017

ABSTRACT

A study on 'Management of banana pseudostem weevil, *Odoiporus longicollis* (Olivier), using safe chemicals and bio-rational methods' was conducted at the College of Agriculture, Vellayani and in farmer's field during 2012-2015. The main objective was to evolve strategies for managing the pest using safe chemicals and bio-rational methods. The study involved documentation of the pest status and farmers' management practices, evaluation of the efficacy of different insecticides, botanicals and bio-agents under laboratory and field conditions and determination of harvest time insecticide residues in edible parts.

Status of pests in banana was documented from Alappuzha, Pathanamthitta, Kollam and Thiruvananthapuram districts during 2013. *O. longicollis* incidence in banana cv. Nendran varied from 5.36 per cent in Kollam to 7.64 per cent in Pathanamthitta. *Erionota* sp., *Bactrocera dorsalis* (Hendel), *Polytus mellerborgi* (Boheman), *Coccus hesperidum* L. were observed as the emerging pests from the area. Pest management practices adopted by banana farmers, documented from the above districts, revealed the use of sixteen types of pesticides, including organic preparations. No specific parasite or predator was recorded from field except earwigs and red ants.

Efficacy of insecticides, botanicals and bio-agents for the management of *O. longicollis* was evaluated under laboratory conditions. Thiamethoxam (0.01%), emamectin benzoate (0.002%) and cartap hydrochloride (0.1%) caused 100 per cent mortality of adults and grubs of the pest within 36 h after treatment. Among the botanicals, cassava leaf distillate based formulation, 'Nanma' (5%) caused 36.67 per cent mortality of adults and grubs, whereas neem soap caused 36.67 and 16.67 per cent mortality of adults and grubs, respectively. Among the bio agents tested, *Metarhizium majus* Bisch, Rehner and Humber (ICAR-CPCRI) 2% caused 80 per cent mortality of grubs on the seventh day of inoculation.

Compatibility of insecticides, fungicides and botanicals with *M. majus* was tested using poisoned media technique. The fungicides *viz*., propiconazole (0.1%), tebuconazole (0.1%), mancozeb (0.3%) and carbendazim (0.1%) resulted in total growth inhibition of *M. majus*, while thiamethoxam (0.01% and 0.03%), cartap hydrochloride (0.05%) and neem soap (1.0%) were found compatible.

Application methods of insecticides, botanicals and bio-agents were standardised through field experiment at the Instructional Farm, College of Agriculture, Vellayani during 2013-2014. Among the application methods, leaf axil filling (LAF) and injection of thiamethoxam (0.01% and 0.03%) recorded a yield of 10.98 and 10.88 kg plant^{-1}, respectively. In the case of biopesticides, the highest yield (6.43 kg plant^{-1}) was recorded with swabbing + LAF application of *M. majus* (20g l^{-1}), whereas among botanicals, spraying +LAF gave the highest yield (8.8 kg plant^{-1}) for neem soap (1.0%) application.

Prophylactic and curative methods for the management of the pest, using thiamethoxam, neem soap, cassava leaf based preparation and *M. majus*, were tested in farmer's field at Konni, Pathanamthitta district during 2014-2015. In prophylactic method thiamethoxam injection (0.03%) at 5th and 6th months after planting recorded an yield of 10.67 kg plant^{-1}, followed by thiamethoxam (0.01%) leaf axil filling (10.32 kg plant^{-1}) at 5th and 6th months after planting. Significantly higher value for BC ratio (2.44) was recorded for thiamethoxam (0.03%) injection. The BC ratio was 2.33 for thiamethoxam (0.01%) leaf axil filling. Application of *M. majus* (2%) at five months after planting, followed by thiamethoxam LAF (0.01%) at 6th month after planting yielded 8.82 kg plant^{-1}.

In curative method, plant survival was the highest (80 per cent) for thiamethoxam injection (0.03%). However, a low BC ratio of 0.86 was observed. Thiamethoxam injection (0.03%) and leaf axil filling (0.01%) were on par with chlorpyrifos (0.03%), as curative method.

No detectable residue of thiamethoxam on any edible parts of the plant was observed at the time of harvest.

To conclude, 'Nendran' was found to be the most susceptible banana cultivar to *O. longicollis*. Thiamethoxam at 0.01 per cent and 0.03 per cent were compatible with the entomopathogen, *M. majus*. Prophylactic method using thiamethoxam injection @ 0.03% and leaf axil filling @ 0.01%, both at five and six months after planting, were found effective, eco friendly and economical practice for *O. longicollis* management. The application of entomopathogenic fungi *M. majus* at five months after planting followed by thiamethoxam (0.03%) injection at six months after planting was also effective for managing the pest.

Appendices

Appendix I

Proforma for documenting pest status and farmers' practices in plant protection of banana

A. Personal profile

1. Name of farmer:

2.Age:

3. Educational qualification:

4. Address:

5. Family size:

6. Monthly income

7. Main occupation

Source	Income in Rs.

Govt. Employee/PSU	
Agriculture	
Retired Govt. Employee	
Pvt. Firm/company	
Own business	
Others	

B. Land details

8. Soil type:

10. Own land area: wet land garden land

11. Leased in land area: wet land: garden land:

12. Soil Health card details :

13. Status of N..... P..... K.....

pH..... Others.....

C. Crop Details

14. Crops grown

Crop	Variety	Area

15. Farming system:

D. Details on Banana crop

16. Total area under banana:

	Wet	garden
Owned		
leased		

Appendix I

17. Area under different cultivars and source of planting material

Cultivar	Area	Source	%

E. Plant protection in banana

18. Whether sucker treatment is done? Yes / No

19 Details of treatment

Name of chemical	Qty (dose)	Method of immersion	Time of immersion	Source of technology

20. Paring done? Yes / No

21. Application of insecticides at the time of planting or within 20 days

Name of chemical	Qty (dose)	Source of technology

22. Major problems encountered in banana cultivation

Problem	Rank/ score

23. Application of pesticides

Name of chemical	Qty/ dose	Purpose	Application method	Time of application wrt crop	Frequency	Cost/spray

Appendix I

24. Source of information on pesticides

Parameter	Shopkeeper	Lead farmer	KVK	RS	KB	Own experience
Type of pesticide						
Qty of pesticide						
Time of application						
Against which problem						

25. Effectiveness of current practice against BPSW

Practices	Rank
Cultural	
Mechanical	
Biological	
Chemical	

26. Extent of damage by BPSW

Cultivar	Area	% damage	Collection in trap

27. Observations on other pests/diseases

Name of pest/ diseases	Cultivar	% damage

28. Surrounding crops/vegetation

Crops	%	Crops	%

Appendix I

29. Use of protection gadgets

Sl.no.	Particulars	Yes	No
1.	Using gloves while handling pesticides		
2.	Use bottle opener		
3.	Using goggles		
4.	Using mask		
5.	Wearing full sleeve shirt/cloth		
6.	Using head cap		
7.	Using boots		
8.	Consuming foods/drink between spraying		
9.	Smoking between spraying		
10.	Chewing between spraying		
11.	Drinking water while spraying		
12.	Wash cloths immediately after spraying		
13.	Taking bath after spraying		
14.	Disposing off bottles promptly		

30. Type of sprayer used to spray in banana

31. Disposal of after-harvest pseudostem waste

Discard		Fiber extraction	
Burning		Drying	
Composting		Heaping	
Put in canal		Stand in the field	
Cattle feed		Others	

32. Details of indigenous practices / ITKs followed against BPSW or any other pest

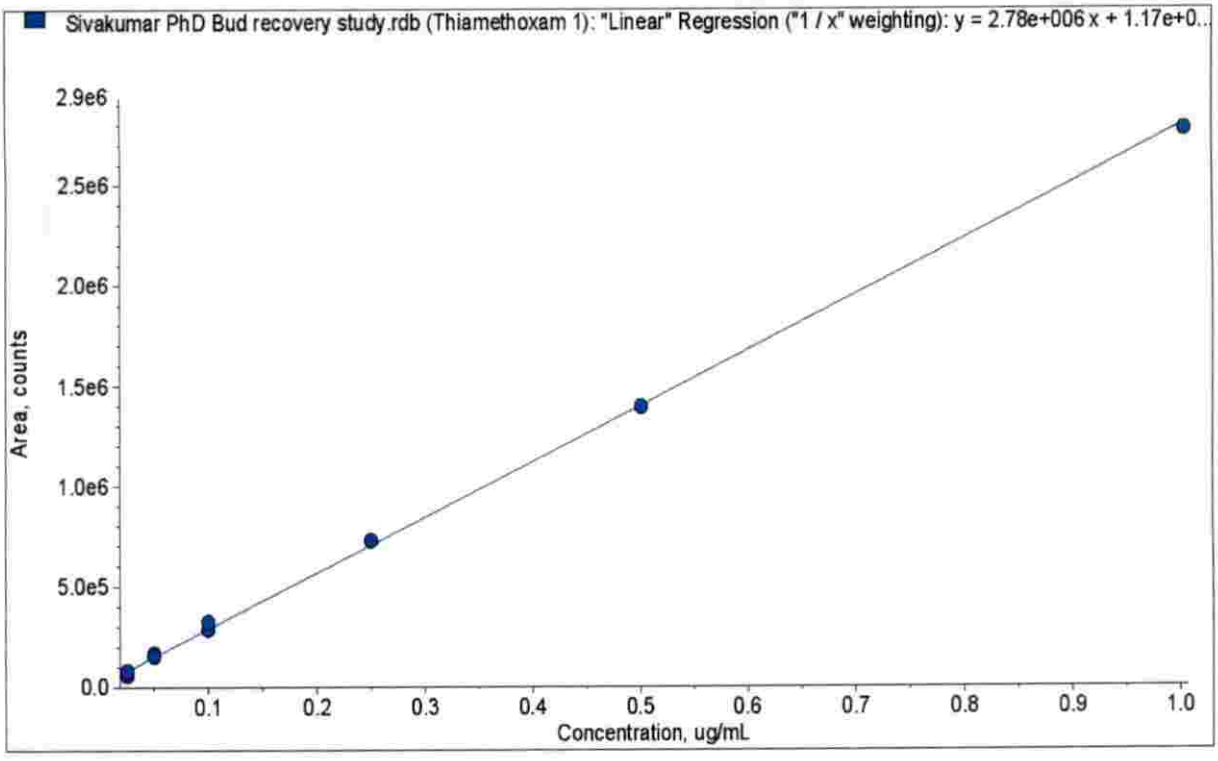
33. Seasonal occurrence

Rainy	Winter	Summer	Through out

34. Knowledge level on BSPM

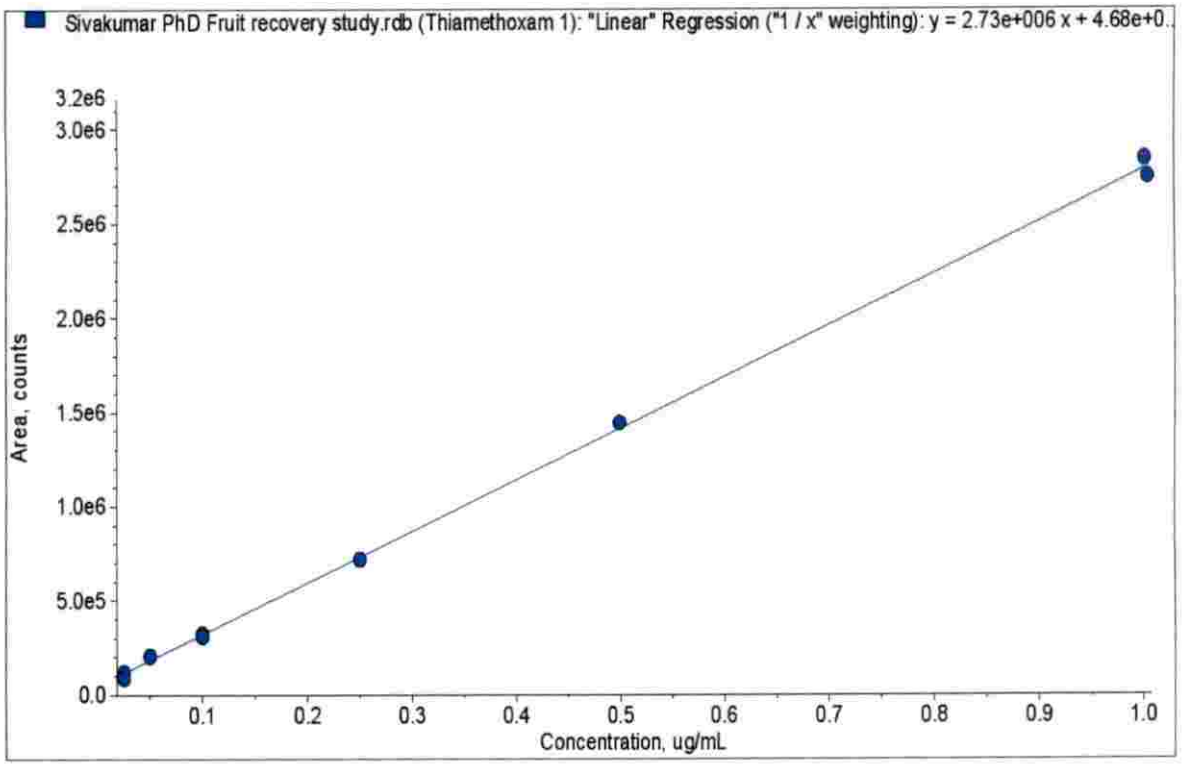
	Correct	Incorrect	Don't know
Where lay eggs?			
Where it Pupates			
What adult feeds on?			
Clean cultivation is essential			
Which stage more prone to attack			
What is the colour of grub?			

Appendix II



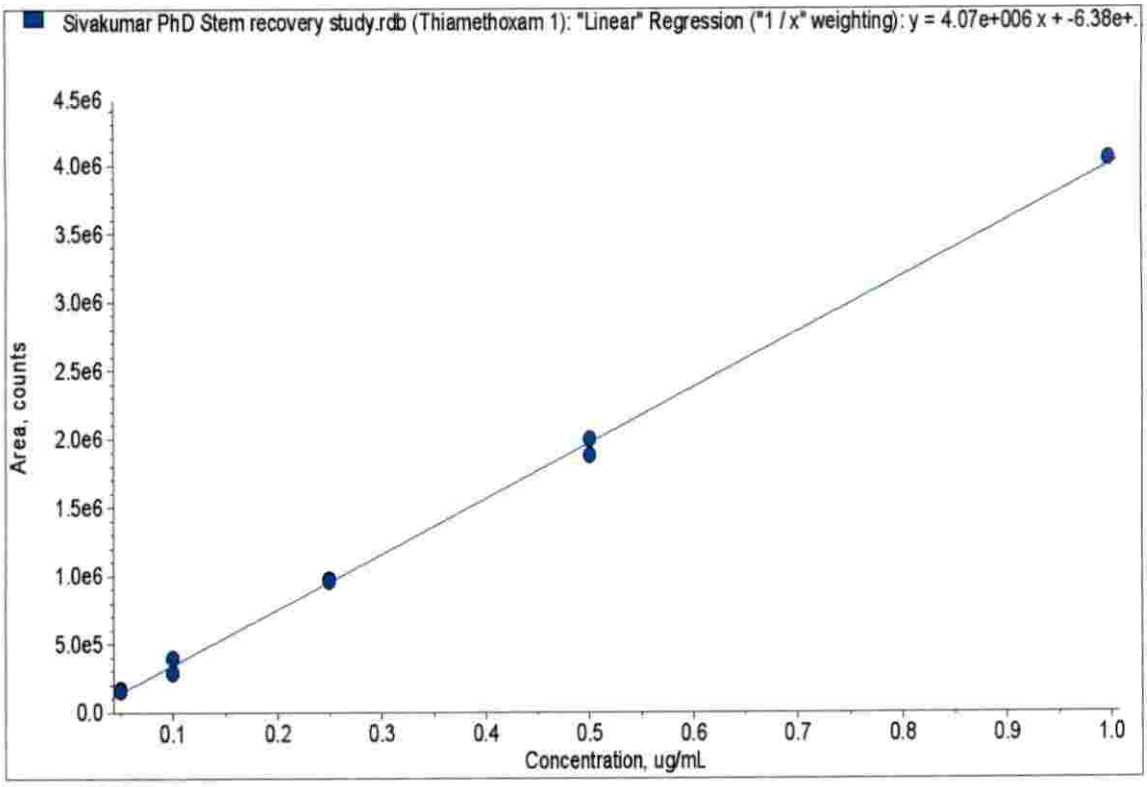
Calibration curve of thiamethoxam in banana cv. Nendran-male bud

Appendix II



Calibration curve of thiamethoxam in banana cv. Nendran-green fruit

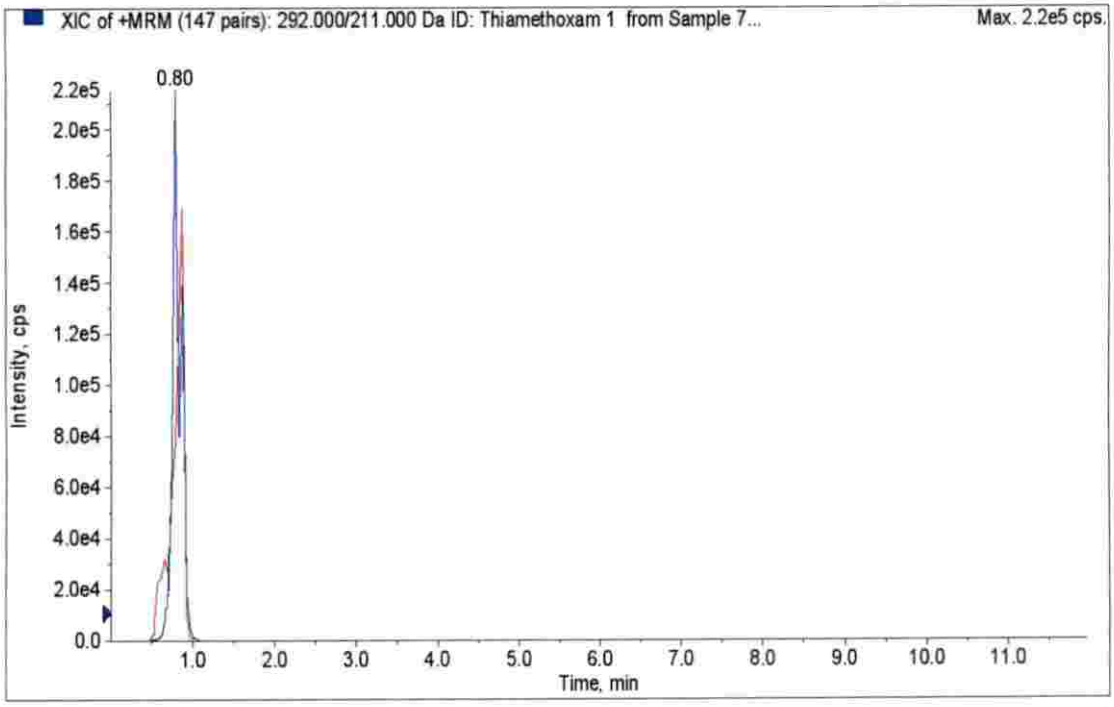
Appendix II



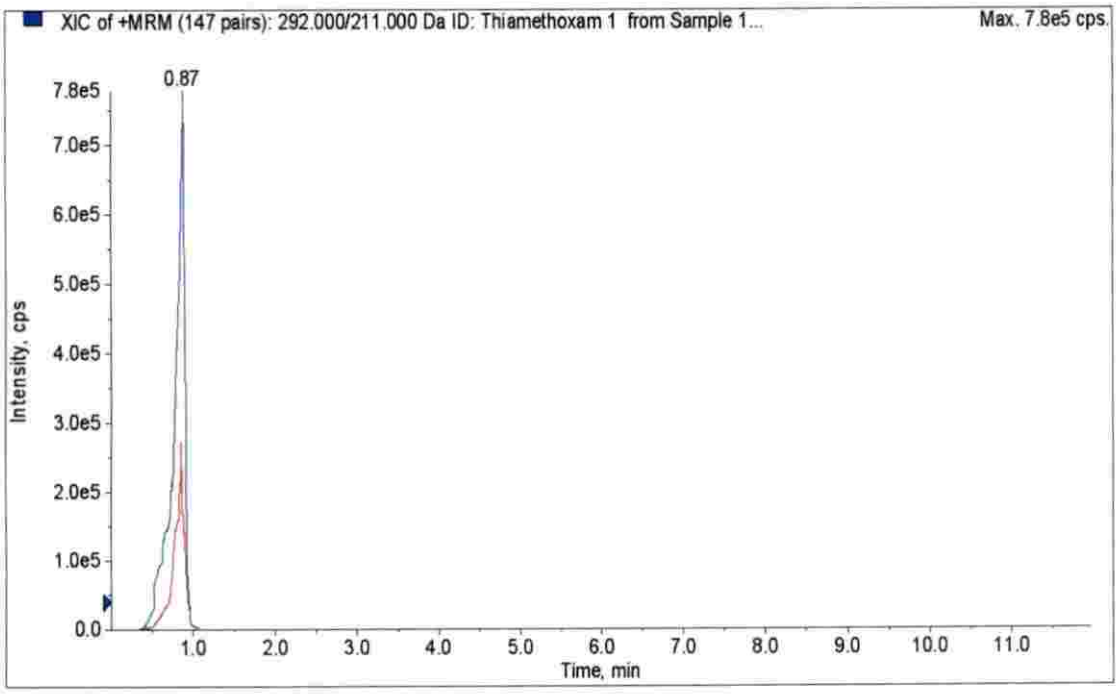
Calibration curve of thiamethoxam in banana cv. Nendran- Stem

Appendix III

Chromatogram of thiamethoxam using standard @ LOQ (0.05 ppm)

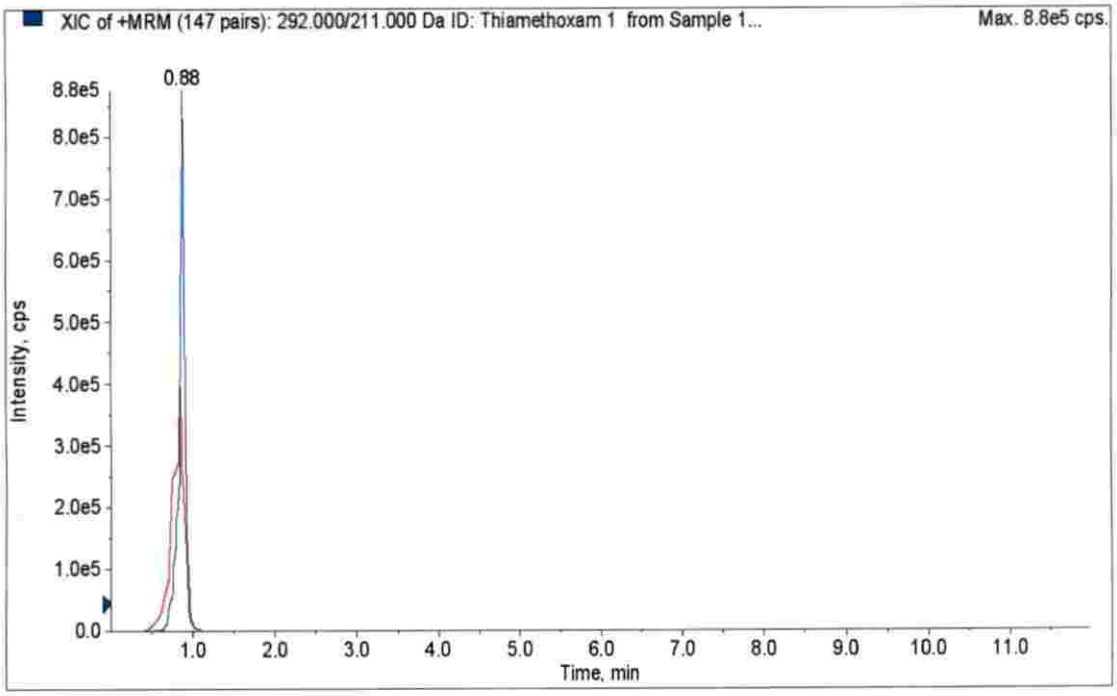


Chromatogram of thiamethoxam using standard @ 5xLOQ (0.25 ppm)

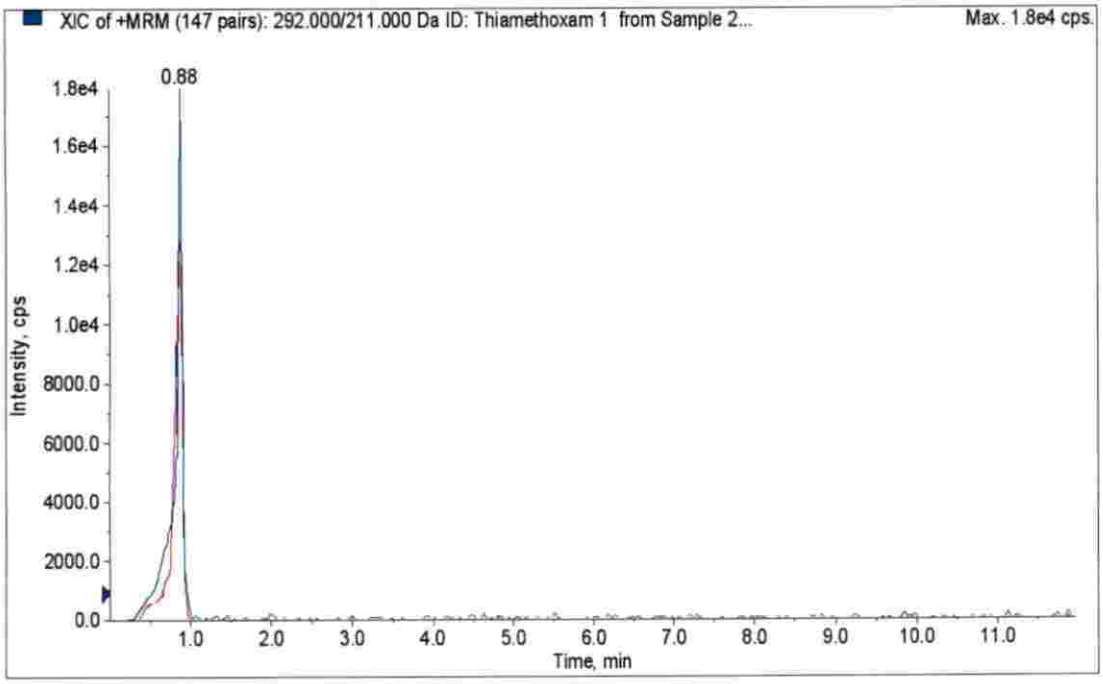


Appendix III

Chromatogram of thiamethoxam using standard @ 10xLOQ (0. 5 ppm)

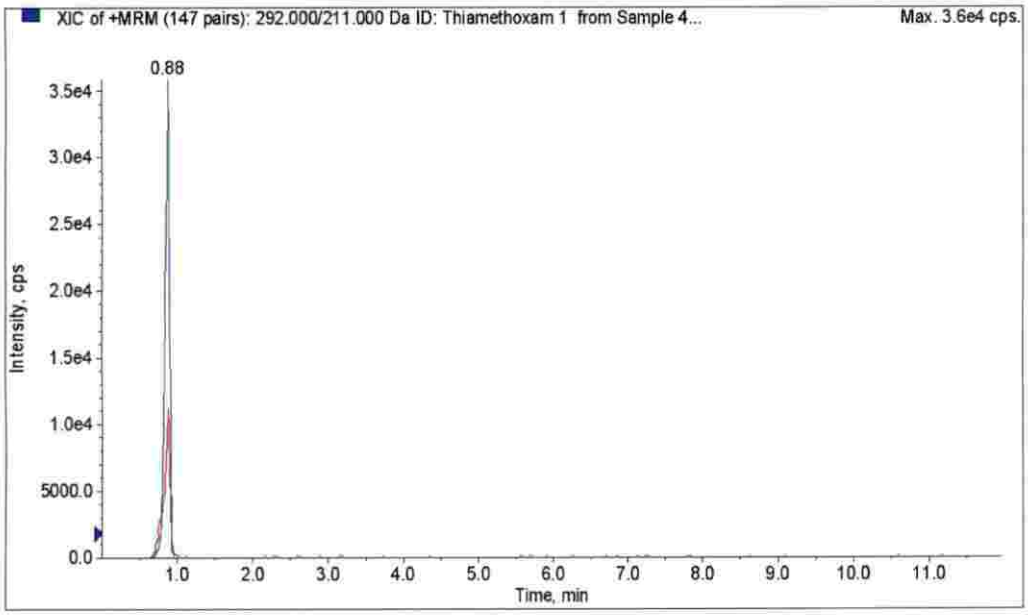


Matrix match chromatogram of thiamethoxam - Fruit @ LOQ (0.05 PPM)

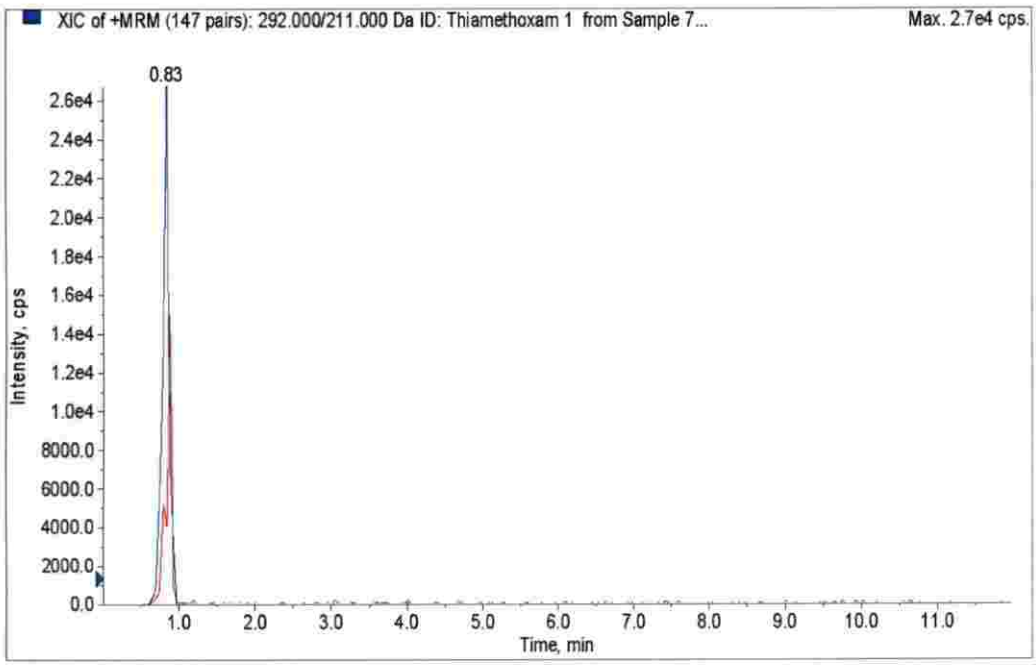


Appendix III

Matrix match chromatogram of thiamethoxam -Bud @ LOQ (0.05 PPM)

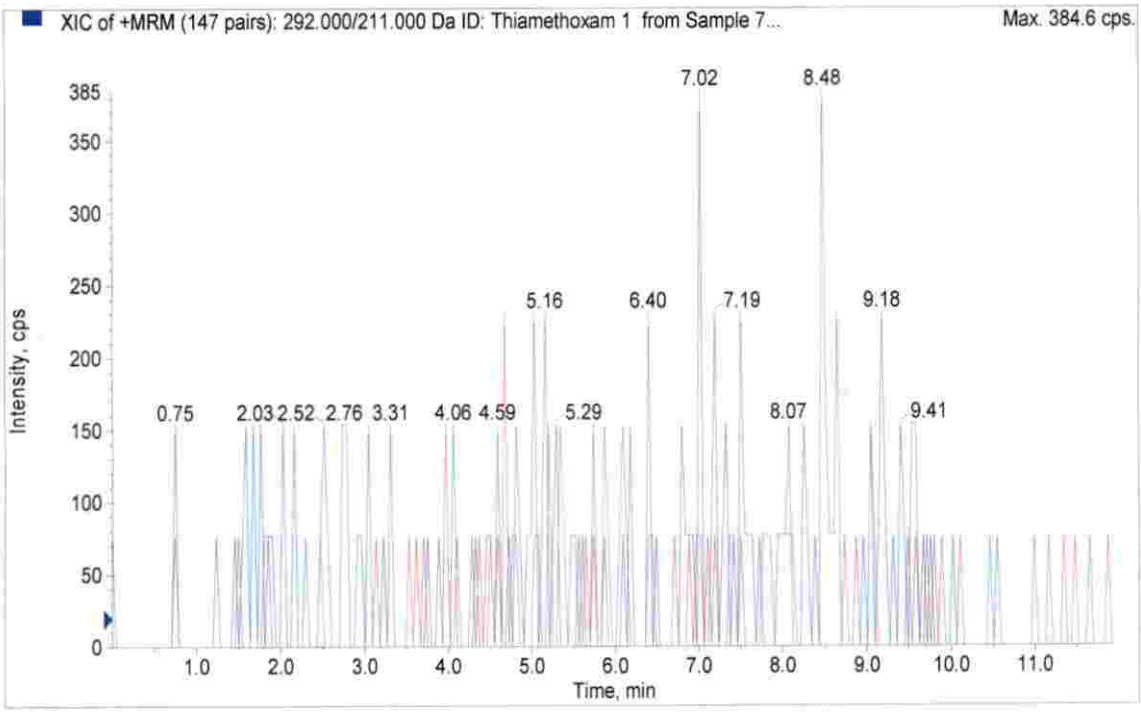


Matrix match chromatogram of thiamethoxam -Stem @ LOQ (0.05 PPM)

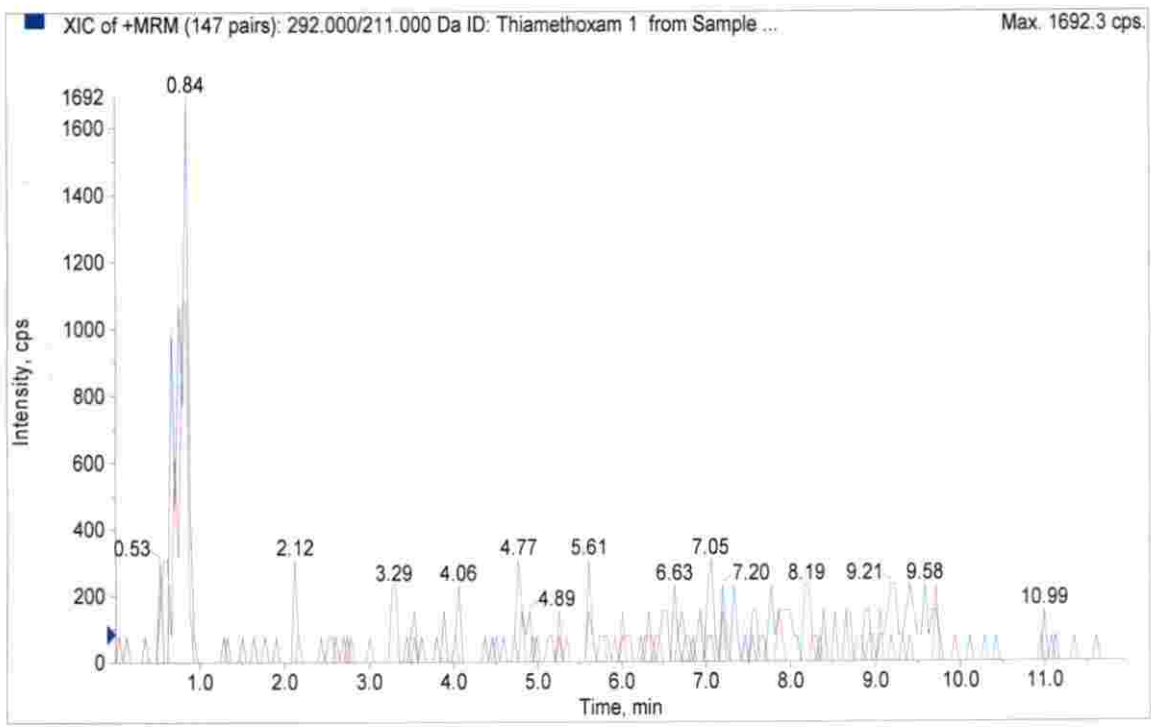


Appendix III

Chromatogram of bud from T1 –thiamethoxam 0.03% injection at 5&6MAP

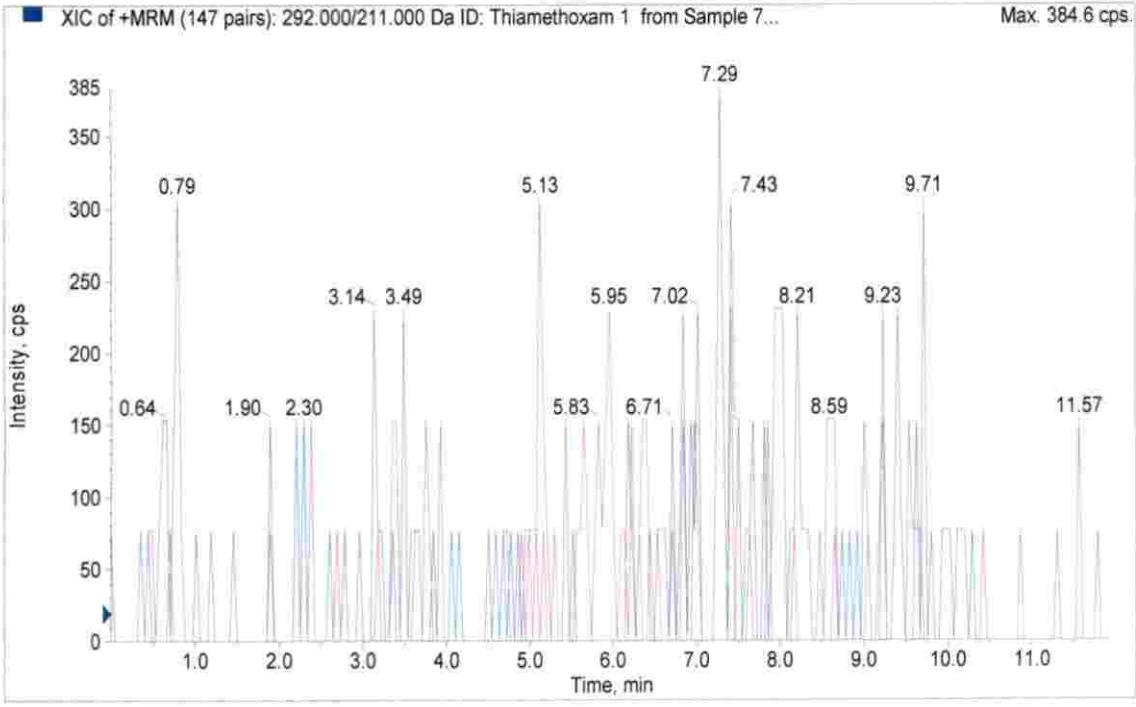


Chromatogram of fruit from T1 –thiamethoxam 0.03% injection at 5&6MAP

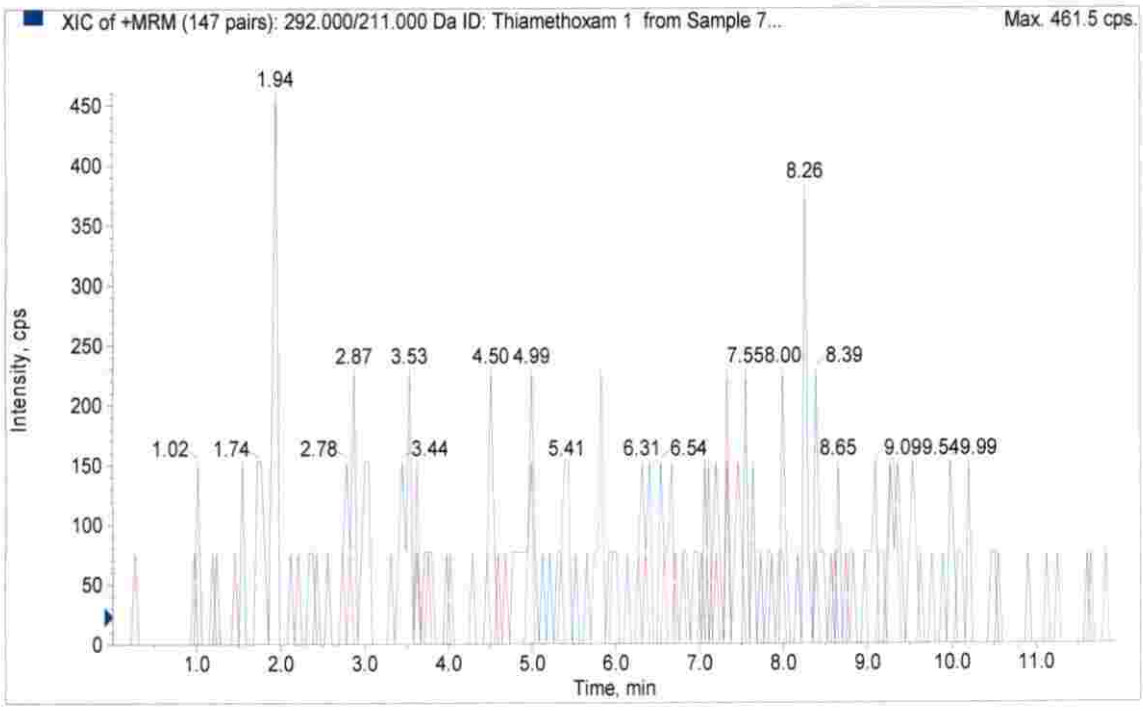


Appendix III

Chromatogram of stem (inner core/peduncle)from T1 –thiamethoxam 0.03% injection at 5&6MAP

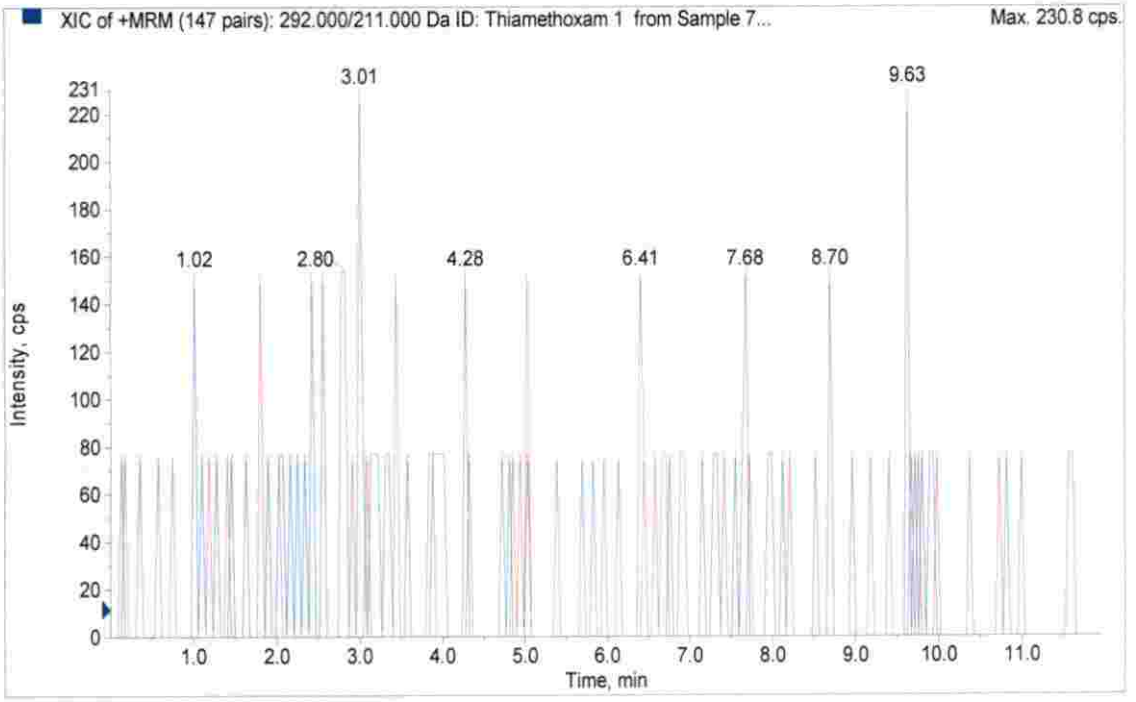


Chromatogram of bud from T12 –thiamethoxam 0.01% LAF at 5&6MAP

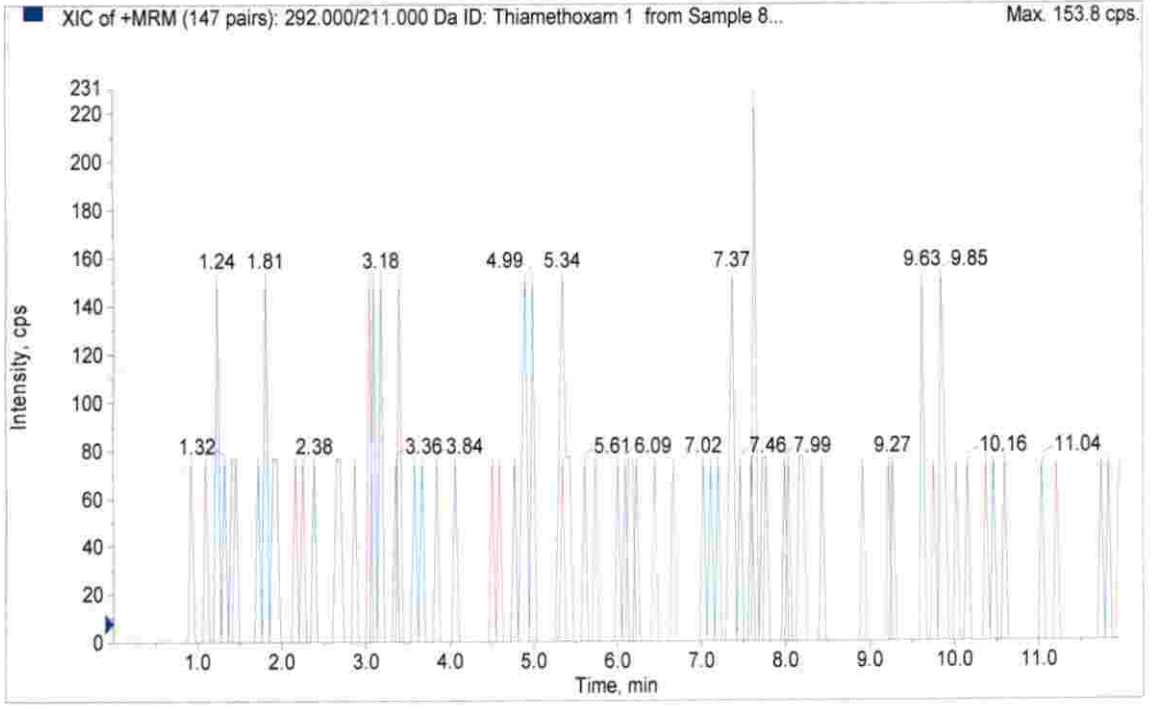


Appendix III

Chromatogram of fruit from T12 –thiamethoxam 0.01% LAF at 5&6MAP



Chromatogram of stem (inner core/peduncle)from T12 –thiamethoxam 0.01% LAF at 5&6MAP



Appendix IV

Proforma for scoring different attributes of pesticide application devices

ഓരോ മരുന്നു തളി ഉപകരണവും താരതമ്യം ചെയ്ത് അഭിപ്രായം രേഖപ്പെടുത്തുക

1–കൊള്ളാം; 2– നല്ലത്; 3– വളരെ നല്ലത്

	പിത്തള പമ്പ്	നീളം കൂട്ടാവുന്ന പ്ലാസ്റ്റിക് പമ്പ്	സിറിഞ്ച് ഉപയോഗിച്ചുള്ള കുത്തിവയ്പ്പ്
താങ്ങാവുന്ന വില			
കീടനാശിനി തെറിച്ചു വീഴൽ			
കീടനാശിനി ലായനി പാഴാകാതിരിക്കുക			
ഈട്നിൽപ്പ്			
പ്രയോഗ സമയം			
ലഭ്യത			
സുരക്ഷിതം			
ഓരോ തവണയും ലായനി നിറയ്ക്കാൻ വേണ്ട സമയം			
കീടനാശിനി എത്തേണ്ടിടത്തു എത്തിക്കുക