Management of fall armyworm, *Spodoptera frugiperda* (J.E. Smith) in Maize

THESIS

By

PALLVI THAKUR

(A-2020-30-030)

Submitted to

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CERTIFICATE – I

This is to certify that the thesis entitled **"Management of fall armyworm, *Spodoptera frugiperda* (J.E. Smith) in maize"** submitted in partial fulfilment of the requirements for the award of the degree of **Master of Science (Agriculture)** in the discipline of **Entomology** of CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur is a bonafide research work carried out by **Ms. Pallvi Thakur (A-2020-30-030)** daughter of **Sh. Vijay Kumar** and **Smt. Lata Kumari**, under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been fully acknowledged.

Place : Palampur
Dated : 4th Nov., 2022

Dr. Pawan Kumar Sharma
Major Advisor

CERTIFICATE- II

This is to certify that the thesis entitled "**Management of fall armyworm, *Spodoptera frugiperda* (J. E.Smith) in maize" submitted by Ms. Pallvi Thakur (A-2020-30-030)** daughter of **Sh. Vijay Kumar** and **Smt. Lata Kumari** to the CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur in partial fulfilment of the requirements for the degree of **Master of Science (Agriculture)** in the discipline of **Entomology** has been approved by the Advisory Committee after an oral examination of the student in collaboration with an External Examiner.

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Place: Palampur

Dated: 4th November, 2022 ***(Pallvi Thakur)***

TABLE OF CONTENTS

LIST OF ABBREVIATIONS USED

Sr. No.	Abbreviations	Meaning
1.	%	Per cent
2.	/	Per
3.	@	At the rate
4.	=	Equal to
5.	>	Greater than
6.	≥	Greater than equal to
7.	+	Plus
8.	×	Multiply
9.	^0C	Degree Celsius
10.	a.i.	Active ingredients
11.	*Bt*	*Bacillus thuringiensis*
12.	cal	Calculated
13.	Cd	Critical difference
14.	cfu	Colony forming units
15.	Conc.	Concentration
16.	DAFS	Days after first spray
17.	DASS	Days after second spray
18.	DAT	Days after treatment
19.	DAG	Days after germination
20.	df	Degree of freedom
21.	EC	Emulsified Concentrate
22.	et al.	Et alii (and other)
23.	Fig.	Figure
24.	FS	Flowable concentrate
25.	g	Gram

26.	hr	Hours
27.	ha	Hectare
28.	*i.e.*	Id est (that is)
29.	Kg	Kilogram
30.	Km	Kilometer
31.	L	Litre
32.	LC	Lethal Concentration
33.	LD	Lethal Dose
34.	LT	Lethal Time
35.	ml	Millilitre
36.	mm	Millimeter
37.	m	Meter
38.	NS	Non-significant
39.	ppm	Parts per million
40.	*P*	Probability level of significance
41.	P	Page
42.	Pp	Particular page
43.	q	Quintal
44.	SC	Suspension Concentrate
45.	SW	Standard week
46.	SG	Soluble Granules
47.	SP	Soluble Powder
48.	sp.	Species
49.	Tab	Tabulated
50.	$t\ ha^{-1}$	Tonne per hectare
51.	*viz.*	Vi delicet (namely)
52.	var.	Variety
53.	v/v	Volume/Volume
54.	WP	Wettable Powder
55.	χ^2	Chi square

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

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ABSTRACT

The present investigations entitled "Management of fall armyworm, *Spodoptera frugiperda* (J. E. Smith) in maize" were carried out at Department of Entomology, CSK HPKV, Palampur. Bioassay studies were conducted in laboratory conditions and evaluation of insecticides and biopesticides was done against *S. frugiperda* under field conditions at Research Farm of the department during *Kharif* 2022. Intrinsic toxicity of chlorantraniliprole 9.3 % + lambda cyhalothrin 4.6 % ZC, spinetoram 11.7 % SC, chlorantraniliprole 18.5 % SC, emamectin benzoate 5 % SG, novaluron 5.25 % + emamectin benzoate 0.9 % SC, azadirachtin 0. 15 % EC, *Bacillus thuringiensis* and *Metarhizium anisopliae* was worked out against 1st instar larvae of *S. frugiperda*. Based on the LC_{50} values, the emamectin benzoate proved to be highly toxic with least LC_{50} (0.052 ppm), followed by chlorantraniliprole (0.646 ppm), spinetoram (0.930 ppm), novaluron + emamectin benzoate (1.418 ppm), chlorantraniliprole + lambda cyhalothrin (1.594 ppm), azadirachtin (2.217 ppm), *Bt* (3.5×10^7 cfu/g/L) and *M. anisopliae* (1.8×10^8 cfu/g/L). Based on the relative toxicity, emamectin benzoate was found to be 30 times more toxic than the least toxic insecticide that was chlorantraniliprole + lambda cyhalothrin. All the insecticidal treatments *viz.*, chlorantraniliprole 9.3 % + lambda cyhalothrin 4.6 % ZC @ 35 g a.i./ha, spinetoram 11.7 % SC @ 30 g a.i./ha, chlorantraniliprole 18.5 % SC @ 40 g a.i./ha, emamectin benzoate 5 % SG @ 10 g a.i./ha and novaluron 5.25 % + emamectin benzoate 0.9 % SC @ 92 g a.i./ha proved promising in checking fall armyworm infestation. Emamectin benzoate was found to be superior to all other treatments as reflected bys minimum number of infested plants and highest mean per cent reduction in plant infestation over control after 1st and 2nd spray i.e. 77.96 and 77.39 %, respectively. The order of efficacy of tested insecticides was emamectin benzoate > spinetoram > chlorantraniliprole > chlorantraniliprole + lambda cyhalothrin > novaluron + emamectin benzoate. Among biopesticides, azadirachtin was most efficacious followed by *Bt* and *M. anisopliae*. The least effective treatment for managing the population of fall armyworm was whorl application of soil. Highest yield was obtained from emamectin benzoate (43.89 q ha^{-1}) followed by spinetoram (43.00 q $ha^{-1)}$ in comparison to the control (30.56 q ha^{-1}). On the basis of incremental output input ratio, emamectin benzoate (16.20) was found to be most cost-effective treatment.

(Pallvi Thakur)	**(Dr. Pawan Kumar Sharma)**
Student	**Major Advisor**
Date: 4th November, 2022	**Date: 4th November , 2022**

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1. INTRODUCTION

Maize (*Zea mays* L.) is one of the most important cereal crops which is able to thrive in a wide range of agro-climatic conditions. Maize is recognized as the "Queen of cereals" around the world due to its wider adaptability and highest production potential among all the cereals. It is the major source of various nutrients such as carbohydrates, proteins, minerals, vitamins, iron etc. This crop is mainly used as food, livestock, fuel, poultry feed and for baby food production. Maize originated from central Mexico and is currently one of the most widely distributed crops of the world. It is grown in more than 160 countries of the world and USA, China, Brazil, Mexico, France and India are the major producer.

The United State of America (USA) is the world's largest producer of maize, accounting for over 36 per cent of global production. In India, maize is the third most important cereal crop after rice and wheat. It is cultivated throughout the year in different season (*Kharif*, *Rabi* and *Spring*) in different parts of the country. In India, it is grown in an area of 9.90 million hectare with production of 31.65 million tonnes and productivity of 3.20 tonnes per hectare (Anonymous 2021a). In Himachal Pradesh, this crop occupies an area of 0.205 million hectare with production of 0.762 million tonnes and productivity of 3.71 t ha^{-1} (Anonymous 2021b).

The crop suffers from the ravages of insect-pests during different growth stages from sowing to maturity which causes damage to all plant parts (root, stem, leaf, tassels, silk and grain). Major insect-pests are maize stem borer (*Chilo partellus* Swinhoe), pink stem borer (*Sesamia inferens* Walker), shootfly (*Atherigona soccata* Rondani), armyworm (*Mythimna separata* Walker), maize cob borer (*Helicoverpa armigera* Hubner), grasshoppers (*Hierogylphus banian* Fabricius) and fall armyworm (*Spodoptera frugiperda* J.E. Smith). Maize is also known to be affected by three major sucking pests *viz.,* aphids (*Rhopalosiphum maidis* Fitch), thrips and mites at various stages of crop growth.

The fall armyworm, *S. frugiperda* (Lepidoptera: Noctuidae) is a polyphagous and noxious pest native to the tropical and subtropical regions of America. Although, it is a major pest of the maize crop, it also causes severe economic losses in a variety of crops such as soyabean, cotton, rice, other grasses, and feeds on a number of weeds (Nabity et al. 2011).

Fall armyworm is a rapidly migrating pest causing considerable damage to the host plant and can fly up to 1,600 km in 30 hours (Rose et al. 1975). It migrated to continents other than America; it was first discovered in 2016 in central and western Africa such as Benin, Nigeria, Sao Tome and Principe and Togo (Goergen et al. 2016).

The first incidence of fall armyworm was reported in India from Shivamogga (Karnataka) in July 2018 (Sharanabasappa et al. 2018). It has also been reported on sugarcane in Tamil Nadu (Srikanth et al. 2018). In 2019, the pest has reached as far as Mizoram in northeast, Uttar Pradesh in the North, Gujarat in the West, Chhattisgarh in central India, and several states in the south such as Karnataka, Andhra Pradesh, Tamil Nadu and Telangana etc. In Himachal Pradesh the incidence of fall armyworm on maize crop was noticed in 2020 from different districts *viz.*, Kangra, Bilaspur, Hamirpur, Una etc.

The name "Fall armyworm" was derived from its damage type, in which the infestation sometimes resembles an army as they move through large agricultural fields and eat all parts of the plant. Fall armyworm larvae are generally characterised by four black spots arranged in a square pattern on the 8^{th} abdominal segment and a trapezoidal pattern on the 1^{st} to 7^{th} abdominal segments of the larvae. The frons has inverted “Y” line on the head (Prasanna et al. 2018). In male moth, the forewings generally shaded grey and brown, with the triangular white spot at the tip and near the centre of the wing while the forewings of the females are less distinctly marked, ranging from the uniformly greyish brown to fine mottling of grey and brown. The hindwings of both male and female are silvery white with dark border.

The larval stage of this pest is the voracious devourer, which causes great damage to the host plant. During the day, larvae hide in the whorls but emerge at night to feed on the leaves. This pest has a great defoliation capacity, which makes it one of the most economically important pest.

Fall armyworm larvae attack maize plants starting from seedling to maturity stage. The larvae also bore inside the maize ears, stem and cob. The early instars feed superficially, usually on the undersides of leaves. Feeding results in semi-transparent patches on the leaves called papery windows. Older instars begin to make holes in the leaf resulting in presence of chewed up frass material and faecal pellets in the leaf whorl. Often only one or two caterpillars are found in each whorl, due to their cannibalistic behaviour (Barlow and Kuhar 2009).

Studies were conducted by the Centre for Agriculture and Bioscience International (CABI 2019), in 12 maize-producing African countries, showed that without proper management, fall armyworm can cause maize yield losses ranging from 8 to 21 million tonne. Food and Agriculture Organization (FAO) has declared fall armyworm as food security threat in the African continent. Several insecticides have been used for the effective management of *S. frugiperda*, but their injudicious use is likely to result in problems like resistance, pest resurgence, health hazards and environmental pollution.

Very little work has been done in Himachal Pradesh regarding the management of this pest. Considering the ravaging nature of this pest, an attempt in the present study has been made to evaluate the insecticides and biopesticide against *S. frugiperda* for effective management with the following objectives:

i. To study intrinsic toxicity of insecticides and biopesticides against *Spodoptera frugiperda* larvae

ii. To evaluate insecticides and biopesticides against the pest

2. REVIEW OF LITERATURE

Invasive species pose a serious threat to agriculture in terms of reduced production and productivity. In India, farmers are currently dealing with a significant problem with maize crop impacted by the fall armyworm (*Spodoptera frugiperda* J.E. Smith). Fall armyworm appears to have expanded to crops other than maize, which is a matter of concern. In this chapter, an attempt has been made on intrinsic toxicity of insecticides and biopesticides to S. *frugiperda* as well as their evaluation under field conditions and relevant literature has been reviewed under the following main headings:

2.1 *In vitro* bioassay of insecticides and biopesticides against fall armyworm

2.2 Evaluation of insecticides and biopesticides

2.1 *In vitro* bioassay of insecticides and biopesticides against fall armyworm

Roel et al. (2010) assessed the effect of *Azadirachta indica (*Meliaceae) oil on the development and survival of *S. frugiperda* larvae. Newly hatched larvae were subjected to three neem oil concentration (0.006, 0.05 and 0.4 %) which were added to their artificial diet. Neem oil caused 100 per cent mortality at 0.4 per cent dose at the 1st instar stage of *S. frugiperda*, prolongation in larval and pupal stage, reduction in the pupal weight and histo-physiological alterations such as degeneration of the epithelial lining of midgut and in the peritrophic matrix were also found at all concentrations of neem oil.

Hardke et al. (2011) evaluated four newer insecticides chlorantraniliprole, cyantraniliprole, fluebendiamide, spinetoram and five standard insecticides indoxacarb, lambda-cyhalothrin, methoxy-fenozide, novaluron, and spinosad to generate dose-mortality response for fall armyworm larvae through diet-incorporated bioassay. In laboratory bioassay LC_{50} value of chlorantraniliprole and spinetoram were generally lower than traditional insecticides.

Salinas-Sanchez et al. (2012) evaluated the bio insecticidal activity of organic extracts of *Tagetes erecta* L. (Asteraceae) on neonate larvae of *S. frugiperda*. The acetone leaf extract (500 ppm) induced an antifeedant effect, causing a 50 per cent reduction of larval weight. Three leaf extract of *T. erecta* caused high larval mortality, with hexane (48 %), acetone (60 %) and ethanol (72 %). Leaf extract also caused pupal mortalities between 40 to 80 per cent.

Romero-Arenas et al. (2014) evaluated native and commercial strains of *Metarhizium anisopliae* using different concentrations of conidia against fall armyworm under laboratory conditions. Conidial concentration of 5.3×10^4 conidia ml^{-1} of native strain CP-MA 1 had higher mortality rate 72.5 per cent at 72 hr post infection as compared to commercial strain of concentration 4×10^4 conidia ml^{-1} with 32.5 per cent mortality which was the lowest.

Silva et al. (2015) assessed the toxicity of aqueous extracts of neem (leaf and seed cake) for controlling *S. frugiperda* by using different methods of application (foliar and systemic). The LC_{50} value for neem seed cake and leaves were 0.13 and 0.23 per cent respectively. Therefore, aqueous extract of neem seed cake is more toxic than the leaf extract and both methods of application provided similar results.

Martinez et al. (2017) studied the biological activity of *Argemone ochroleuca* (Papaveraceae) to detect lethal and sublethal effects of ethanolic extracts (15 and 30 %) from a mixture of dried stems, leaves, and flowers of *A. ochroleuca* on the 3rd instar larvae of the fall armyworm through their continuous ingestion of treated maize leaves for 48 hr. The primary effect of ethanolic *A. ochroleuca* appeared to be a reduction in feeding, which simultaneously slow larval growth and increased mortality.

Akutse et al. (2019) assessed twenty entomopathogenic fungal isolates (14 *Metarhizium anisopliae* and 6 *Beauveria bassiana*) against eggs, neonate and second instar larvae of fall armyworm. Among the isolates tested, only *B. bassiana* ICIPE 676 caused moderate mortality of 30 per cent to second instar larvae. Five fungal isolates of *M. anisopliae* (ICIPE 7, 655, 40, 20 and 78) caused mortalities that ranged ≥92 to 96 per cent. Isolates such as *M. anisopliae* ICIPE 41 outperformed all the other fungal isolates by causing total cumulated mortality of 97.50 per cent (eggs and neonate larvae) hold potential for development as biopesticide for fall armyworm management.

Fernandes et al. (2019) examined the efficacy of insecticides for the control of fall armyworm larvae under laboratory conditions. Residual contact and direct contact bioassay were used for 2^{nd} and 5^{th} instar caterpillars. The result showed that management with chlorfenapyr + zeta cypermethrin was effective with 100 per cent efficacy in the mortality of both instars.

Mallapur et al. (2019) studied the effectiveness of novel insecticides against fall armyworm. The laboratory results revealed that spinetoram 11.7 SC and emamectin benzoate 5 SG were superior over other treatments and caused 100 per cent mortality after 60 hr of treatment.

Sisay et al. (2019) studied the efficacy of different insecticides against fall armyworm under laboratory conditions. In bioassay insect mortality was assessed 24, 48, 72 hr after treatment application. Result indicated that radiant, tracer, karate and ampligo caused 90 per cent larval mortality while carbaryl was least effective causing 28 per cent mortality after 72 hr of treatment.

Siddhartha et al. (2019) evaluated the effect of plant oils on the 3^{rd} instar larvae of *S. frugiperda*. The bioassay was conducted by allowing the larvae to feed on maize leaves treated with essential oil (clove oil 1%, basil oil 1%, lemon grass 1%, rosemary oil 1%). The leaf dip method demonstrated that clove oil (1%) showed highest mean mortality of 77.77 per cent which is the most effective among all the plant oils to control larvae of *S. frugiperda*.

Worku and Ebabuye (2019) evaluated the efficacy of insecticides against fall armyworm. In laboratory dermal toxicity was evaluated with topical application and stomach poison test was made using fresh maize leaves dipped in insecticidal solution. Bioassay test revealed that chlorpyriphos ethyl, profenaphos + lambda cyhalothrin, profenaphos + cypermethrin gave maximum mortality.

Deshmukh et al. (2020) conducted an experiment under laboratory conditions against fall armyworm. Leaf dip bioassay method was used against second instar larvae. Emamectin benzoate 5 SG showed highest acute toxicity followed by chlorantraniliprole 18.5 SC and spinetoram 11.7 SC.

Phambala et al. (2020) evaluated potential effects of ten pesticidal plants on the fall armyworm larvae, assessing direct toxicity as well as post-ingestive toxicity and feeding deterrence. In laboratory, contact toxicity and feeding bioassay showed different effects. In contact toxicity tests, high larval mortality was obtained from *Nicotiana tabacum* (66 %) and *Lippia javanica* (66 %). Similarly, in a feeding bioassay *L. javanica* (62 %) *and N. tabacum* (60 %) exhibited high larval mortality. On the other hand, *Cymbopogan citratus* (36 %) and *Azadirachta indica* (20 %) were the most potent feeding deterrents among the pesticidal plant evaluated.

Ramanujam et al. (2020) evaluated ten indigenous entomofungal strains of *B. bassiana*, *M. anisopliae* and *M. riley* against 2^{nd} instar larvae of the maize fall armyworm. Among the ten-strain tested, *M. anisopliae* ICAR-NBAIR Ma-35 and *B. bassiana* ICAR-NBAIR Bb-45 were recommended as potential isolates for control of fall armyworm.

Ahissou et al. (2021) reported the susceptibility of 3^{rd} instar larvae to insecticides with different mode of action *viz;* methomyl, chlorpyriphos-ethyl (acetylcholinesterase inhibitors), deltamethrin and lambda-cyhalothrin (sodium channel modulators), emamectin benzoate and abamectin (chloride channel activators) through leaf bioassay. Result showed that lambda-cyhalothrin was the least efficient and the emamectin benzoate most effective for the control of fall armyworm.

Herlinda et al. (2021) evaluated fungal isolates against *S. frugiperda* larvae. Results revealed that fungal species consisted of *Chaetomium sp*. *Aspergillus niger, B. bassiana*, *Curvularia lunata*, *Aspergillus flavus*, *Penicillium citrinum* and *M. anisopliae*. The endophytic fungi species of *B. bassiana*, *C. lunata* and *M. anisopliae* caused up to 22.67 per cent, 17.33 per cent and 8 per cent mortality of the larvae and had potentials as entomopathogens of *S. frugiperda*.

Susanto et al. (2021) conducted experiment under laboratory conditions to check the efficacy of insecticides against *S. frugiperda*. The results showed that among insecticide tested, the highest mortality (>80 %) was noted with emamectin benzoate, chlorfenapyr, phoxim, methomyl and indoxacarb.

Shahzad et al. (2021) evaluated the toxicity of two entomopathogenic fungi (*M. anisopliae* and *B. bassiana)* against 2nd instar larvae of fall armyworm under controlled conditions. The results showed that among tested entomopathogenic fungi, *B. bassiana* was found more toxic than *M. anisopliae*. *B. bassiana* caused 79 per cent larval mortality while *M. anisopliae* 59 per cent. *M. anisopliae* and *B. bassiana* were showed LT_{50} of 84.01 and 80.99 hr, respectively and LC_{50} of 1.3×10^{7} and 1.8×10^{7} spores ml^{-1}, respectively.

Tulashie et al. (2021) assessed the toxicity of two neem extracts: Neem seed oil extracts (NSOE) and methanolic neem leaf extract (MNLE) against fall armyworm. NSOE at concentration of 2.5 v/v showed more potency as it caused more than 70 per cent mortality as compared to MNLE which achieved 70 per cent or more mortality at a slightly high concentration of 3.0v/v. This result indicated the potential of NSOE and MNLE as a natural pesticide for the management of fall armyworm.

Mubeen et al. (2022) evaluated different conidial concentrations of *Metarhizium anisopliae* against *S. frugiperda*. The result revealed that 46.7 per cent of the larvae were found dead with conidial concentration of (1×10^{9}conidia ml^{-1}).

Shareef et al. (2022) assessed ten insecticides against 3rd instar larvae of *S. frugiperda* using topical application method, emamectin benzoate proved to be highly toxic to larvae with least LC_{50} value (1.0 ppm) followed by spinetoram, chlorantraniliprole, novaluron+emamectin benzoate, novaluron, novaluron + Indoxacarb, flubendiamide, indoxacarb, lambda-cyhalothrin and chlorpyriphos. LC_{50} value of chlorpyriphos was 184.7 ppm which exerted least toxic for fall armyworm larvae.

2.2 Evaluation of insecticides and biopesticides

Capalbo et al. (2001) produced strain of *B*t var. *tolworthi* (Btt) against *S. frugiperda*. More than 10^9 CFU g^{-1} were obtained using humidified rice as substrate. This active complex (substrate+spore crystal) of *Bt* was prepared in order to obtain 28×10^6 spores ml^{-1}; the final suspension then sprayed in fields. On the treated plants, mortality of neonate larvae was 100 per cent within two days of spraying, and all larvae were found dead on leaves.

Hardke at al. (2011) conducted a field experiment to evaluate the efficacy of newer and traditional insecticides against fall armyworm. The result indicated that chlorantraniliprole (10.0 %), cyantraniliprole (12.5 %) and novaluron (15.0 %) reduced the number of infested whorl when compared to control (50.0 %) at 3 DAT.

Mallapur et al. (2019) conducted field experiment to evaluate the efficacy of novel insecticides against fall armyworm. The result revealed that spinetoram, emamectin benzoate and spinosad were superior over all other treatments with larval reduction of 98.13, 96.26 and 96.26 per cent respectively, while thiamethoxam and fipronil were least effective.

Sisay et al. (2019) evaluated synthetic insecticides and botanicals against fall armyworm under field conditions. Results showed extensive leaf injury in the non-treated plants when compared to synthetic and botanical treated plants. No live larvae were recorded from the plants sprayed with Radiant, Karate 5 EC and *Azadirachta indica.*

Worku and Ebabuye (2019) tested the efficacy of insecticides against fall armyworm in the field conditions. Only two insecticides profenophos + cypermethrin and spinosad gave maximum mortality of the larvae in the whorls followed by profenophos + lambda cyhalothrin and indoxacarb.

Bajracharya et al. (2020) assessed the commercial formulation of insecticides *viz;* spinosad, chlorantraniliprole, emamectin benzoate, imidacloprid along with non-treated control against fall armyworm under natural infestation in maize crop. On the basis of percent plant infestation with live larvae, foliar damage by larvae, spinosad, chlorantraniliprole and emamectin benzoate were found effective against fall armyworm due to their novel mode of action.

Bharadwaj et al. (2020) studied the bio-efficacy of different insecticides against fall armyworm under field conditions. They reported that among all the treatments *viz*; chlorantranliprole 18.5 SC, emamectin benzoate 5 SG, spinetoram 11.7 SC, lambda-cyhalothrin 5 EC, chlorantraniliprole 9.3+ lambda- cyhalothrin 9.5 ZC, thiamethoxam 12.6+ lambda-cyhalothrin 9.5ZC. Spinetoram 11.7 SC @ 0.011 % was found extremely effective for control of larval population on maize.

Deshmukh et al. (2020) carried out an experimental trial to evaluate insecticides against fall armyworm. The result of field efficacy revealed that chlorantraniliprole 18.5 % SC, followed by emamectin benzoate 5 % SG and spinetoram 11.7 % SC were the most effective insecticides.

Dhobi et al. (2020) determined the efficacy of different biopesticides against fall armyworm. The data revealed that *Nomuraea riley* 1 per cent WP recorded lowest larval population (1.81 larvae per 10 plants) followed by *B. thruringiensis* 1 per cent WP (2.03 larvae per 10 plants) and these two treatments were significantly superior to rest of the biopesticides.

Ompraksh et al. (2020) tested different chemicals modules for the management of fall armyworm in maize crop. Among different modules, module 4 (Seed treatment with imidacloprid 600 FS, 20 DAG-chlorantraniliprole 18.5 SC (0.3ml L^{-1}), 30 DAG- spinetoram (0.5 ml L^{-1}), 40 DAG-poison bait with thiodicarb (100g/acer) was found effective. Thus, it was concluded that insecticides with novel mode of action were effective against the control of fall armyworm.

Sangle et al. (2020) examined the efficacy of seven insecticides on larval population of fall armyworm. Among all the seven insecticides, spraying emamectin benzoate 5 SG recorded minimum larval population of fall armyworm and also gave highest yield followed by chlorantraniliprole 18.5 SC, flubendiamide 39.35 SC, indoxacarb 14.5 SC and thiamethoxam 12.6 + lambda cyhalothrin 9.5 ZC.

Siazemo and Simfukwe (2020) evaluated the effectiveness of botanicals *viz;Melia azedarach* (Chinaberry) leaves, *Allium sativa* (Garlic), *Azadirachta indica* (Neem) leaves were in comparison to cypermethrin (synthetic pesticide) for the control of *S. frugiperda* in maize crop. Result showed that neem treatment had the highest yield of 4.9 t ha^{-1} followed by cypermethrin with 4.7 t ha^{-1}, Chinaberry and garlic with 4.3 t ha^{-1}. It was concluded that these three botanicals were as effective as the cypermethrin and may be an alternative method for fall armyworm control.

Thumar et al. (2020) studied the efficacy of different insecticides on *S. frugiperda* infesting maize. Ten plants were randomly selected from each plot and the number of larvae and damaged plants were counted. Application of spinetoram 11.7 SC (0.117 %), emamectin benzoate 5 SG (0.0025 %), chlorantraniliprole 18.5 EC (0.006 %) was found effective in managing larval population which also showed on the grain yield.

Bai et al. (2021) conducted field experiment to check efficacy of insecticides against fall armyworm in sweet corn. Per cent mean larval reduction value showed that emamectin benzoate 5SG @ 0.4 L^{-1} was superior most with 83.19 per cent reduction in larval incidence followed by spinosad.

Divya et al. (2021) evaluated whorl application of insecticides mixed with river sand against *S. frugiperda*. Sand mixed with chlorantraniliprole 18.5 SC @ 0.4 ml kg^{-1}, emamectin benzoate 5SG @ 0.4g kg^{-1} and spinosad 45SC @ 0.4 ml kg^{-1} sand were found to be effective, with significant reduction in leaf damage. The quantity of insecticide required per unit area was 50 per cent less than the spray while maximum grain yield/cost benefit ratio was obtained.

Kumar et al. (2021) studied the bio efficacy of chlorantraniliprole 18.5 SC at different doses (100, 150, 200, 250 ml ha^{-1}) used as a foliar spray against fall armyworm. Higher grain yield was obtained from both the concentration of chlorantraniliprole @ 200 and 250ml ha^{-1} when compared with all other treatments including untreated control. Lower dose of chlorantraniliprole @ 200 ml ha^{-1} is recommended to use against fall armyworm.

Nonci et al. (2021) evaluated four synthetic insecticides derived from four active ingredients (emamectin benzoate, spinetoram, carbofuran, chlorantraniliprole + thiamethoxam), one vegetable pesticide (nano pesticide; a.i. citronella, geraniol and citronellol) against fall armyworm. Insecticides found effective in controlling fall armyworm were spinetoram (37.1 %), followed by chlorantraniliprole (38.5 %) and emamectin benzoate (39.1 %) both in vegetative and in generative phase. The highest yield was obtained in the spinetoram treatment, which was 10.7 t ha^{-1}, while the lowest yield was obtained in the control treatment, which was 5.2 t ha^{-1}.

Susanto et al. (2021) studied the efficacy of insecticides against fall armyworm. The result showed that among all the treatments emamectin benzoate gave higher yield 29.28 t ha^{-1} with 33.89 per cent increase over control. The lowest yield was observed in untreated control (24.11 t ha^{-1}).

Dahal et al. (2022) recorded the effect of five different insecticides against fall armyworm in the field. Three sprays of insecticides were made at 7 days interval with the appearance of the pest. The result showed that there is 89 per cent reduction in live larvae as well as foliar damage after 1st spray in the plots sprayed with chlorantraniliprole and spinetoram as compared to other insecticides.

Osae et al. (2022) tested different concentrations of chlorantraniliprole + lambda cyhalothrin (Ampligo) against fall armyworm. Chlorantraniliprole + lambda cyhalothrin @ 200 ml ha^{-1} and 240 ml ha^{-1} caused a significant reduction in the population of fall armyworm on maize as compared to the non-treated. It was concluded that two applications of ampligo at one-week interval at 200 ml ha^{-1} are sufficient to sustain the crop.

Patidar et al. (2022) evaluated the bio-efficacy of nine insecticides *viz.,* acephate 75 SP, chlorantraniliprole 18.5 SC, deltamethrin 2.8 EC, emamectin benzoate 5 SG, flubendiamide 480 SC, spinetoram 11.7 SC, spinosad 45 SC, thiamethoxam 12.6 + lambda cyhalothrin 9.5 ZC and lambda cyhalothrin 4.6 + chlorantraniliprole 9.3 ZC against *S. frugiperda* under field condition. Results revealed that spinetoram 11.7 SC @ 0.5 ml litre^{-1} was found to be most effective in reducing larval population followed by emamectin benzoate 5 SG.

Ravikumar et al. (2022) tested the efficacy of cypermethrin 10 % + indoxacarb 10 % SC formulation against fall armyworm and stem borer under field conditions at various dosages. High dose of cypermethrin 10 % +indoxacarb 10 % SC @ 2500 g a.i ha^{-1} recorded least larval population and percent plant damage as compared to another lower doses @ 1562.5, 1250 and 1000 g a.i ha^{-1}. Maximum damage was recorded in the untreated control.

3. MATERIALS AND METHODS

The present studies on "Management of fall armyworm, *Spodoptera frugiperda* (J. E.Smith) in maize" were conducted in the laboratory conditions and experimental farm of Department of Entomology, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur. The experimental farm is situated at latitude of 32.6^0 North and longitude of 76.3^0 East in the North-West Himalayan region at an altitude of 1290.8 m above mean sea level. A detailed account of materials used and methods adopted during the course of study are being presented in this chapter.

3.1 Collection and mass rearing of fall armyworm larvae

For maintaining the culture of fall armyworm, *S. frugiperda* under laboratory conditions, artificial diet was prepared or maize seeds were grown in plastic pots filled with soil to ensure regular availability of culture for conducting experiments on bioassay.

Fall armyworm larvae were collected from the untreated maize fields of Department of Seed Science, Agronomy and Soil Science, CSK HPKV, Palampur. The presence of frass, windowpanes and cut whorls on the plants made location of the larvae easy. When a larva was identified, a small brush was used to transfer it into the plastic vials. Field collected larvae were reared on artificial diet and fresh maize leaves under laboratory conditions till the adult emergence. After the pupation the emerged adults were sexed on the basis of wing pattern and kept for oviposition in closed jars and provided with 10 per cent honey solution as food. The freshly laid eggs were picked up gently for hatching and further development. The culture of the test insect was maintained under prevailing conditions in the laboratory.

3.2 Artificial diet for larvae of *Spodoptera frugiperda*

The composition of diet for rearing *S. frugiperda* larvae as given by Nalin (1991) was used during present study and is presented in Table 3.1. The diet consisted of part A and part B, part A was made by mixing 240 g of Kidney bean (major component of the diet) with 120 g wheat germ, 72 g yeast, 7.3 g ascorbic acid, 4.4 g of methyl-p-hydroxybenzoate, 2.4 g of sorbic acid, 10 ml of multivitamin solution and 6.0 ml of formaldehyde in 500 ml of distilled water. Ingredients in part A were transferred to blender and mixed thoroughly for two minutes to get a homogenous mixture. In part B, agar solution was made with 500ml of distilled water, and added to part A. The entire diet was again mixed thoroughly. The homogenous diet was poured in sterilized glass Petri dishes and allowed to cool down at room temperature and later stored at 4^{o}C.

Table 3.1 Composition of artificial diet for *Spodoptera frugiperda*

Ingredients	Quantity	
	Part A	Part B
Kidney bean	240 g	-
Wheat germ	120 g	-
Brewer's yeast	72 g	-
Ascorbic acid	7.3 g	-
Sorbic acid	2.4 g	-
Methyl p-hydroxybenzoate	4.4 g	-
Vitamin solution	10.0 ml	-
Formaldehyde	6.0 ml	-
Agar	-	20 g
Distilled water	500 ml	500 ml

3.3 Intrinsic toxicity of insecticides and biopesticides against *Spodoptera frugiperda*

The details of insecticides and biopesticides that were used for bioassay studies are given in Table 3.2.

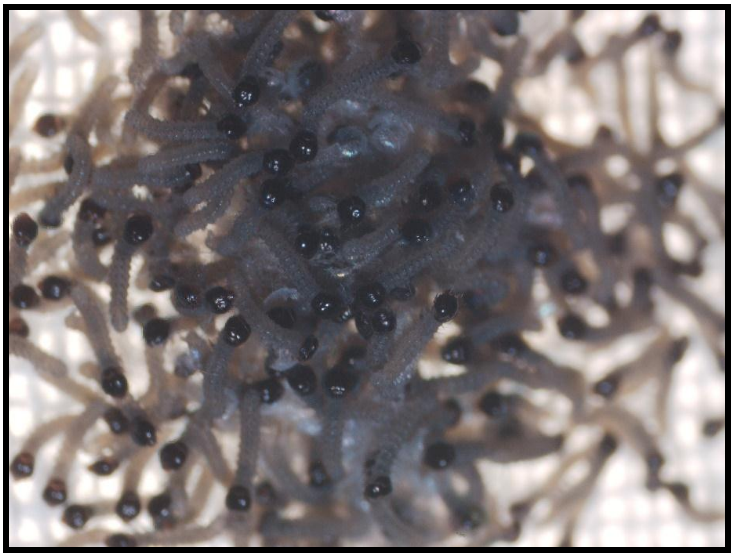
Table 3.2 Different treatments evaluated against *Spodoptera frugiperda*

Common name	Trade name	Source
Chlorantraniliprole 9.3 % + Lambda cyhalothrin 4.6 % ZC	Ampligo	Syngenta India Ltd.
Spinetoram 11.7 % SC	Largo	Helena Industries, Inc.
Chlorantraniliprole 18.5% SC	Coragen	FMC India Pvt. Ltd.
Emamectin benzoate 5 % SG	Rudra	Annu Products Pvt. Ltd.
Novaluron 5.25 %+ Emamectin Benzoate 0.9 % SC	Barazide	Shivalik crop. Sciences Pvt. Ltd.
Azadirachtin 0.15 % EC	Neem baan	Ozone Biotech
Bacillus thuringiensis $2{\times}10^{11}$ c.f.u/g/L	Green larvicide	Green life Biotech laboratory
Metarhizium anisopliae $2{\times}10^{8}$ c.f.u/g/L	Bio-magic	Indore Biotech Inputs and Research Pvt. Ltd.

For preparing the working concentration of each insecticide and biopesticide, firstly stock solutions of the insecticides and biopesticides were prepared in distilled water. From these stock solutions, graded concentrations were made with distilled water by serial dilutions. The concentrations were prepared afresh every time before the conduct of an experiment. In preliminary experiments, the concentration of insecticides and biopesticides giving mortality between 20 and 80 per cent were ascertained.

The 1st instar larvae (Plate 3.1) were used for testing insecticides under laboratory conditions. The potted maize plants were sprayed using atomizer and then shade dried. For each treatment, 10 larvae with camel hair brush were released on treated maize plant which was replicated thrice. An untreated control was also maintained by spraying the maize plants sprayed only with water. The mortality data were recorded at 24 hr in case of insecticides and after 72 hr in case of biopesticides. A larva was considered dead if it failed to move. The corrected per cent mortality was calculated as per Abbott’s (1925) formula.

(a)



(b)

Plate 3.1 *S. frugiperda* (a) Eggs (b) First instar larvae

$$\text{Corrected per cent mortality} = \frac{\text{\% mortality in treatment - \% mortality in control}}{\text{100 - \% mortality in control}} \times 100$$

The data so obtained were subjected to Probit analysis to workout LC_{50} and LC_{90} values of insecticides and biopesticides for 1st instar larvae of *S. frugiperda* (Finney, 1971). The data were also presented in the form of log concentration- probit mortality regression line of each insecticide.

3.4 Evaluation of insecticides and biopesticides against the pest

The experiment was laid out in plots of size 3 m × 2 m with ten treatments replicated thrice including control in randomized block design at Experimental Farm, Department of Entomology, College of Agriculture, CSK HPKV, Palampur during 2022. Maize variety Kanchan Gold was used for sowing on June 9th, 2022. The crop was raised as per recommended Package of Practices of CSK HPKV, Palampur except crop protection (Anonymous 2018) (Plate 3.2). The details of insecticides and biopesticides that were used for field trial are given in the Table 3.3.

Table 3.3 Details of insecticides and biopesticides

Treatment	**Insecticides/biopesticides**	**Dose (g ai/ha or L/kg/ha)**
T_1	Chlorantraniliprole 9.3% + Lambda-cyhalothrin 4.6% ZC	35g
T_2	Spinetoram11.7%SC	30g
T_3	Chlorantraniliprole 18.5%SC	40g
T_4	Emamectin benzoate 5%SG	10g
T_5	Novaluron 5.25%+ Emamectin benzoate 0.9%SC	92g
T_6	Azadirachtin 0.15% EC	5L
T_7	*Bacillus thuringiensis*	1L
T_8	*Metarhizium anisopliae*	5kg
T_9	Whorl application of soil	-
T_{10}	Control	-

Plate 3.2 A view of field experiment at Experimental Farm, Department of Entomology CSK HPKV Palampur

The insecticides were applied with the help of knapsack sprayer. First application of chemicals was made on July 26th, 2022 *i.e.*, with the appearance of pest and second application was made after 15 days. Observations on number of healthy and infested plants out of 20 randomly selected plants per plot was recorded one day before the spraying (DBS) and 3, 5,7, 10 and 14 days after treatments. Per cent reduction over control was also worked out by using formula:

$$\text{Per cent reduction (\%)} = \frac{\text{No. of infested plants in control - No. of infested plants in treatment}}{\text{No. of infested plants in control}} \times 100$$

The grain yield of all the plots was recorded from all the three replications and was converted to quintals per hectare. Incremental input output ratio was also worked out to test their cost effectiveness.

The meteorological data during the experimental period were obtained from the meteorological observatory of the Department of Agronomy, CSK HPKV, Palampur. The meteorological data in respect of minimum and maximum temperature (^{o}C), relative humidity (%), bright sunshine (hr) and rainfall (mm) are given in appendix I and represented graphically in Fig. 3.1.

Statistical analysis of data

The data of experiment on the evaluation of insecticides and biopesticides were subjected to analysis of variance after transformation of data using OPSTAT software.

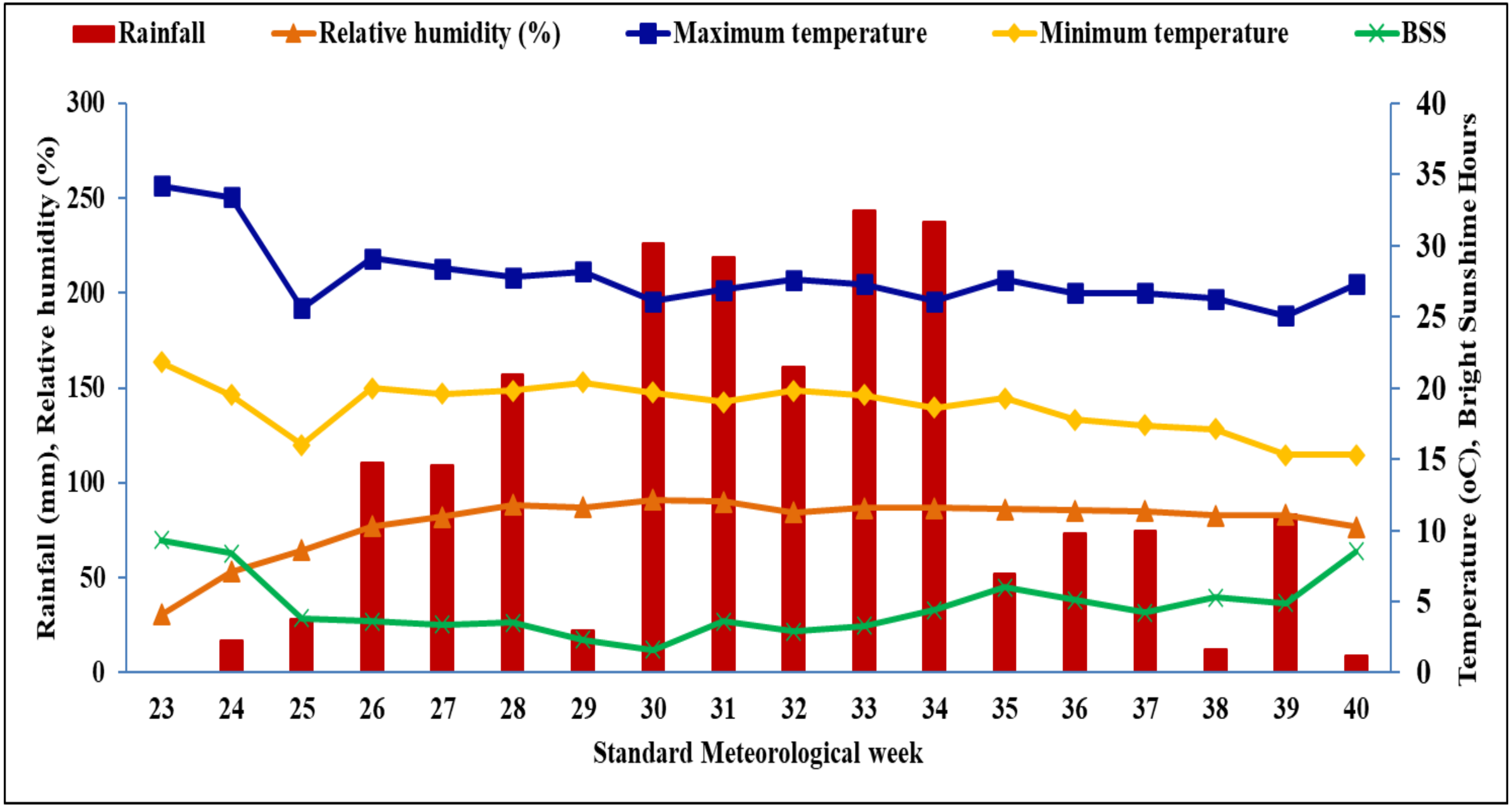


Fig. 3.1 Meteorological data of experimental period during 2022

4. RESULTS AND DISCUSSION

The present investigation entitled "Management of fall armyworm, *Spodoptera frugiperda* (J. E.Smith) in maize" was undertaken to study the efficacy of some insecticides and biopesticides for the management of fall armyworm. Bioassay studies were carried out to determine the intrinsic toxicity of insecticides and biopesticides against 1st instar larvae of fall armyworm under laboratory conditions on maize seedlings. Evaluation of different treatments including insecticides, biopesticides and whorl application of soil was also done under field conditions. The results obtained are presented and discussed under the following heads.

4.1. Intrinsic toxicity of insecticides and biopesticides against 1st instar larvae of *S. frugiperda*

4.2. Evaluation of insecticides and biopesticides against pest

4.1. Intrinsic toxicity of insecticides and biopesticides against 1st instar larvae of *S. frugiperda*

Five insecticides, chlorantraniliprole 9.3 %+ lambda cyhalothrin 4.6 % ZC, spinetoram 11.7 % SC, chlorantraniliprole 18.5 % SC, emamectin benzoate 5 % SG and novaluron 5.25 % + emamectin benzoate 0.9 % SC and three biopesticides *viz.*, azadirachtin 0.15 % EC, *Bt*, *Metarhizium anisopliae* were tested against 1st instar larvae of *S. frugiperda* under laboratory conditions. The results obtained are presented below:

4.1.1 Chlorantraniliprole + lambda cyhalothrin

The 1st instar larvae of fall armyworm when treated with chlorantraniliprole + lambda cyhalothrin at concentrations ranging from 0.437 to 7.000 ppm caused 10.7 to 89.3 per cent mortality. The LC_{50} and LC_{90} values were worked out to be 1.594 and 7.891 ppm, respectively. The fiducial limits of LC_{50} were 1.056 and 2.133 ppm whereas fiducial limits of LC_{90} were 5.623 and 10.159 ppm (Table 4.1). The data were homogenous (χ^2 = 0.142) at 5 per cent level of significance and 3 df. The slope was calculated as 1.854. Concentration mortality response of chlorantraniliprole + lambda cyhalothrin to 1st instar larvae of *S. frugiperda* is presented in Fig. 4.1.

Table 4.1 Toxicity of chlorantraniliprole + lambda cyhalothrin to 1st instar of *Spodoptera frugiperda*

Conc. (ppm)	Log (Conc. × 10) (x)	No. of insects treated	Observed mortality (%)	Corrected mortality (%)	Empirical Probit	Expected Probit
7.000	1.85	30	90.0	89.3	6.24	6.20
3.500	1.54	30	73.3	71.4	5.57	5.63
1.750	1.24	30	56.7	53.6	5.09	5.08
0.875	0.94	30	36.7	32.1	4.54	4.52
0.437	0.64	30	20.0	10.7	3.93	3.94
Control	-	30	6.7	-	-	-

Regression equation Y = 2.761 + 1.854x

LC_{50} =1.594 ppm — Fiducial limits=1.056 and 2.133 ppm

LC_{90} =7.891 ppm — Fiducial limits=5.623 and 10.159 ppm

χ^2_{cal}(p=0.05) =0.142 — χ^2_{tab} (p=0.05) = 7.814

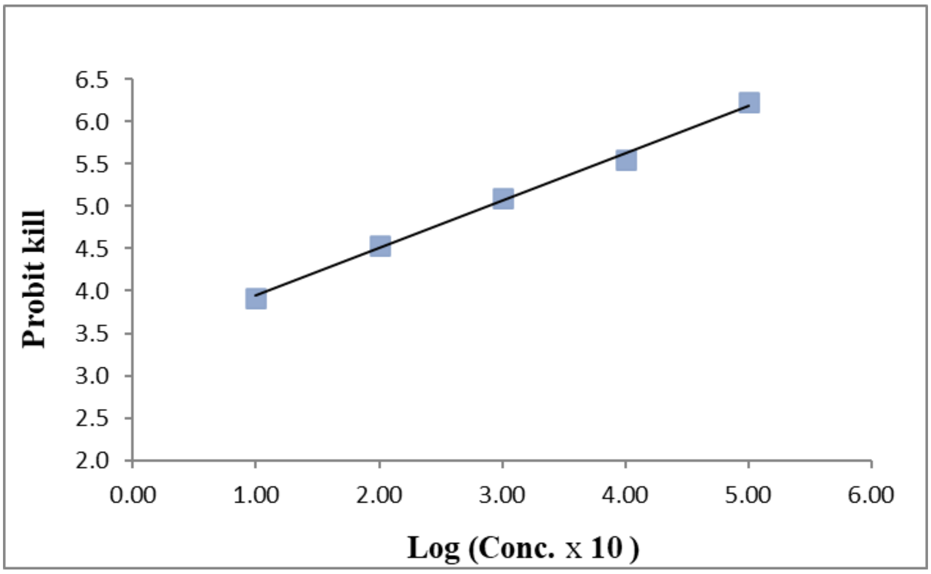


Fig. 4.1 Concentration mortality response of chlorantraniliprole + lambda cyhalothrin to 1st instar larvae of *S. frugiperda*

4.1.2 Spinetoram

The corrected mortality data of 1st instar larvae of *S. frugiperda* for spinetoram are presented in Table 4.2 and regression line is given in Fig. 4.2. Spinetoram when tested at the concentrations between 0.225 to 3.600 ppm resulted in mortality of 13.8 to 86.2 per cent. The LC_{50} and LC_{90} values were worked out to be 0.930 and 5.104 ppm, respectively. The fiducial limits of LC_{50} were 0.602 and 1.258 ppm whereas fiducial limits of LC_{90} were 3.465 and 6.744 ppm. The data were homogenous (χ^2 = 0.396) at 5 per cent level of significance and 3 df. The slope was calculated as 1.732.

Table 4.2 Toxicity of spinetoram to 1st instar larvae of *Spodoptera frugiperda*

Conc. (ppm)	Log (Conc. × 10) (x)	No. of insects treated	Observed mortality (%)	Corrected mortality (%)	Empirical Probit	Expected Probit
3.600	1.65	30	86.7	86.2	6.09	6.04
1.800	1.35	30	66.7	65.5	5.39	5.41
0.900	1.05	30	53.3	51.7	5.04	4.99
0.450	0.75	30	33.3	31.0	4.50	4.48
0.225	0.45	30	16.7	13.8	3.91	3.92
Control	-	30	3.3	0.0	-	-

Regression equation Y= 3.320 +1.732x

LC_{50} =0.930 ppm Fiducial limits =0.602 and 1.258 ppm

LC_{90} =5.104 ppm Fiducial limits =3.465 and 6.744 ppm

χ^2_{cal}(p=0.05) =0.396 χ^2_{tab} (p=0.05) =7.814

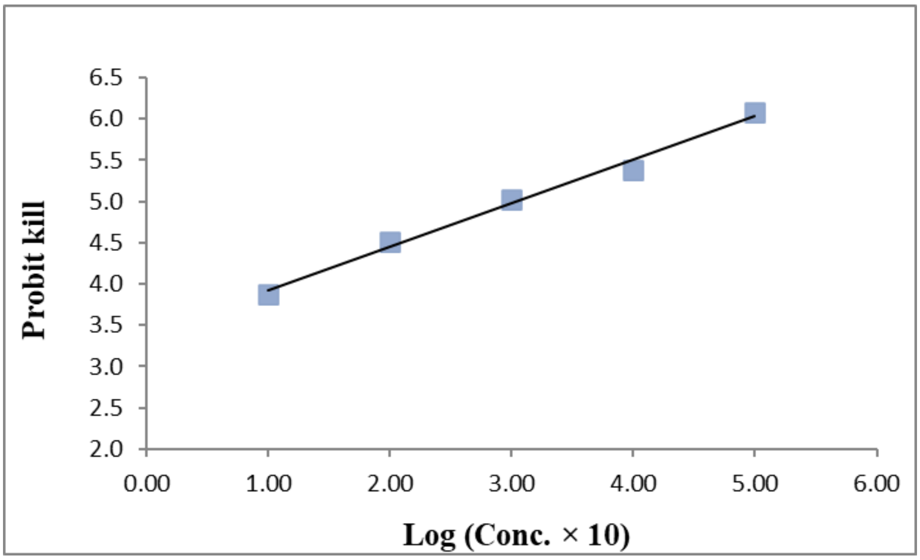


Fig. 4.2 Concentration mortality response of spinetoram to 1st instar larvae of *S. frugiperda*

4.1.3 Chlorantraniliprole

The 1st instar larvae of fall armyworm when treated with chlorantraniliprole concentrations ranging from 0.143 to 2.300 ppm caused 17.2 to 82.8 per cent mortality. The LC_{50} and LC_{90} values were worked out to be 0.646 and 4.451 ppm, respectively. The fiducial limits of LC_{50} were 0.383 and 0.909 ppm whereas fiducial limits of LC_{90} were 2.672 and 6.231 ppm. The data were homogenous (χ^2 = 0.353) at 5 per cent level of significance and slope was 1.521 (Table 4.3).

Table 4.3 Toxicity of chlorantraniliprole to 1st instar larvae of *Spodoptera frugiperda*

Conc. (ppm)	Log (Conc. × 10) (x)	No. of insects treated	Observed mortality (%)	Corrected mortality (%)	Empirical Probit	Expected Probit
2.300	0.37	30	83.3	82.8	5.95	5.85
1.150	0.67	30	63.3	62.1	5.31	5.39
0.575	0.97	30	46.7	44.8	4.87	4.93
0.287	1.27	30	33.3	31.0	4.50	4.48
0.143	1.57	30	20.0	17.2	4.05	4.02
Control	-	30	3.3		-	-

Regression equation Y= 3.371 +1.521x

LC_{50} =0.646 ppm Fiducial limits =0.383 and 0.909 ppm

LC_{90} =4.451 ppm Fiducial limits =2.672 and 6.231 ppm

χ^2_{cal}(p=0.05) = 0.353 $\chi2_{tab}$ (p=0.05) = 7.814

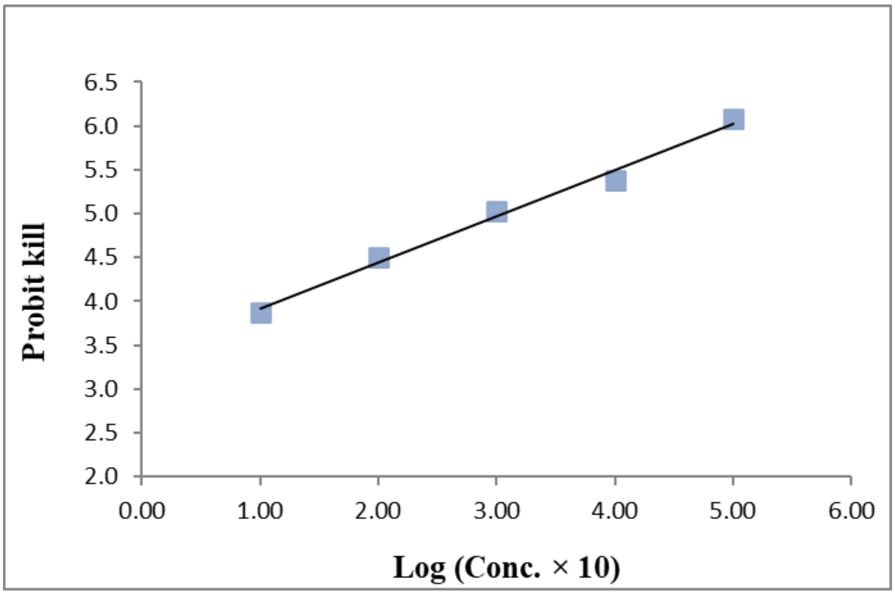


Fig. 4.3 Concentration mortality response of chlorantraniliprole to 1st instar larvae of *S. frugiperda*

4.1.4 Emamectin benzoate

Emamectin benzoate concentrations ranging from 0.016 to 0.250 ppm caused 17.2 to 89.7 per cent mortality for first instar larvae (Table 4.4). The LC_{50} values were worked out to be 0.052 and LC_{90} was 0.272 ppm. The fiducial limits of LC_{50} were 0.035 and 0.070 ppm whereas fiducial limits of LC_{90} were 0.196 and 0.347 ppm. The data were homogenous (χ^2 = 0.193) at 5 per cent level of significance and 3 df. The slope was calculated as 1.814.

Table 4.4 Toxicity of emamectin benzoate to 1st instar larvae of *Spodoptera frugiperda*

Conc. (ppm)	Log (Conc.× 10^2) (x)	No. of insects treated	Observed mortality (%)	Corrected mortality (%)	Empirical Probit	Expected Probit
0.250	1.40	30	90.0	89.7	6.26	6.19
0.125	1.10	30	73.3	72.4	5.59	5.67
0.063	0.80	30	56.7	55.2	5.13	5.14
0.031	0.49	30	36.7	34.5	4.60	4.63
0.016	0.20	30	20.0	17.2	4.04	4.03
Control	-	30	3.3	-	-	-

Regression equation Y =3.676+1.814x

LC_{50} =0.052 ppm   Fiducial limits =0.035 and 0.070 ppm

LC_{90} =0.272 ppm   Fiducial limits = 0.196 and 0.347 ppm

χ^2_{cal}(p=0.05) = 0.193 χ^2_{tab} (p=0.05) = 7.814

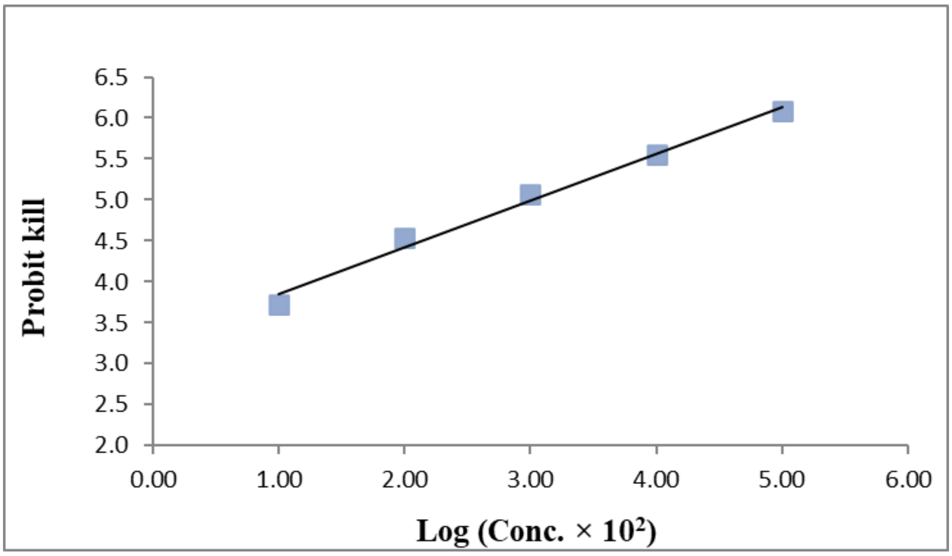


Fig. 4.4 Concentration mortality response of emamectin benzoate to 1st instar larvae of *S. frugiperda*

4.1.5 Novaluron + emamectin benzoate

Novaluron + emamectin benzoate concentrations when tested in a range of 0.362 to 5.800 ppm resulted in larval mortality of 10.7 to 85.7 per cent. The corrected mortality data of first instar larvae of *S. frugiperda* for novaluron + emamectin benzoate are presented in Table 4.5 and regression line is given in Fig. 4.5. The LC_{50} and LC_{90} values were worked out to be 1.418 and 6.920 ppm, respectively. The fiducial limits of LC_{50} were 0.944 and 1.893 ppm whereas fiducial limits of LC_{90} were 4.942 and 8.898 ppm. The data were homogenous (χ^2 = 0.495) at 5 per cent level of significance and 3 df. The slope was calculated as 1.869.

Table 4.5 Toxicity of novaluron + emamectin benzoate to 1st instar larvae of *Spodoptera frugiperda*

Conc. (ppm)	Log (Conc. × 10) (x)	No. of insects treated	Observed mortality (%)	Corrected mortality (%)	Empirical Probit	Expected Probit
5.800	2.09	30	86.7	85.7	6.07	6.12
2.900	1.79	30	73.3	71.4	5.57	5.58
1.450	1.49	30	56.7	53.6	5.09	5.00
0.725	1.19	30	36.7	32.1	4.54	4.43
0.362	0.89	30	16.7	10.7	3.76	3.89
0	-	30	6.7	-	-	-

Regression equation Y =2.839+1.869x

LC_{50} =1.418 ppm Fiducial limits =0.944 and 1.893 ppm

LC_{90} = 6.920ppm Fiducial limits =4.942 and 8.898 ppm

χ^2_{cal}(p=0.05) = 0.495 χ^2_{tab} (p=0.05) = 7.814

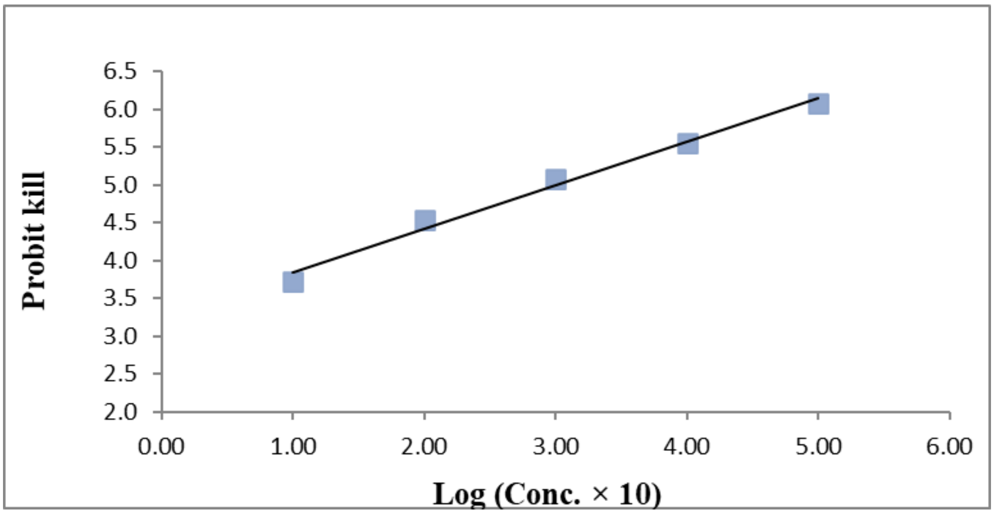


Fig. 4.5 Concentration mortality response of novaluron + emamectin benzoate to 1st instar larvae of *S. frugiperda*

4.1.6 Azadirachtin

The corrected mortality data of 1st instar larvae of *S. frugiperda* for azadirachtin are presented in Table 4.6 and regression line is given in Fig. 4.6. Azadirachtin concentrations ranging from 0.468 to 7.500 ppm resulted in mortality of 10.7 to 85.7 per cent. The LC_{50} value was worked out to be 2.217 ppm with the fiducial limits of 1.506 and 2.927 ppm. The LC_{90} value was 9.806 ppm with fiducial limits of 7.064 and 12.549 ppm. The data were homogenous (χ^2 = 0.216) at 5 per cent level of significance and 3 df. The slope was calculated as 1.979.

Table 4.6 Toxicity of azadirachtin to first instar larvae of *Spodoptera frugiperda*

Conc. (ppm)	Log (Conc. × 10) (x)	No. of insects treated	Observed mortality (%)	Corrected mortality (%)	Empirical Probit	Expected Probit
7.500	1.88	30	86.7	85.7	6.07	6.05
3.750	1.57	30	70.0	67.9	5.46	5.44
1.875	1.27	30	46.7	42.9	4.82	4.86
0.937	0.97	30	26.7	21.4	4.21	4.28
0.468	0.67	30	16.7	10.7	3.76	3.60
Control		30	6.7		-	-

Regression equation Y =2.337+1.979 x

LC_{50} =2.217ppm Fiducial limits =1.506 and 2.927 ppm

LC_{90} =9.806ppm Fiducial limits =7.064 and 12.549 ppm

χ^2_{cal}(p=0.05) = 0.216 χ^2_{tab} (p=0.05) = 7.81

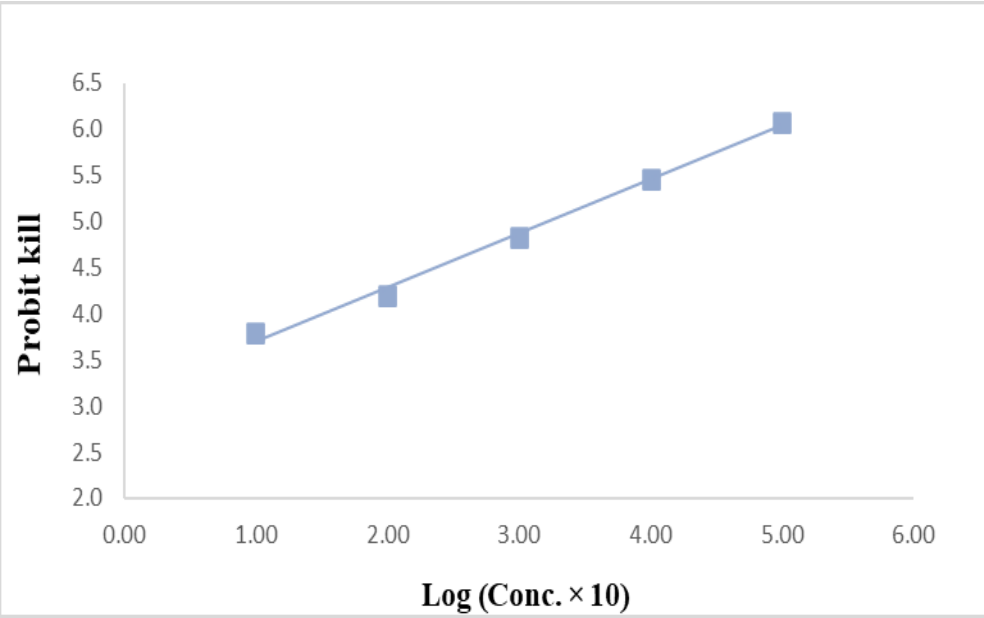


Fig. 4.6 Concentration mortality response of azadirachtin to 1st instar larvae of *S. frugiperda*

4.1.7 *Bacillus thuringiensis*

Bt concentrations when tested in a range of 6.4× 10^5 and 4.0× 10^8 resulted in larval mortality of 10.3 to 82.8 per cent. The corrected mortality data of 1st instar larvae of *S. frugiperda* for *Bt* are presented in Table 4.7 and regression line is given in Fig. 4.7. The LC_{50} and LC_{90} values were worked out to be 3.5 × 10^7 and 1.7× 10^9

cfu/g/L, respectively. The fiducial limits of LC_{50} were 5.8× 10^6 and 6.4× 10^7 cfu/g/L whereas fiducial limits of LC_{90} were 3.1× 10^8 and 3.1× 10^9 cfu/g/L. The data were homogenous (χ^2 = 0.808) at 5 per cent level of significance and 3 df. The slope was calculated as 0.750.

Table 4.7 Toxicity of *Bt* to 1st instar larvae of *Spodoptera frugiperda*

Conc. (cfu/g/L)	Log (Conc. × 10^{-4}) (x)	No. of insects treated	Observed mortality (%)	Corrected mortality (%)	Empirical Probit	Expected Probit
4.0× 10^8	3.70	30	83.3	82.8	5.95	5.81
8.0×10^7	3.40	30	56.7	55.2	5.13	5.30
1.6 × 10^7	3.10	30	43.3	41.4	4.78	4.77
3.2 × 10^6	2.80	30	26.7	24.1	4.30	4.28
6.4 × 10^5	2.49	30	13.3	10.3	3.74	3.73
Control	-	30	3.3	0.0		-

Regression equation Y=2.359 + 0.750x

LC_{50} =3.5 × 10^7cfu g/L — Fiducial limits =5.8× 10^6 and 6.4× 10^7cfu g/L

LC_{90} =1.7× 10^9 cfu g/L — Fiducial limits =3.1× 10^8 and 3.1× 10^9 cfu g/L

χ^2_{cal}(p=0.05) =0.808 — χ^2_{tab} (p=0.05) = 7.814

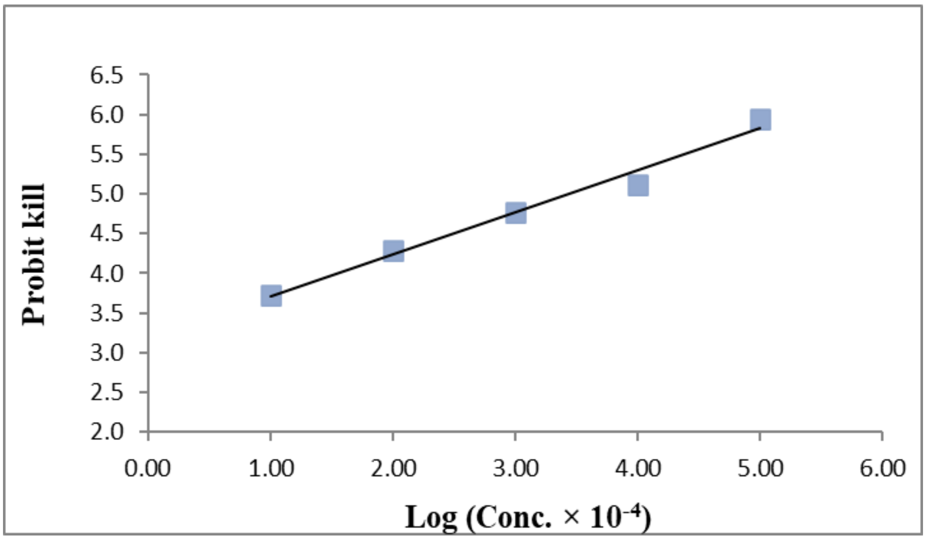


Fig. 4.7 Concentration mortality response of *Bt* to 1st instar larvae of *S. frugiperda*

4.1.8 *Metarhizium anisopliae*

The 1st instar larvae of fall armyworm when treated with *M. anisopliae* at concentrations ranging from 3.125×10^7 to 5.000×10^8 cfu/g/L caused 13.8 to 75.9 per cent mortality. The LC_{50} and LC_{90} values were worked out to be 1.8×10^8 and 1.5×10^9 cfu/g/L, respectively. The fiducial limits of LC_{50} were 9.6×10^7 and 2.7×10^7 cfu/g/L whereas fiducial limits of LC_{90} were 7.3×10^8 and 2.2×10^9 cfu g/L. The data were homogenous (χ^2 = 0.583) at 5 per cent level of significance and 3 df. The slope of regression line was calculated as 1.378.

Table 4.8 Toxicity of *Metarhizium anisopliae* to 1st instar larvae of *Spodoptera frugiperda*

Conc. (cfu/g/lit)	Log (Conc. × 10^{-4}) (x)	No. of insects treated	Observed mortality (%)	Corrected mortality (%)	Empirical Probit	Expected Probit
5.000×10^8	3.70	30	76.7	75.9	5.70	5.70
2.500×10^8	3.40	30	56.7	55.2	5.13	5.20
1.250×10^8	3.10	30	43.3	41.4	4.78	4.80
6.250×10^7	2.80	30	33.3	31.0	4.50	4.40
3.125×10^7	2.49	30	16.7	13.8	3.91	4.00
Control	-	30	3.3	-	-	-

Regression equation Y=0.530 + 1.378 x

LC_{50} =1.8×10^8 cfu/g/L — Fiducial limits =9.6×10^7 and 2.7×10^7 cfu/g/L

LC_{90} =1.5×10^9 cfu g/L — Fiducial limits =7.3×10^8 and 2.2×10^9 cfu g/L

χ^2_{cal}(p=0.05) =0.583 — χ^2_{tab} (p=0.05) = 7.814

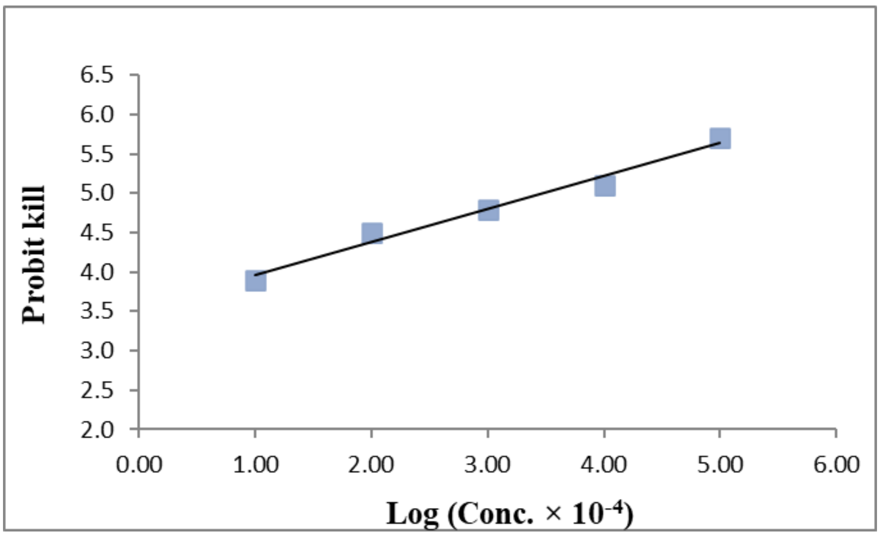


Fig. 4.8 Concentration mortality response of *M. anisopliae* to first instar larvae of *S. frugiperda*

The order of relative toxicity of insecticides calculated on the basis of LC_{50} value (Table 4.9) was emamectin benzoate (0.052) > chlorantraniliprole (0.646) > spinetoram (0.930) > novaluron + emamectin benzoate (1.418) > chlorantraniliprole + lambda cyhalothrin (1.594), respectively. When compared to chlorantraniliprole + lambda cyhalothrin, emamectin benzoate was 30.65 times more toxic to first instar larvae followed by chlorantraniliprole (2.467 times), spinetoram (1.713 times) and novaluron + emamectin benzoate (1.124 times).

Table 4.9 Relative toxicity of insecticides to 1st instar larvae of *Spodoptera frugiperda*

Treatment	**LC_{50} (ppm)**	**Relative Toxicity**	**LC_{90} (ppm)**	**Relative toxicity**
Chlorantraniliprole 9.3% + Lambda cyhalothrin 4.6% ZC	1.594	1.000	7.891	1.000
Spinetoram 11.7% SC	0.930	1.713	5.104	1.546
Chlorantraniliprole 18.5% SC	0.646	2.467	4.451	1.772
Emamectin benzoate 5% SG	0.052	30.65	0.272	29.01
Novaluron 5.25% + Emamectin benzoate 0.9% SC	1.418	1.124	6.920	1.140

The present findings are in close proximity with the results of Sharreef et al. (2022), who reported that emamectin benzoate was most toxic with least LC_{50} value (1ppm). Possible reason for higher value in their studies could be the use of third instar larvae and hence required higher dose for mortality. Deshmukh et al. (2020) studied intrinsic toxicity of insecticides against fall armyworm by leaf dip bioassay method and results revealed that LC_{50} value of emamectin benzoate (0.0051ppm), chlorantraniliprole (0.0159 ppm) and spinetoram (0.0411 ppm) were found to be very low. In diet-incorporated bioasaay, the LC_{50} value of chlorantraniliprole (0.068 ug ml^{-1}) and spinetoram (0.066 ug ml^{-1}) were significantly lower than LC_{50} value of indoxacarb (0.392 ug ml^{-1}) and flubendiamide (0.930 ug ml^{-1}) (Hardke et al. 2011). The variation in LC_{50} values may be due to difference in bioassay method used by different workers.

4.2 Evaluation of insecticides and biopesticides against pest

Nine treatments *viz.*, chlorantraniliprole 9. 3 % + lambda cyhalothrin 4.6 % ZC @ 35 g a.i. ha^{-1}, spinetoram 11.7 % SC @ 30 g a.i. ha^{-1}, chlorantraniliprole 18.5 % SC @ 40 g a.i. ha^{-1}, emamectin benzoate 5 % SG @ 10 g a.i. ha^{-1}, novaluron 5.25 % + emamectin benzoate 0.9 % SC @ 92 g a.i. ha^{-1}, azadirachtin 0.15 % EC @ 2.5L ha^{-1}, *Bacillus thuringiensis* @ 1L ha^{-1}, *Metarhizium anisopliae* @ 2.5 kg ha^{-1}, and whorl application of soil including control were evaluated for their efficacy against *S. frugiperda* in maize (Table 4.10). The pre-treatment data on number of infested plants varied from 1.33 to 1.67 in 20 randomly selected plants per plot which was non-significant.

i) First spray

The data on number of infested plants and per cent reduction over control in different treatments after first spray against *S. frugiperda* are given in Table 4.10, Fig 4.9 and also appended in appendix II.

3 DAFS

After three days of 1st spray**,** the minimum number of infested plants were observed in emamectin benzoate and spinetoram *i.e.* 1.00 out of 20 randomly selected plants which were statistically at par to all other insecticidal treatments (Table 4.10). However, all the treatments were significantly superior to control (6.33). Among the biopesticides, the number of infested plants was recorded minimum in azadirachtin (2.00) followed by *Bt* (2.33) and *M. anisopliae* (3.33). The whorl application of soil resulted in 3.67 infested plants which was statistically at par with *M. anisopliae.* The highest per cent reduction in plant infestation over control was observed in emamectin benzoate (84.92), followed by spinetoram (84.13) being statistically at par with each other proving them to be more efficacious against the pest (Fig. 4.9). Further spinetoram was also at par with chlorantraniliprole + lambda cyhalothrin and chlorantraniliprole with 73.81 and 73.02 per cent reduction in plant infestation, respectively. The next best treatments were azadirachtin (68.25 %), *Bt* (62.70 %), *M. anisopliae* (46.83%) and whorl application of soil (42.06 %). The whorl application of soil gave lowest per cent reduction over control remaining statistically at par with *M. anisopliae* and *Bt,* further *Bt* was statistically at par with azadirachtin.

5 DAFS

Similar trend was observed after five days of first spray. The number of infested plants were found to be minimum in emamectin benzoate (1.33) and spinetoram (1.33) being at par with each other whereas, the highest number of infested plants were recorded in control (7.00). On the basis of per cent reduction, among different treatments over control, emamectin benzoate and spinetoram resulted in maximum reduction *i.e.* 80.95 over control followed by chlorantraniliprole, chlorantraniliprole + lambda cyhalothrin, novaluron + emamectin benzoate with reduction of 71.43 per cent which were statistically at par with each other (Fig. 4.9). In case of biopesticides, azadirachtin resulted in 61.90 per cent reduction over control followed *Bt* (57.14%), which remained statistically at par with each other.

7 DAFS

The minimum number of infested plants was observed in emamectin benzoate (2.00) followed by spinetoram (2.33) and chlorantraniliprole (2.33) being at par with each other (Table 4.10). The next best treatments were chlorantraniliprole + lambda cyhalothrin (2.67), novaluron + emamectin benzoate (3.00), azadirachtin (3.33), *Bt* (4.00), *M. anisopliae* (4.67) and whorl application of soil (5.67) as compared to control (8.67). The data on per cent reduction after 7 days of 1st spray in different treatments ranged from 34.72 to 76.85 per cent, being highest in emamectin benzoate (76.85 %) (Fig. 4.9). Spinetoram (73.15 %) was the next best treatment which was also at par with emamectin benzoate, chlorantraniliiprole, chlorantraniliprole + lambda cyhalothrin. Among biopesticides, azadirachtin showed its superiority by registering 61.57 per cent reduction over control and was statistically at par with *Bt* and *M. anisopliae*.

10 DAFS

After 10 days of 1st spray, number of infested plants were observed to be minimum in emamectin benzoate (2.33) followed by spinetoram (3.00) both statistically at par with each other (Table 4.10). Among the biopesticides, the number of infested plants in azadirachtin, *Bt* and *M. anisopliae* were 4.33, 4.67 and 5.33, respectively and being at par with each other. The number of infested plants in control were (10.00). Emamectin benzoate resulted in highest per cent reduction (76.16 %) followed by chlorantraniliprole (73.13%) and spinetoram (69.80 %) which were significantly at par with each other. The next best treatments were chlorantraniliprole + lambda cyhalothrin (66.46 %), novaluron + emamectin benzoate (66.09 %), azadirachtin (56.70 %) and *Bt* (53.37 %).

14 DAFS

After 14 days of 1st spray, emamectin benzoate resulted in minimum number of infested plants *i.e.* 3.00 which was statistically at par with spinetoram (3.00) and chlorantraniliprole (3.33) as compared to 10.33 in control (Table 4.10). The highest per cent reduction in plant infestation over control was observed in spinetoram (71.21 %) followed by emamectin benzoate (70.91 %) being statistically at par with each other and were found to be highly efficacious. The lowest per cent reduction was recorded in whorl application of soil (32.12 %) which proved that whorl application was least effective treatment against the pest (Fig. 4.9). However, slightly higher per cent reduction over control was recorded in *M. anisolpiae* (41.82 %) being at par with whorl application of soil. Further *M. anisopliae* was at par with azadirachtin (48.48 %) and *Bt* (45.15 %).

A perusal of mean data on number of infested plants after 1st spray indicated that emamectin benzoate was found to be the most effective treatment with 1.93 infested plants as compared to 8.47 infested plants in control. Emamectin benzoate was followed by spinetoram (2.13), chlorantraniliprole (2.40), chlorantraniliprole + lambda cyhalothrin (2.67) and novaluron + emamectin benzoate (2.80). Among biopesticides azadirachtin proved to be most efficacious treatment with 3.53 infested plants against 8.47 in control. Similar trend in efficacy was observed in per cent reduction over control (Fig. 4.9) emamectin benzoate was found to be the most effective treatment resulting in 77.96 per cent reduction in plant infestation followed by spinetoram 75.85 per cent.

ii) Second Spray

The data on number of infested plants and per cent reduction over control after second spray is presented in Table 4.10, Fig. 4.10 and Appendix II.

3 DASS

The data contained in Table 4.10 revealed that the minimum number of infested plants were observed in emamectin benzoate (2.00) followed by spinetoram (2.33) and chlorantraniliprole (3.00) being statistically at par with each other. Among the biopesticides, the minimum number of infested plants were recorded in azadirachtin (5.67), followed by *Bt* (6.00) and *M. anisopliae* (6.67) as compared to control (11.33) which were at par with each other. The highest per cent reduction over control was observed in emamectin benzoate (82.32 %) followed by spinetoram (79.55 %) and chlorantraniliprole (73.23 %) being statistically at par with each other. The lowest reduction was recorded in whorl application of soil (38.13 %) which was at par with *M. anisopliae* (41.16 %), *Bt* (47.22 %) and azadirachtin (50.00 %), respectively.

5 DASS

After 5 days of 2nd spray**,** emamectin benzoate (2.33) showed minimum number of infested plants followed by spinetoram (2.33) and chlorantraniliprole (3.00) being at par with each other. The next best treatments in line were, chlorantraniliprole + lambda cyhalothrin (3.67), novaluron + emamectin benzoate (4.00), azadirachtin (6.00), *M. anisopliae* (6.67), *Bt* (7.00) and whorl application of soil (7.00). The maximum number of infested plants were observed in control (11.33). The highest per cent reduction was recorded in emamectin benzoate (79.39 %) followed by spinetoram (78.74 %) and chlorantraniliprole (71.33 %) statistically at par with each other. The next best treatments were chlorantraniliprole + lambda cyhalothrin, novaluron + emamectin benzoate, azadirachtin, *Bt* and *M. anisopliae* with 67.24, 62.89, 46.63, 37.52 and 39.23 per cent reduction in plant infestation over control (Fig. 4.10 and Appendix II).

7 DASS

After 7 days of 2nd spray, the number of infested plants was significantly minimum in emamectin benzoate (2.67) and remained at par with spinetoram (3.00) and chlorantraniliprole (3.67). The maximum number of infested plants was recorded in control (12.00). Among biopesticides, azadirachtin resulted in 6.67 infested plants followed by *Bt* (7.33) and *M. anisopliae* (7.33) being at par with each other. The highest per cent reduction was found in emamectin benzoate (77.86 %) followed by spinetoram (74.52 %) and chlorantraniliprole (67.86 %) which were statistically at par with each other. The per cent reduction recorded in azadirachtin was 44.29 followed by *Bt* (38.17 %) and *M. anisopliae* (38.17 %) being at par with each other.

10 DASS

Emamectin benzoate and spinetoram remained to be the most effective treatments resulting in minimum number of infested plants (3.33) (Table 4.10). Among the biopesticides, azadirachtin recorded minimum number of infested plants (7.00) as compared to *Bt* (8.33) and *M. anisopliae* (8.67)**.** The highest reduction was recorded in emamectin benzoate (75.09 %) followed by spinetoram (74.53 %) being at par with each other. Lowest reduction was observed in whorl application of soil (31.92 %) which was at par with *M. anisopliae* (34.70 %) presented in Fig. 4.10.

14 DASS

Similar trend was recorded after 14 days of 2nd spray, emamectin benzoate showed minimum number of infested plant (3.67) followed by spinetoram (4.00) being statistically at par with each other as against 13.33 infested plants in control. The per cent reduction of infested plants over control ranged from 29.70 to 72.31 in all the treatments. Among all treatments highest reduction over control (72.31 %) was recorded in emamectin benzoate which was at par with spinetoram. The next best treatment chlorantraniliprole resulted in 62.18 per cent reduction over control which was statistically at par with chlorantraniliprole + lambda cyhalothrin and novaluron + emamectin benzoate (59.96 %). The lowest per cent reduction was found in whorl application of soil (29.70%) followed by *M. anisopliae* (31.92%).

Perusal of mean data on number of infested plants after 2nd spray depicted in Table 4.10 revealed that the number of infested plants were significantly minimum in emamectin benzoate (2.80) followed by spinetoram (2.99) as compared to infested plant in control (12.27). Emamectin benzoate (77.39 %) proved to be most effective treatment in terms of per cent reduction over control followed by spinetoram (75.53 %). It was evident that minimum per cent reduction over control was recorded in whorl application of soil (34.16%) (Fig. 4.10).

The present findings are in agreement with Sangle et al. (2020) and Susanto et al. (2021), who reported that emamectin benzoate 5 SG was most effective insecticides against fall armyworm. Bajracharya et al. (2020) concluded that spinosad, chlorantraniliprole and emamectin benzoate were effective in reducing *S. frugiperda* infestation in maize field due to their novel mode of action. Mallapur et al. (2019) tested different insecticides against *S. furgiperda* and ascertained that spinetoram was significantly superior followed by emamectin benzoate and spinosad with larval reduction of 98.13, 96.26 and 96.26 per cent, respectively. Hardke et al. (2014) observed higher mortality of fall armyworm with new insecticides like chlorantraniliprole, flubendiamide, and spinetoram compared to traditional ones like lambda - cyhalothrin during laboratory studies.

Table 4.10 Efficacy of insecticides and biopesticides against *Spodoptera frugiperda*

Treatments	Dose (g ai/ha or L/kg/ha)	Pre-treatment	No. of infested plants											
			First spray						Second Spray					
			3 DAFS	5 DAFS	7 DAFS	10 DAFS	14 DAFS	Mean	3 DASS	5 DASS	7 DASS	10 DASS	14 DASS	Mean
Chlorantraniliprole 9.3% + Lambda cyhalothrin 4.6% ZC	35g	1.33	1.67 (1.62)	2.00 (1.71)	2.67 (1.91)	3.33 (2.07)	3.67 (2.15)	2.67	3.67 (2.15)	3.67 (2.15)	4.33 (2.30)	5.00 (2.44)	5.33 (2.51)	4.40
Spinetoram 11.7% SC	30g	1.00	1.00 (1.41)	1.33 (1.52)	2.33 (1.82)	3.00 (2.00)	3.00 (1.98)	2.13	2.33 (1.82)	2.33 (1.82)	3.00 (2.00)	3.33 (2.07)	4.00 (2.23)	2.99
Chlorantraniliprole 18.5% SC	40g	1.67	1.67 (1.62)	2.00 (1.71)	2.33 (1.82)	2.67 (1.91)	3.33 (2.07)	2.40	3.00 (1.98)	3.00 (1.98)	3.67 (2.15)	4.67 (2.37)	5.00 (2.44)	3.87
Emamectin benzoate 5% SG	10g	1.00	1.00 (1.38)	1.33 (1.52)	2.00 (1.73)	2.33 (1.82)	3.00 (2.00)	1.93	2.00 (1.71)	2.33 (1.82)	2.67 (1.91)	3.33 (2.07)	3.67 (2.15)	2.80
Novaluron 5.25% + Emamectin benzoate 0.9% SC	92g	1.33	1.67 (1.62)	2.00 (1.73)	3.00 (2.00)	3.33 (2.07)	4.00 (2.22)	2.80	3.67 (2.15)	4.00 (2.23)	4.33 (2.30)	5.33 (2.51)	5.33 (2.51)	4.53
Azadirachtin 0.15% EC	2.5 L	1.67	2.00 (1.71)	2.67 (1.91)	3.33 (2.07)	4.33 (2.30)	5.33 (2.51)	3.53	5.67 (2.58)	6.00 (2.64)	6.67 (2.76)	7.00 (2.82)	7.33 (2.88)	6.53
Bacillus thuringiensis	1L	1.67	2.33 (1.82)	3.00 (2.00)	4.00 (2.23)	4.67 (2.37)	5.67 (2.58)	3.93	6.00 (2.64)	7.00 (2.82)	7.33 (2.88)	8.33 (3.05)	8.33 (3.05)	7.40
Metarhizium anisopliae	2.5 kg	1.33	3.33 (2.07)	4.00 (2.23)	4.67 (2.37)	5.33 (2.51)	6.00 (2.64)	4.67	6.67 (2.76)	6.67 (2.76)	7.33 (2.88)	8.67 (3.10)	9.00 (3.16)	7.67
Whorl application of soil	-	1.67	3.67 (2.15)	4.33 (2.30)	5.67 (2.58)	6.33 (2.70)	7.00 (2.82)	5.40	7.00 (2.82)	7.00 (2.82)	7.67 (2.94)	9.00 (3.16)	9.33 (3.21)	8.00
Control	-	1.33	6.33 (2.70)	7.00 (2.82)	8.67 (3.10)	10.00 (3.31)	10.33 (3.36)	8.47	11.33 (3.51)	11.33 (3.50)	12.00 (3.59)	13.33 (3.78)	13.33 (3.78)	12.27
CD (P =0.05)		NS	(0.30)	(0.28)	(0.20)	(0.22)	(0.21)		(0.30)	(0.33)	(0.28)	(0.19)	(0.15)	

Figures in the parentheses are square root transformation values; DAFS= Days after first spray; DASS= Days after second spray

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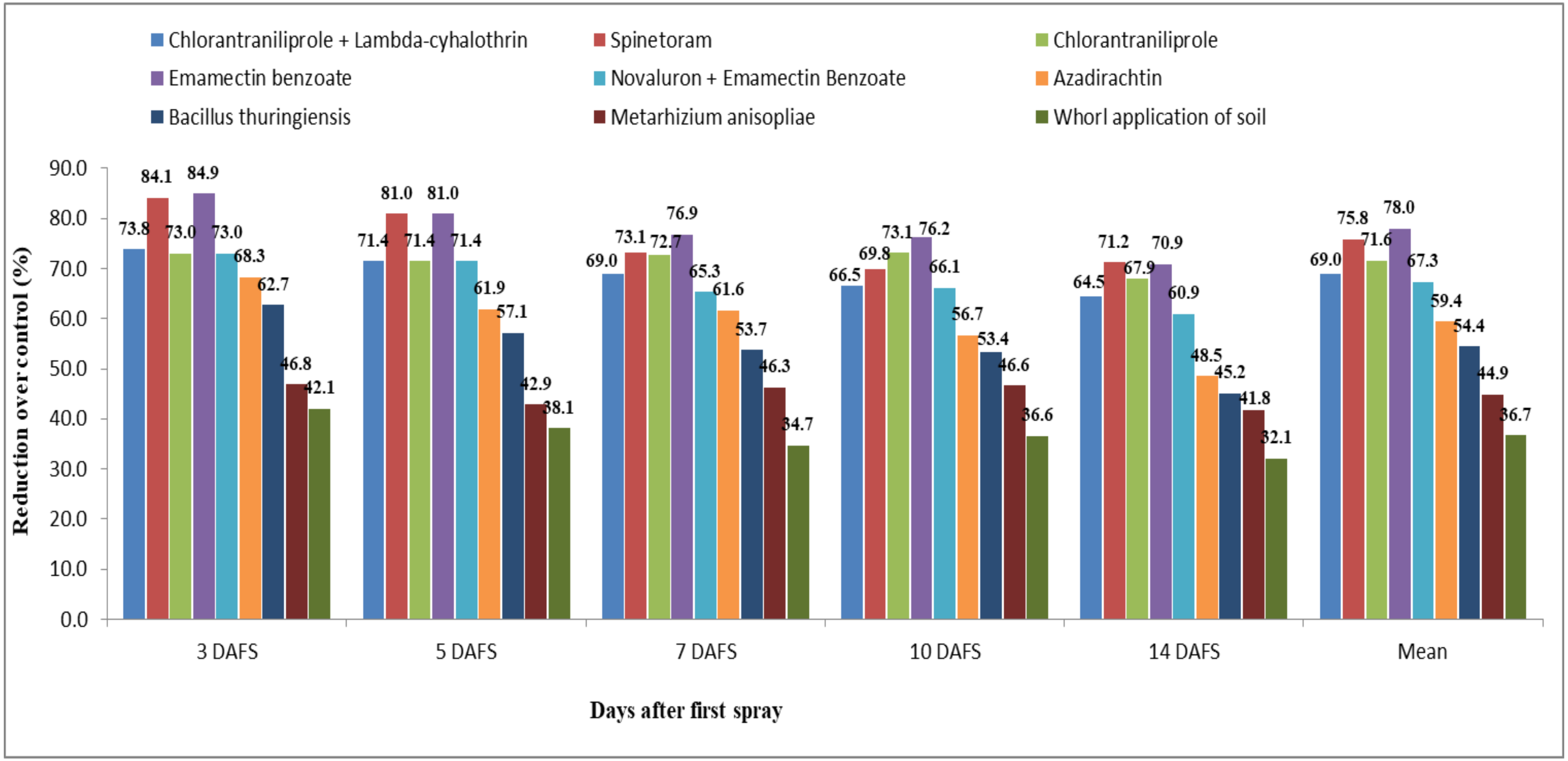

Fig. 4.9 Per cent reduction in plant infestation over control in first spray; DAFS – Days after first spray

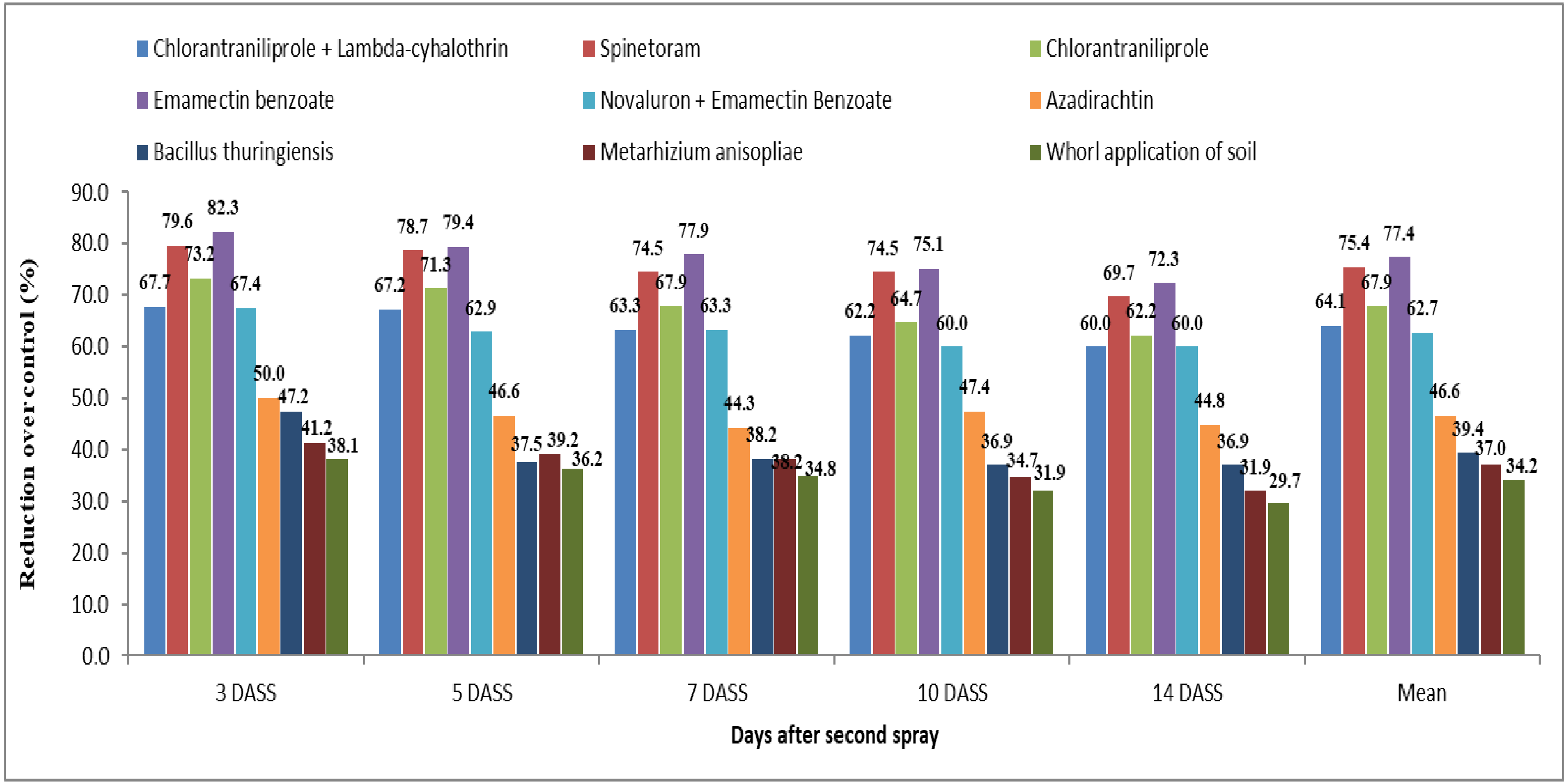

Fig. 4.10 Per cent reduction in plant infestation over control in second spray; DASS - Days after second spray

4.2.2 Grain yield and incremental input output ratio

The data on the grain yield in different treatments are given in the Fig. 4.11. Maximum yield was recorded in the plots treated with emamectin benzoate followed by spinetoram, chlorantraniliprole, chlorantraniliprole + lambda cyhalothrin, novaluron + emamectin benzoate, azadirachtin, *Bt*, *M. anisopliae* and whorl application of soil giving 43.89, 43.00. 41.67, 39.22, 38.39, 36.11, 34.44, 31.94 and 31.50 q ha^{-1}, respectively. However, yield obtained from plots treated with emamectin benzoate and spinetoram remained at par with each other. The lowest yield was recorded in control (30.56 q ha^{-1}).

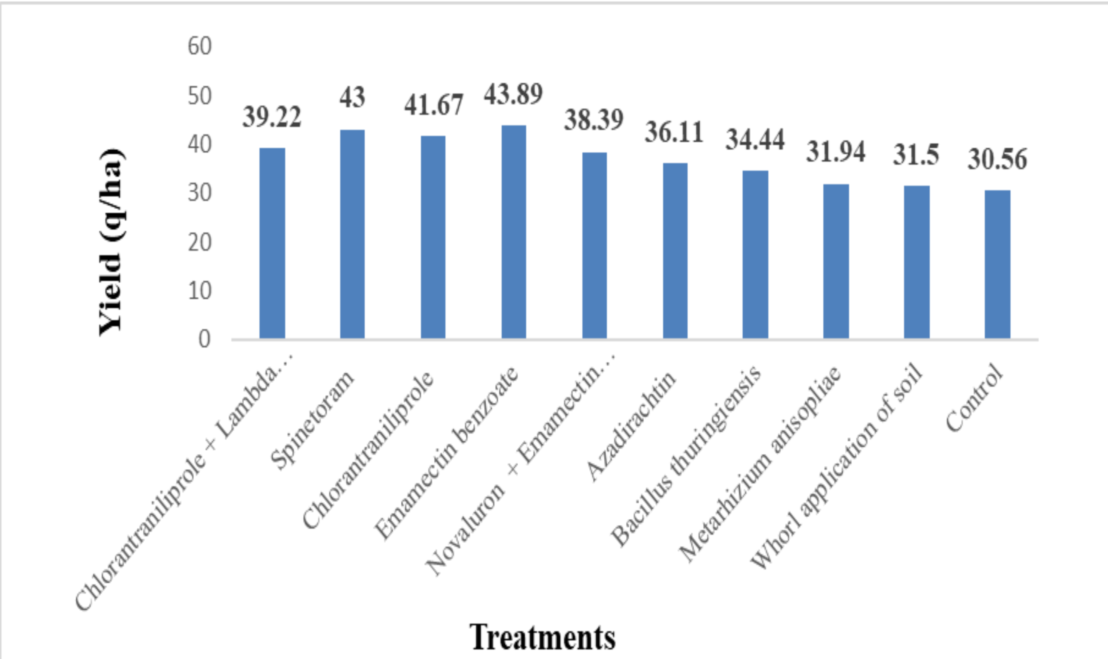

Fig 4.11 Grain yield in different treatments evaluated against *S. frugiperda*

Incremental output input ratio for various treatments presented in Table 4.11 revealed that the highest input output ratio corresponded to emamectin benzoate @ 10 g a.i. ha^{-1} (16.20), rendering it as the most cost-effective treatment. It was followed by *Bt* @ 1L ha^{-1} (16.10), *M. anisopliae* @ 2.5 kg ha^{-1} (13.58), azadirachtin @ 2.5L ha^{-1} (10.55), whorl application of soil (10.52), chlorantraniliprole + lambda cyhalothrin @ 35 g a.i. ha^{-1} (8.77), spinetoram @ 30 g a.i. ha^{-1} (7.31), chlorantraniliprole @ 40 g a.i. ha^{-1} (16.49) and novaluron + emamectin benzoate @ 92 g a.i. ha^{-1} (5.41).

The results are in close proximity to those of Bai et al. (2021), who revealed that emamectin benzoate gave maximium yield and incremental output input ratio of 22.57. The variation in the value of IOIR might be due to the difference in prevailing market price of produce. Deshmukh et al. (2020) also reported higher grain yield (6233 kg ha^{-1}) in case of chlorantraniliprole followed by emamectin benzoate (6180 kg ha^{-1}).

Table 4.11 Incremental output input ratio (IOIR) of different insecticidal treatments

Treatments	Market rate of insecticide (Rs)	Dose (g/ml/ha)	Cost of insecticide/spray (Rs/ha)	Yield (q//ha)	Increase in yield over control (q/ha)	Total cost/ha (Insecticide spray + labour cost) *	Value of additional grain yield (Rs)	IOIR
Chlorantraniliprole 9.3% + Lambda cyhalothrin 4.6% ZC	889/80ml	250	2778.13	39.22	8.67	8356.25	73341	8.77
Spinetoram 11.7% SC	320/20ml	256.4	4102.40	43.00	12.44	11004.80	80410	7.31
Chlorantraniliprole 18.5% SC	213/10ml	216.2	4605.06	41.67	11.11	12010.12	77917	6.49
Emamectin benzoate 5% SG	566/100g	200	1132.00	43.89	13.33	5064.00	82072	16.20
Novaluron 5.25% + Emamectin benzoate 0.9% SC	350/100ml	1495.9	5235.65	38.39	7.83	13271.30	71787	5.41
Azadirachtin 0.15% EC	360/500ml	2500	1800.00	36.11	5.56	6400.00	67528	10.55
Bacillus thuringiensis	600/ L	1000	600.00	34.44	3.89	4000.00	64411	16.10
Metarhizium anisopliae	320/ kg	2500	800.00	31.94	1.39	4400.00	59736	13.58
Whorl application of soil	-	-	0.00	31.50	0.94	5600.00	58905	10.52
Control	-	-	0.00	30.56	-	0.00	57139	-
CD (*P* =0.05)				2.8				

***Cost of two sprays + labour charges**
Labour cost- 350/ day (2 sprays @ 4 man days/ spray/ ha)
Price of maize grain- Rs 1870/q

5. SUMMARY AND CONCLUSIONS

The present investigations entitled “Management of fall armyworm, *Spodoptera frugiperda* (J.E. Smith) in maize" were undertaken at Department of Entomology, College of Agriculture, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur. Bioassay studies were undertaken in the Laboratory of Department of Entomology. The maize crop (var. Kanchan Gold) was raised at Research Farm of the department during *Kharif* 2022 for evaluation of insecticides and biopesticides against *S. frugiperda* under field conditions.

Intrinsic toxicity of different treatments *viz.*, chlorantraniliprole + lambda cyhalothrin, spinetoram, chlorantraniliprole, emamectin benzoate, novaluron + emamectin benzoate, azadirachtin, *Bacillus thuringiensis* and *Metarhizium aniospliae* was worked out against first instar larvae of *S. frugiperda*.

Based on LC_{50} values, the emamectin benzoate proved to be highly toxic to *S. frugiperda* with the least LC_{50} (0.052 ppm), followed by chlorantraniliprole (0.646ppm), spinetoram (0.930 ppm), novaluron + emamectin benzoate (1.418 ppm), chlorantraniliprole + lambda cyhalothrin (1.594 ppm), azadirachtin (2.217 ppm), *Bt* (3.5×10^7 cfu/g/L) and *M. anisopliae* (1.8×10^8 cfu/g/L).

The order of relative toxicity based on LC_{50} values in the descending order over chlorantraniliprole + lambda cyhalothrin was emamectin benzoate > chlorantraniliprole > spinetoram > novaluron + emamectin benzoate. Emamectin benzoate was found 30 times more toxic to the least toxic insecticide that was chlorantraniliprole + lambda cyhalothrin under laboratory conditions followed by chlorantraniliprole (2.467 times), spinetoram (1.713 times) and novaluron + emamectin benzoate (1.124 times).

Nine treatments *viz.*, chlorantraniliprole 9.3 % + lambda cyhalothrin 4.6 % ZC @ 35 g a.i ha^{-1}, spinetoram 11.7 % SC @ 30 g a.i ha^{-1}, chlorantraniliprole 18.5 % SC @ 40 g a.i ha^{-1}, emamectin benzoate 5 % SG @ 10 g a.i ha^{-1}, novaluron 5.25 % + emamectin benzoate 0.9 % @ 92 g a.i ha^{-1}, azadirachtin 0.15 % EC @ 2.5 L ha^{-1}, *Bacillus thuringiensis* @ 1 L ha^{-1}, *Metarhizium anisopliae* @ 2.5 kg $ha^{-1}$and whorl application of soil including control were evaluated under field conditions for their effectiveness against *S. frugiperda* in maize.

Among the tested insecticides, mean number of infested plants after 1st and 2nd spray indicated that emamectin benzoate was the most effective treatment with 1.93 and 2.80 infested plants followed by spinetoram (2.13 and 2.99) and chlorantraniliprole (2.67 and 4.40), whereas highest per cent reduction in plant infestation over control was recorded in emamectin benzoate with 77.96 and 77.39 per cent reduction during 1st and 2nd spray, respectively followed by spinetoram. Among biopesticides, azadirachtin proved moderately effective than *Bt* and *M. anisopliae*. However, whorl application of soil turned out to be the least effective treatment.

Similar trend was observed in the efficacy of these treatments in terms of yield. The highest yield was obtained from emamectin benzoate (43.89 q ha^{-1}) followed by spinetoram (43.00 q ha^{-1}), chlorantraniliprole (41.67 q ha^{-1}), chlorantraniliprole + lambda cyhalothrin (39.22 q ha^{-1}), novaluron + emamectin benzoate (38.39 q ha^{-1}), azadirachtin (36.11 q ha^{-1}), *Bt* (34.44 q ha^{-1}), *M. anisopliae* (31.94 q ha^{-1}) and minimum in whorl application of soil (31.50 q ha^{-1}). However, all the treatments gave significantly higher yield as compared to control (30.56 q ha^{-1}).

Incremental output input ratio for various treatments revealed that emamectin benzoate (16.20) was the most cost-effective treatment followed by *Bt* (16.10), *M. anisopliae* (13.58), azadirachtin (10.55), whorl application of soil (10.52), chlorantraniliprole + lambda cyhalothrin (8.77), spinetoram (7.31), chlorantraniliprole (6.49) and novaluron + emamectin benzoate (5.41).

From the present study, it can be concluded that Emamectin benzoate 5 SG proved to be highly effective against *S. frugiperda* under laboratory and field conditions and also resulted in the higher yield. Emamectin benzoate and *Bt* were the most economically viable treatments as they resulted in higher IOIR of 16.20 and 16.10, respectively. Hence both can be used alternatively for the management *of S. frugiperda* under field conditions. Further investigations, however, are needed to develop pest management modules for the sustainable management of fall armyworm.

LITERATURE CITED

Abbott WS. 1925. Method for computing the effectiveness of an insecticide. *Journal of Economic Entomology* 18: 265-267

Ahissou BR, Sawadogo WM, Bokonon-Ganta AH, Somda I, Kestemont MP and Verheggen FJ. 2021. Baseline toxicity data of different insecticides against the fall armyworm *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) and control failure likelihood. *African Entomology* 29(2): 435-444

Akutse KS, Kimemia JW, Ekesi S, Khamis FM, Ombura OL and Subramanian. 2019. Ovicidal effects of entomopathogenic fungal isolates on the invasive fall armyworm *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *Journal of Applied Entomology* 145(6): 626-634

Anonymous 2021a. Agricultural Statistics. Directorate of Economics and Statistics, Department of Agriculture, Cooperation and Farmers, Welfare, Ministry of Agriculture, Government of India, New Delhi p 44-48

Anonymous 2021b. Economic Survey, Economic and Statistics Department, Government of Himachal Pradesh p 74-80

Anonymous. 2018. *Package of Practices for Kharif Crops Of Himachal Pradesh*, CSK HPKV, Palampur p 20-29

Bai DG, Ramtj PS, Dhljrtja S and Suresh M. 2021. Field evaluation of insecticides against fall armyworm *Spodoptera frugiperda* (JE Smith) in sweet corn. *Indian Journal of Entomology* 83(2): 219-222

Bajracharya ASR, Bhat B and Sharma P. 2020. Field efficacy of selected insecticides against fall armyworm, *Spodoptera frugiperda* (JE Smith) in maize. *Journal of the Plant Protection Society* 6: 127-133

Barlow VM and Kuhar TP. 2009. Fall armyworm in vegetable crops. *Virginia Cooperative extension.* p 444-015

Bhardwaj GS, Mutkule DS, Thakre BA and Jadav AS. 2020. Bio-efficacy of different insecticides against fall armyworm, *Spodoptera frugiperda* (J.E. Smith) on maize. *Journal of Pharmacognosy and Phytochemistry* 9(5): 603-607

CABI (2019) *Spodoptera frugiperda* (fall armyworm) https://www.cabi.org/isc/datasheet/29810

Capalbo DMF, Valicente FH, Moraes IO and Pelizer LH. 2001. Solid-state fermentation of *Bacillus thuringiensis tolworthi* to control fall armyworm in maize. *Electronic Journal of Biotechnology* 4(2): 9-10

Dahal A, Dahal K, Koirala S and Wagle P. 2022. Effect of different insecticides against fall armyworm, *Spodoptera frugiperda* (J.E. Smith) in maize at Belaka municipality, Udayapur, Nepal. *Asian Journal of Research in Agriculture and Forestry* 8(1): 1-6

Deshmukh S, Pavithra HB, Kalleshwaraswamy CM, Shivanna BK, Maruthi MS and Mota-Sanchez D. 2020. Field efficacy of insecticides for management of invasive fall armyworm, *Spodoptera frugiperda (*J.E. Smith) (Lepidoptera: Noctuidae) on maize in India. *Florida Entomologist* 103(2): 221-227

Dhobi CB, Zala MB, Verma HS, Sisodiya DB, Thumar RK, Patel MB, Patel JK and Board PK. 2020. Evaluation of bio-pesticides against fall armyworm, *Spodoptera frugiperda* (J.E. Smith) in maize. *International Journal of Current Microbiology and Applied Sciences* 9(8): 1150-1160

Divya J, Kalleshwaraswamy CM, Deshmukh S, Ambarish S and Sunil C. 2021. Evaluation of whorl application of insecticides mixed with sand against fall armyworm *Spodoptera frugiperda* in maize. *Indian Journal of Entomology* 84(3): 617-621

Fernandes FO, Abreu JA, Christ LM and Rosa APSA. 2019. Efficacy of insecticides against *Spodoptera frugiperda* (Smith, 1797). *Journal of Agricultural Science* 11(1): 494-503

Finney DJ. 1971. Probit Analysis. Cambridge University Press, Cambridge, London 318 pp

Goergen G, Kumar PL, Sankung SB, Togola A and Tamo M. 2016. First report of outbreak of the fall armyworm *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae), a new alien invasive pest in West and Central Africa. *Plos One* 10:1371

Hardke JT, Jackson RE and Leonard BR 2014. Opportunities to manage fall armyworm (Lepidoptera: Noctuidae) on Bollgard IIVR cotton with reduced rates of insecticides. *Journal of Cotton Science* 18(1): 59-67

Hardke JT, Temple JH, Leonard BR and Jackson RE. 2011. Laboratory toxicity and field efficacy of selected insecticides against fall armyworm (Lepidoptera: Noctuidae). *Florida Entomologist* 94(2): 272-278

Herlinda S, Gustianingtyas M, Suwandi S, Suharjo R, Sari JMP and Lestari RP. 2021. Endophytic fungi confirmed as entomopathogens of the new invasive pest, the fall armyworm, *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae), infesting maize in South Sumatra, Indonesia. *Egyptian Journal of Biological Pest* Control 31(1): 1-13

Kumar KP, Vishnuvardhan KM, Kamakshi N, Murthy KD and Rao KM. 2021. Field efficacy of selected insecticides against invasive pest, fall armyworm *Spodoptera frugiperda* (J.E. Smith) on maize crop. *The Pharma Innovation Journal* 10(10): 884-889

Mallapur CP, Naik AK, Hagari S, Praveen T and Naik M. 2019. Laboratory and field evaluation of new insecticide molecules against fall armyworm, *Spodoptera frugiperda* (JE Smith) on maize. *Journal of Entomology and Zoology Studies* 7(5): 729-733

Martinez AM, Aguado-Pedraza AJ, Vinuela E, Rodriguez-Enriquez CL, Lobit P, Gomez B and Pineda S. 2017. Effects of ethanolic extracts of *Argemone ochroleuca* (Papaveraceae) on the food consumption and development of *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *Florida Entomologist* 100(2): 339-345

Mubeen N, Khalid A, Ullah MI, Altaf N, Arshad M, Amin L, Talat Q, Sadaf A and Farwa. 2022. Effect of *Metarhizium anisopliae* on the nutritional physiology of the fall armyworm, *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae). *Egyptian Journal of Biological Pest Control* 32(1): 1-5

Nabity PD, Zangerl AR, Berenbaum MR and Delucia EH. 2011. Bioenergy crops *Mis-canthus giganteus* and *Panicum virgatum* reduce growth and survivorship of *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *Journal of Economic Entomology* 104: 459-464

Nalin DM. 1991. Biology, quantitative nutrition and quality control of populations of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) on two artificial diets. Ph.D. Thesis, Submitted to School of Agriculture, Luiz de Queiroz, Piracicaba, Brazil

Nonci N, Pakki S and Muis A. 2021. Field testing of synthetic insecticides on fall armyworm (*Spodoptera frugiperda* JE Smith) in corn plant. *IOP Conference Series: Earth and Environmental Science* 911(1): 012059

Ompraksh S, Reddy SS, Reddy ML and Reddy RU. 2020. Evaluation of different modules for the management of fall armyworm, *Spodoptera frugiperda* in maize. *Journal of Pharmacognosy and Phytochemistry* 9(3): 1765-1767

Osae MY, Frimpong JO, Sintim JO, Offei BK Marri D and Ofori SEK. 2022. Evaluation of different rates of Ampligo insecticides against fall armyworm (*Spodoptera frugiperda*) (JE Smith); (Lepidoptera: Noctuidae) in the coastal Savannah agroecological zone of Ghanna. Advances in Agriculture 2022 https://doi.org/10.1155/2022/5059865

Patidar S, Das SB, Vishwakarma R, Kumari P, Mohanta S and Paradkar VK. 2022. Field evaluation of insecticides against fall armyworm infesting maize. *The Pharma Innovation Journal* 11(4): 892-895

Phambala K, Tembo Y, Kasambala T, Kabambe VH, Stevenson PC and Belmain SR. 2020. Bioactivity of common pesticidal plants on fall armyworm larvae (*Spodoptera frugiperda*). *Plants* 9(1): 112

Prasanna BM, Huesing JE, Eddy R and Peschke VM. 2018. Fall armyworm in Africa: A guide for integrated pest management, First Edition. Mexico, CDMX: CIMMYT

Ramanujam B, Poornesha B and Shylesha AN. 2020. Effect of entomopathogenic fungi against invasive pest *Spodoptera frugiperda* (JE Smith) (Lepidoptera:Noctuidae) in maize. *Egyptian Journal of Biological Pest Control* 30: 1-5

Ravikumar A, Basavaraj K and Kumar A. 2022. Evaluation of Cypermethrin 10%+Indoxacarb 10% SC against fall armyworm, *Spodoptera frugiperda* and stem borer in maize. *Journal of Experimental Zoology* 25: 259-265

Roel AR, Dourado DM, Matias R, Proto KRA, Bednaski AV and Costa RB. 2010. The effect of sub-lethal doses of *Azadirachta indica* (Meliaceae) oil on the midgut of *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *Revista Brasileira de Entomologia* 54(3): 505-510

Romero-Arenas O, Rivera A, Aragon A, Parraguirre C, Cabrera E and Lopez F. 2014. Mortality evaluation of armyworm (*Spodoptera frugiperda* J.E. Smith) by using *Metarhizium anisopliae* in vitro. *Journal of Pure and Applied Microbiology* 8(2): 59-67

Rose AH, Siversides RH and Lindquist OH. 1975. Migration flight by an aphid, *Rhopalospihum madis* (Hemiptera: Aphididae), and a noctuid, *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *The Canadian Entomologist* 107(6): 567-576

Salinas-Sanchez DO, Aldana-Llanos L, Valdes-Estrada ME, Gutierrez-Ochoa M, Valladares-Cisneros G and Rodriguez- Flores E. 2012. Insecticidal activity of *Tagetes erecta* extracts on *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *Florida Entomologist* 95(2): 428-432

Sangle SV, Jayewar NE and Kadam DR. 2020. Efficacy of insecticides on larval population of fall armyworm, *Spodoptera frugiperda* on maize. *Journal of Entomology and Zoology Studies* 8(6): 1831-1834

Shahzad MA, Irfan M, Wahab AA and Zafar F. 2021. Toxicity of entomopathogenic fungi against *Spodoptera frugiperda* larvae under laboratory conditions. *Journal of Agricultural Science and Food Technology* 7(3): 355-358

Sharanabasappa, Kalleshwaraswamy CM, Asokan R, Mahadeva Swamy HM, Maruthi MS, Pavithra HB, Hegde K, NaviS, Prabhu ST and Goergen G. 2018. First report of the fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae), an alien invasive pest on maize in India. *Pest Management in Horticulture Ecosystem* 24(1): 23-29

Shareef SM, Madhumathi T, Swathi M and Patibanda AK. 2022. Toxicity of some insecticides to the fall armyworm *Spodoptera frugiperda*. *Indian Journal of Entomology* 84(3): 680-682

Siazemo MK and Simfukwe. 2020. An evaluation of efficacy of botanicals pesticides for fall armyworm control in maize production. *Open Access Library Journal* 7(9): 1-12

Siddhartha K, Chinniah C and Shanthi M. 2019. In vitro bioassay of certain botanical oils for their efficacy against maize fall armyworm (J.E.Smith) *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *Journal of Entomology and Zoology Studies* 7(5): 606-609

Silva MS, Broglio SMF, Trindade RCP, Ferreira ES, Gomes IB and Micheletti LB. 2015. Toxicity and application of neem in fall armyworm. *Comunicata Scientiae* 6(3): 359-336

Sisay B, Tefera T, Wakgari M, Ayalew G and Mendesil E. 2019. The efficacy of selected synthetic insecticides and botanicals against fall armyworm, *Spodoptera frugiperda*, in maize. *Insects* 10(2): 45

Srikanth J, Geetha N, Singaravelu B, Ramasubramanian T, Mahesh P, Saravanan L, Salin KP, Chitra N and Muthukumar M. 2018. First report of occurrence of fall armyworm *Spodoptera frugiperda* in sugarcane from Tamil Nadu, India. *Journal of Sugarcane Research* 8(2): 195-202

Susanto A, Setiawati W, Udiarto BK and Kurniadie D. 2021.Toxicity and efficacy of selected insecticides for managing invasive fall armyworm, *Spodoptera frugiperda* (JE. Smith) (Lepidoptera: Noctuidae) on maize in Indonesia. *Research on Crops* 22(3): 652-665

Thumar RK, Zala MB, Varma HS, Dhobi CB, Patel BN, Patel MB and Board PK. 2020. Evaluation of insecticides against fall armyworm, *Spodoptera frugiperda* (J. E. Smith) infesting maize. *International Journal of Chemical Studies* 8(4): 100-104

Tulashie SK, Adjei F, Abraham J and Addo E. 2021. Potential of neem extracts as natural insecticides against fall armyworm *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae). *Case Studies in Chemical and Environmental Engineering* 4: 100130

Worku M and Ebabuye Y. 2019. Evaluation of efficacy of insecticides against the fall armyworm *Spodoptera frugiperda*. *Indian Journal of Entomology* 81(1): 13-15

APPENDICES

APPENDIX-I

Mean weekly weather data during *Kharif* season 2022

SW	Date (2022)	Temperature (^oC)		Relative humidity (%)	BSS (hr)	Rainfall (mm)
		Maximum	Minimum			
23	4-10 June	34.2	21.8	30.5	9.3	0
24	11-17 June	33.4	19.5	53.35	8.4	16.6
25	18-24 June	25.6	16	64.45	3.8	28
26	25-1July	29.1	20	77.15	3.6	110.8
27	2-8 July	28.4	19.6	82.05	3.4	109.2
28	9-15 July	27.8	19.8	88.55	3.5	157.4
29	16-22 July	28.2	20.4	87.05	2.3	22
30	23-29 July	26.1	19.7	91.15	1.6	226
31	30-5 August	26.9	19	90	3.6	219
32	6-12 August	27.6	19.8	84.55	2.9	161
33	13-19 August	27.3	19.5	86.75	3.3	243.4
34	20-26 August	26.1	18.6	86.8	4.4	237.6
35	27-2 September	27.6	19.3	86	6	51.8
36	3-9 September	26.7	17.8	85.35	5.1	73.6
37	10-16 September	26.7	17.4	85.15	4.2	74.4
38	17-23 September	26.3	17.1	82.8	5.3	12.2
39	24-30 September	25.1	15.3	83.15	4.9	83
40	1-7 October	27.3	15.3	76.75	8.5	8.8

APPENDIX-II

Per cent reduction in plant infestation over control in different treatment against *Spodoptera frugiperda*

Treatments	Dose (g ai/ha or L/kg/ha)	Per cent reduction in plant infestation over control											
		First spray						Second spray					
		3 DAFS	5 DAFS	7 DAFS	10 DAFS	14 DAFS	Mean	3 DASS	5 DASS	7 DASS	10 DASS	14 DASS	Mean
Chlorantraniliprole 4.6% + Lambda cyhalothrin 9.3% ZC	35 g	73.81 (59.47)	71.43 (58.23)	68.98 (56.31)	66.46 (54.70	64.55 (53.52)	69.05	67.68 (55.42)	67.24 (55.14)	63.25 (52.78)	62.18 (52.09)	59.96 (50.77)	64.06
Spinetoram 11.7% SC	30 g	84.13 (66.57)	80.95 (64.46)	73.15 (58.90)	69.80 (56.71)	71.21 (57.74)	75.85	79.55 (63.21)	78.74 (62.76)	74.52 (59.77)	74.53 (59.85)	69.74 (56.68)	75.53
Chlorantraniliprole 18.5% SC	40 g	73.02 (59.12)	71.43 (58.23)	72.69 (58.69)	73.13 (58.93)	67.88 (55.53)	71.63	73.23 (59.14)	71.33 (58.20)	67.86 (55.84)	64.74 (53.64)	62.18 (52.09)	67.87
Emamectin benzoate 5SG	10 g	84.92 (71.23)	80.95 (64.46)	76.85 (61.28)	76.16 (61.01)	70.91 (57.39)	77.96	82.32 (65.66)	79.39 (63.05)	77.86 (61.98)	75.09 (60.10)	72.31 (58.34)	77.39
Novaluron 5.25% + Emamectin benzoate 0.9% SC	92 g	73.02 (59.12)	71.43 (57.72)	65.28 (53.93)	66.09 (54.53)	60.91 (51.45)	67.35	67.42 (55.40)	62.89 (52.77)	63.25 (52.78)	59.96 (50.77)	59.96 (50.77)	62.69
Azadirachtin 0.15% EC	2.5 L	68.25 (56.23)	61.90 (51.99)	61.57 (51.75)	56.70 (48.88)	48.48 (44.15)	59.38	50.00 (45.02)	46.63 (43.09)	44.29 (41.73)	47.39 (43.52)	44.83 (42.05)	46.63
Bacillus thuringiensis	1 L	62.70 (52.50)	57.14 (49.13)	53.70 (47.15)	53.37 (46.96)	45.15 (42.23)	54.41	47.22 (43.42)	37.52 (37.77)	38.17 (38.12)	36.92 (37.37)	36.92 (37.37)	39.35
Metarhizium anisopliae	2.5 kg	46.83 (43.15)	42.86 (40.91)	46.30 (42.84)	46.63 (43.09)	41.82 (40.31)	44.89	41.16 (39.91)	39.23 (38.53)	38.17 (38.12)	34.70 (36.08)	31.92 (34.32)	37.04
Whorl application of soil	-	42.06 (40.41)	38.10 (38.05)	34.72 (36.11)	36.57 (37.21)	32.12 (34.52)	36.71	38.13 (38.14)	36.20 (36.76)	34.84 (35.91)	31.92 (34.32)	29.70 (33.00)	34.16
C.D (*P* =0.05)		(12.76)	(9.72)	(5.95)	(5.22)	(5.85)		(7.61)	(7.58)	(6.59)	(4.64)	(3.60)	

Figures in the parentheses are arc sine transformation values; DAFS= Days after first spray; DASS= Days after second spray

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10+2	2015	HP Board of school education, Dharamshala	81.8	First
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