

**“ECO-FRIENDLY MANAGEMENT OF FALL ARMYWORM,
Spodoptera frugiperda (J.E. SMITH) IN MAIZE”**

by

Mr. Pagire Kailas Sampat

(Reg. No. 2020/37)

A Thesis submitted to the
**MAHATMA PHULE KRISHI VIDYAPEETH,
RAHURI – 413 722, DIST. AHMEDNAGAR,
MAHARASHTRA, INDIA.**

in partial fulfillment of the requirements for the degree

of

DOCTOR OF PHILOSOPHY (AGRICULTURE)

in

ENTOMOLOGY



DEPARTMENT OF ENTOMOLOGY

**POST GRADUATE INSTITUTE
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2024

CANDIDATE'S DECLARATION

I hereby declare that this thesis or part
there of has not been submitted
by me or other person to any
other University or Institution
for a Degree or
Diploma

Place : MPKV, Rahuri

Date : / /2024

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CERTIFICATE

This is to certify that the thesis entitled, “**ECO-FRIENDLY MANAGEMENT OF FALL ARMYWORM, *Spodoptera frugiperda* (J.E.SMITH) IN MAIZE**” submitted to the Faculty of Agriculture, Mahatma Phule Krishi Vidyapeeth, Rahuri Dist. Ahmednagar (Maharashtra) in partial fulfillment of the requirements for the award of the degree of **DOCTOR OF PHILOSOPHY (AGRICULTURE) in ENTOMOLOGY**, embodies the results of a piece of *bona fide* research work carried out by **Mr. PAGIRE KAILAS SAMPAT**, under my guidance and supervision and that no part of the thesis has been submitted for any other degree or diploma.

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

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Place : MPKV, Rahuri

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LIST OF ABBREVIATIONS

%	: Per cent
/	: Per
@	: At the rate of
⁰ C	: Degree celsius
a. i.	: active ingredient
AICRP	: All India Coordinated Research Project
Avg.	: Average
<i>B. bassiana</i>	: <i>Beauveria bassiana</i>
<i>B. thuringiensis v. kurstaki</i>	: <i>Bacillus thuringiensis v. kurstaki</i>
<i>Bt</i>	: <i>Bacillus thuringiensis</i>
CD	: Critical difference
DAA	: Days after application
DAS	: Days after spray
DAT	: Days after treatment
EC	: Emulsifiable concentrate
EIL	: Economic injury level
EPF	: Entomopathogenic fungi
<i>et al.</i>	: Co-workers
ETL	: Economic threshold level
FAW	: Fall armyworm
Fig.	: Figure
g	: Gram
ha	: Hectare
ha ⁻¹	: Per hectare
Hrs	: Hours
i.e.,	: (that is)
ICBR	: Incremental Cost Benefit Ratio
IPM	: Integrated Pest Management
Kg	: Kilogram

l	: Liter
Ltd.	: Limited
M	: Meter
<i>M. anisopliae</i>	: <i>Metarhizium anisopliae</i>
<i>M.rileyi</i>	: <i>Metarhizium rileyi</i>
ml	: Milliliter
MS	: Maharashtra State
MSW	: Standard meteorological week
No.	: Number
NS	: Non significant
NSE	: Neem Seed Extract
Pvt. Ltd	: Private limited
q/ha	: quintal per hectare
RBD	: Randomized Block Design
RF	: Rainfall
RH	: Relative humidity
Rs	: Rupees
<i>S. frugiperda</i>	: <i>Spodoptera frugiperda</i>
<i>S. litura</i>	: <i>Spodoptera litura</i>
S.E.	: Standard Error
SC	: Soluble concentration
SG	: Soluble granules
Sig.	: Significant
Spp.	: Species
Sr. No.	: Serial Number
<i>T. chilonis</i>	: <i>Trichogramma chilonis</i>
Temp.	: Temperature
Tr. No.	: Treatment number
<i>viz.</i> ,	: Videlicet (Namely)
WP	: Wettable Powder

ABSTRACT

“ECO-FRIENDLY MANAGEMENT OF FALL ARMYWORM, *S. frugiperda* (J. E. SMITH) IN MAIZE”

by

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The present investigation was conducted at All India Coordinated Maize Improvement Project and eco-friendly laboratory, Department of Entomology MPKV, Rahuri, Maharashtra during *kharif* and *rabi* season 2020-21 and 2021-22. This experiment focused on eco-friendly management of fall armyworm, *S. frugiperda* infesting maize. Field experiments covered natural enemies, efficacy of biopesticides, evaluation of poison baits, farmer's practices and Integrated Pest Management.

Studies on natural enemy complex revealed that, during *kharif*-2021, highest parasitism (27.50 %) was recorded by egg parasitoid, *Telenomus remus*. This was followed by *M. rileyi* and *C. chloridae* with 14.33 and 10.31 per cent, respectively. Interaction studies between weeks and natural enemies revealed that the egg parasitoid, *Telenomus remus*, was proved significantly superior which recorded the highest parasitism (65.33 %) in the 36th SMW. Among the predators the highest population (0.38 adults/plant) was recorded by earwigs. This was followed by spiders (0.36 adults /plant). Among the weeks, 35th SMW recorded the highest population (0.55 adults/plant) of predators in maize fields. During *rabi* -2021, *C. chloridae* was the dominant species which recorded highest parasitism of 21.33 per cent. The highest parasitism of natural enemies (28.47 %) were recorded during the 48th SMW followed by 47th week (21.88 %). Further, *Telenomus remus* in the 48th SMW recorded highest parasitism (38.32 %) in interaction studies between weeks and natural enemies. Among the predators, highest

population (0.33 adults/plant) was recorded by earwigs. This was followed by spiders (0.28 adults/plant). The highest population of predators (0.50 adults/plant) of fall armyworm was recorded in 46th SMW. Eight different natural enemies were recorded in field survey and experiment study which includes two species of *Telenomus remus* Nixon and *Trichogramma* spp. as egg parasitoids, *Chelonus formosanus* as an egg/larval parasitoid, *C. chloridae* as a larval parasitoid, the fungal pathogen *M. rileyi* and three species of earwigs, spiders and coccinellids as predators.

B. thuringiensis 0.5 %WP was found most effective against larvae of *S. frugiperda* in which more than 82 per cent mortality of larvae was obtained at 8 DAT in the laboratory study. This was followed by *M. rileyi* 1.15 % WP and *M. anisopliae* 1.15 % WP recorded more than 75 per cent mortality of larvae.

Data obtained from the field experiment on efficacy of biopesticides revealed that standard check chlorantraniliprole 18.5 % SC was found most effective and significantly reduced plant damage, larval population and leaf damage score with 18.15 per cent, 0.86 larvae per plant and 2.60, respectively. Among the biopesticides *B. thuringiensis* 0.5 %WP was highly effective in reducing plant damage (28.78 %), larval population (1.03 larvae/plant) and leaf damage score (3.31) followed by *M. rileyi* 1.15 % WP and *M. anisopliae* 1.15 % WP. The highest grain yield (65.42q/ha) was registered in the plot treated with chlorantraniliprole 18.5 % SC. However, *B. thuringiensis* @ 2g/l was the most economical treatment by recording highest ICBR 1:4.45 followed by *M. rileyi* @ 5g/l with ICBR of 1:3.31.

The whorl application of poison baits revealed that application of bait GF -4867@ 0.1 % was proved most effective in reducing plant damage (17.40 %), larval population (0.83 larvae/plant) and leaf damage score (2.42) followed by bait of chlorantraniliprole 18.5 % SC. The highest grain yield (75.56 q/ha) was registered by GF-4867@ 0.1 per cent. Whereas, highest incremental cost benefit ratio (1:2.44) was observed in the bait of chlorantraniliprole 18.5 % SC @ 1.88 ml/kg.

It was observed from the experiment of evaluation of farmer's practices that chlorantraniliprole 18.5 % SC was proved significantly superior treatment followed by whorl application of neem seed powder. The highest yield (64.01 q/ha) was registered by chlorantraniliprole 18.5 % SC followed by neem seed powder with grain yield of 56.33 quintal per ha.

Studies on different IPM modules revealed that proposed IPM module (Major components as use of pheromones traps, intercropping with marigold, biopesticides like *B. thuringiensis* 0.5 % WP, *M. rileyi* 1.15% WP and whorl application of poison bait of chlorantraniliprole 18.5 % SC) was most effective in reducing plant damage and larval population in maize. The highest population of earwigs, spiders and coccinellids were recorded in proposed IPM module. It was also observed that the highest grain yield (73.90 q/ha) and monetary returns (1:1.63) were obtained by proposed IPM module followed by existing IPM module.

1. INTRODUCTION

Maize (*Zea mays* L.) is one of the most important cereal crops cultivated all over the world for both human and animal sustenance. It is known as the "Queen of Cereals" due to its great genetic yield potential. It is an important crop in the world agribusiness and is cultivated all over the world. Compared to wheat and rice, maize is a more versatile crop due to its variety of roles in industry but its main usage is for animal feed followed by human food. Thus, it is emerged out as a dynamic crop in global agri-food systems (Grote *et al.*, 2021). Asia is a classic example of a region where economic development particularly income growth and urbanization has accelerated the consumption of animal sourced meals and driven up the need for maize as feed (Erenstein, 2010). Worldwide, out of the total maize produced 17 per cent is used as food, 61 per cent of the crop is utilized as feed and 22 per cent as an industrial raw material (FAOSTAT, 2020).

More than 170 nations produced together almost 1147.7 million MT of maize on 193.7 million ha of land with an average productivity of 5.75 t/ha . Among the maize growing nations, India represents around 4 per cent of the world's total maize area and 2 per cent of its total production with fourth rank in terms of total area and seventh in terms of total production (Anon., 2020). In India, maize is grown in an area of 98.92 lakh ha and ranks third in production after rice and wheat with a production of 316.47 lakh tonnes having a productivity of 31.99 q / ha . In Maharashtra, the area grown under this crop is 11.26 lakh ha with an annual production of 19.60 lakh tonnes (Anon., 2021).

According to Wainaina *et al.* (2016), major constraints limiting the maize productivity are diseases and pests reported in the agriculture sector of sub-Saharan Africa. Stalk borers, cutworms and fall armyworm were the most common insect pests, whereas downy mildew, rust, leaf blight and maize streak virus are important diseases. Also, important abiotic constraints are identified viz., drought, excessive rains, hail storms and soil fertility. Further, John *et al.* (2019) stated that the major maize production constraints reported by farmers were observed due to the drought (97.2 %), *Striga* infestation (93.1 %), insect pests in the field (90.1 %) and in stores (72.7 %).

Insect and pest infestations are just one of the factors that contribute to a decrease in maize output which includes about 20–25 major insect pests (Singh and Jaglan, 2018). The invasive fall armyworm is a major pest in agriculture. FAW spread within the continents as well as in the Indian subcontinent in a very short duration which was possible for the pest due to its capacity to migrate long-distance, polyphagy, high fecundity and strong adaptability (Wan *et al.*, 2021). Being a pest with several feeding habits, it is well recognized to seriously harm economically significant cultivated crops and vegetables, including rice, sorghum, maize, cotton, soybean, sugarcane, peanuts, millets, onion, tomato, potato and cabbage. About 76 plant families were on the record of host status of this pest primarily the Poaceae (106 plants), Asteraceae (31 plants) and Fabaceae (31 plants) (Chormule *et al.*, 2019). Currently, it has spread to 47 African and 19 Asian countries resulting in cross-cutting negative impacts by affecting the resource of smallholders.

The FAW is a cosmopolitan pest of the maize crop (Wiseman *et al.*, 1966). It feeds on all growth stages of maize but most frequently in the whorl of young plants up to 45 days old. Fall armyworm larvae usually consume a large amount of foliage and sometimes destroy the growing point of the plant. The adult female lays the eggs in masses, randomly distributed within the crop. During the summer, egg hatch occurs in 3 days. The newly hatched larvae immediately start feeding on the tissues, usually beginning with tender portions. First instar larvae usually eat the green tissue from one side of the leaf, leaving the membranous epidermis on the other side intact. Older instars begin to make holes in the leaf and the fourth to sixth instars may completely destroy small plants and strip larger ones. Severe losses are found in the seedling stage which persists up to cob development. Yield reductions in maize due to feeding of the fall armyworm have been reported as high as 34 per cent (Davis and Williams, 1992).

Fall armyworm (FAW) *Spodoptera frugiperda* (J E Smith) (Lepidoptera: Noctuidae), invasive pest, a native to America was recently reported on maize in West Africa in 2016 (Goergen *et al.*, 2016). *S. frugiperda*, was recognized as a fall armyworm, an important lepidopteran pest in the USA which became important during the mid-19th century due to its infestation in maize, sugarcane, rice and grasses in the southern USA

(Hinds and Dew, 1915). On the report of USAID (2018), in Asia, Yemen was the first country where FAW was detected in April 2018. Whereas, in India, it was reported first time at Shivamogga in the state of Karnataka (Sharanbasappa *et al.*, 2018) in May 2018 and at the end of July it was found in several neighbouring states. Further, it was detected in several states to the north of Karnataka by the following month while in the month of October, it was reported from states in the north-west, north-east and Kerala (Firake and Behere, 2020a, Firake *et al.*, 2019 and Rakshit *et al.*, 2019). FAW was found in nearly all maize-growing regions of India along with the hilly areas bordering Pakistan and Tibet in 2020 (Sharma, 2021). In Maharashtra, it was reported in the month of September 2018 at Tandulwadi village, Taluka Karmala, District Solapur (Chormule *et al.*, 2019).

According to Day *et al.* (2017), fall armyworm reported to cause an annual loss of 8.3 - 20.6 million tonnes per annum (21–53 % of production) of maize in just 12 of Africa's maize growing countries which is enough to feed 40 -100 million people and is worth US \$ 2.5–6.2 billion in the absence of any management measures (FAO, 2020). Similarly, Eschen *et al.* (2021) stated that the estimated overall annual cost of FAW to agriculture in Africa which amounts to US \$ 9.4 billion. Estimated maize yield losses due to FAW in the Rangareddy area of Telangana state in India were 33 per cent (Balla *et al.*, 2019).

Many farmers used the different pesticides to control fall armyworm which disturbs the ecosystem by contamination of harmful insecticide and killing non-target organisms (Kumela *et al.*, 2019). The early larval instars scrap the epidermis while the third instar onwards, larvae feeds in the leaf whorl under protected conditions and this protected feeding has reduced the efficacy of contact insecticides as well as a newer group of insecticides (Goerge *et al.*, 2016; Sisay *et al.*, 2019b).

In the recent past, reports showed that *S. frugiperda* has already developed a resistance to the newer group of insecticides such as spinosyn (Lira *et al.*, 2020) and pyrethroids, organophosphates and carbamates (Mota and Wise, 2017). In India, transgenic cotton was widely adopted which has reflected a significant reduction in insecticides consumption in the cotton ecosystem but *S. frugiperda* has registered

resistance against the transgenic Cry1F and Cry1Ab *Bt* maize in field circumstances (Omoto *et al.*, 2016 and Huang *et al.*, 2014).

Insecticides are nowadays an integral part of the management of pest menace. The scan of the literature indicated that more emphasis has been given to insecticidal control of FAW by using synthetic insecticides and chemical use have its own limitations on its overuse like residues in silage and grains, pest resurgence and resistance in insects to insecticides. Furthermore, the high fecundity and dispersion potential, great physiological and behavioral adaptability of fall armyworm leads to rapid emergence of pesticide resistance in population exposed to insecticides which make the management of fall armyworm difficult with current chemical control measures (Paredes *et al.*, 2021).

As of today, there is no any label claim chemical insecticide in fodder maize by CIB & RC considering pesticide residual issues. It has created a thrust to develop more effective and environment-friendly alternative control methods (FAO, 2019). The use of eco-friendly management practices for protecting crops from pest infestation may lead to reduce the concerned threats of chemical control.

Therefore, the identification and use of potential beneficial organisms acting as NEs (Natural enemies) viz., parasitoids, predators, fungi, viruses, bacteria and nematodes have a very crucial role in biological control (Cruz *et al.*, 2002). Also, environment friendly microbial insecticides have also been successful in controlling lepidopteran larvae and it includes the bacteria *Bacillus thuringiensis var. kurstaki* and *B. thuringiensis var. aizawai*, the fungi *Metarhizium anisopliae* (Metsch.) and *Beauveria bassiana* (Bassi.), the nematodes *H. indica*, *S. carpocapsae* and various nucleopolyhedroviruses (Barrera *et al.*, 2017 and Bateman *et al.*, 2018).

Similarly, use of poison bait is another option to control FAW and it reduces the overall amount of active ingredients needed and therefore, reduces the amount of insecticide load present in the environment (Johnson and Henry, 1987). As reported by Hruska and Gould (1997) when 55 to 100 per cent of the plants were damaged by *S. frugiperda* during the mid to late maize stage it affected yield losses of 15 to 73 per cent. It is necessary to use an alternative strategy to reduce the occurrence of the pest because it remains inside the leaf whorl and it is challenging to control by direct

spraying. Consequently, poison baits are one of the efficient and specific methods of controlling the FAW.

In addition to the eco-friendly management of FAW, many smallholder farmers use locally accessible materials such as soil, sand, wood ash, lime, oils and soaps as well as local botanical extracts. Farmers also assert that adding soil, sand, lime, wood ash and other materials to the whorl of maize lowers FAW infestation and damage. While soil may prevent the pest from accessing the plant or also negatively affect the larvae by abrasion and ash may obstruct the spiracles of target insects, causing asphyxiation and death (Wyckhuys and O'Neil, 2007).

However, after going through the literature, it was noticed that very little work has been done on the study of eco-friendly approaches for the management of fall armyworm. Therefore, there is a need to develop a sustainable, cost-effective management strategy through the identification of eco-friendly and locally available alternative tools for pest control.

In the present investigation, major emphasis was given on the formulation of eco-friendly tools for the effective management of *S. frugiperda* in maize. Hence, the present study was planned with the following objectives:

1. To study the natural enemy complex of *S. frugiperda* infesting maize.
2. To evaluate the efficacy of biopesticides against *S. frugiperda*.
3. To evaluate the efficacy and economics of the poison baits against *S. frugiperda* in maize.
4. To validate different fall armyworm management practices adopted by the farmers.
5. To evaluate different IPM strategies against fall armyworm, *S. frugiperda* in maize.

2. REVIEW OF LITERATURE

Studies were conducted on the eco-friendly management of fall armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith, 1797) and its associated natural enemies, evaluation of different biopesticides, poison baits, farmers practice and integrated pest management of FAW in maize are reviewed briefly under this chapter.

2.1 Natural enemy complex of *S. frugiperda* infesting maize

According to Reis *et al.* (1988) fall armyworm mostly reside inside the whorl of maize where predatory earwig, *Doru luteipes* (Scudder) occurs throughout the life span of maize whose nymphs feed 8-12 larva daily and adult consumes 10- 21 larva daily.

Capinera (2000) stated that ants, wasps and spiders were most important predators of FAW eggs, larvae or pupa. Similarly, vertebrate predator like birds, skunks and rodents around the maize field was also beneficial as they feed larva as well as pupae of fall armyworm.

Fritzsche and Turlings (2001) reported that the *Campoletis sonorensis* (Cameron) and *Campoletis marginiventris* (Cresson) accounted for at least 85 per cent of the observed parasitism. These solitary parasitoids were very similar in biology and a precise estimate was obtained for the maize fitness benefit posed by *C. marginiventris*.

Figueiredo *et al.* (2002) conducted an experiment on the effect of *Telenomus remus* Nixon density on the control of *S. frugiperda* egg masses upon release in a maize field. It revealed that the highest parasitism values 74 and 88.3 per cent were recorded in plots where 9 and 12 females of *T. remus* /m² were released. It was also concluded that the average *T. remus* parasitism on the egg mass was much higher, representing 80.4 per cent, while the parasitism was only 21.3 per cent in the case of *Trichogramma* spp.

Molina *et al.* (2003) recorded 3.5 per cent FAW larval mortality in Mexico due to naturally occurring entomopathogens and parasitic nematodes. The authors recovered three species of entomopathogenic fungi representing two different classes, Hyphomycetes (*Nomuraea rileyi* Farlow and *Hirsutella* sp.) and Zygomycetes (*Entomophthora* sp.) from FAW larvae and additional two species of Hyphomycetes (*M. anisopliae* and *B. bassiana*) from soil samples.

Hoballah *et al.* (2004) found ten species of parasitoids emerged from the collected larvae and eight species of predators that are known to feed on larvae and eggs were observed on the plants. Among the parasitoids, *Campoletis sonorensis* (Cameron) and *Cotesia marginiventris* (Cresson) were recorded parasitism rate of 34.8 and 6.2 per cent, respectively. Among the predators the most common predators were the true bugs *Castolus* sp., *Podisus sagittal* (Fabricius), *Zelus longipes* (Linnaeus) and an unidentified Reduviidae, which all predominantly attack larger *S. frugiperda* larvae while, the coccinellid *Coleomegilla* sp., an unidentified Chrysopidae, a forficulid *Doru* sp. and the bug *Orius* sp. which attack newly emerged larvae.

Kris and Robert (2006) reported that the braconid *Aleiodes laphygmae* (Viereck) and the ichneumonid *Campoletis sonorensis* (Cameron) were the most often seen parasitoids, accounting 1 to 11 per cent of parasitism of *S. frugiperda*. The earwig *Doru taeniatum* (Dorhn) was the most prevalent predator with the maximum density of 2.3 individuals per plant. The ant community was dominated by the fire ant *Solenopsis geminate* (Fabricius). High abundance of spiders were also recorded throughout the early phases of maize development. However, research revealed that social wasps, fire ants, earwigs, ground beetles, spiders and *Solenopsis geminata* (F.) were involved in the control of fall armyworm populations.

Sueldo *et al.* (2008) studied that *Doru lineare* female may be able to consume almost half the offspring of a single egg cluster. It was also reported that at the lowest prey density (1 larva /plant), 66.6 per cent of *D. lineare* individuals failed to attack the prey; although facing up to 10 larvae/plant and earwigs ate at least 2 of them.

Carneiro and Fernandes (2012) conducted an experiment on interspecific interaction between *Telenomus remus* and *Trichogramma pretiosum* on *S. frugiperda* eggs. It was found that when the *T. remus* and *T. pretiosum* females were placed together with *S. frugiperda* eggs, *T. remus* had a greater parasitism rate except for searching time, all *T. pretiosum* behaviors took a longer time than *T. remus* behaviors.

Gutierrez *et al.* (2012) studied the per centage of parasitism by *T. remus* Nixon on *S. frugiperda* eggs in maize-bean, maize-squash and maize-bean-squash polyculture and maize monoculture systems. Highly significant differences were recorded in the per centage of parasitism of *S. frugiperda* eggs by *T. remus* in plots with *Jarocho*

crema (Frierson) maize in polyculture systems (91.00 ± 1.42 %) compared to the yellow maize genotype (68.90 ± 3.10 %).

Virgin *et al.* (2013) reported six parasitoid species of *S. frugiperda* in maize with parasitism rate such as *Cotesia* sp. (0.3 %) and *Chelonus insularis* (Cresson) (3.9 %), *Pristomerus spinator* (Fabricius) (1.1 %), *Campoletis* sp. (0.3 %) and *Hyposoter* sp. (0.1 %) and one tachinid fly *Archytas marmoratus* (Townsend) (0.07 %). Also, two entomopathogenic fungi were isolated *viz.*, *B. bassiana* (3.7 %) and *N. rileyi* (8.9 %) and one nucleopolyhedrosisvirus (11 %) *SfMNPV* (Baculoviridae). A total per centage of parasitism 29.7 per cent was recorded.

Xinzhi *et al.* (2014) conducted the survey and reported a total 10 species of predators were recorded. Among that five lady beetles *viz.*, convergent lady beetle, *Hippodamia convergens* (Guerin), pink-spotted lady beetle, *Coleomegilla maculate* (DeGeer), multicolored Asian lady beetle, *Harmonia* sp., seven spotted lady beetle, *Coccinella septempunctata* (Linnaeus) and dusky lady beetle, *Scymnus* spp were recorded. Three of Hemipteran predators were recorded in the experimental plots *viz.*, insidious flower bugs, *Orius* spp., big-eyed bugs, *Geocoris* spp. and the damsel bugs, *Nabis* spp. In addition, the hooded beetle, *Notoxus* spp., earwigs and spiders were recorded.

Bahena and Cortez (2015) stated that the most frequently cited parasitoid of FAW throughout its native range was the egg-larval parasitoid *Chelonus insularis* (Cresson). While pupal parasitism has been poorly studied due to the difficulty in collecting large numbers of pupae. *Diapetimorpha introita* (Cresson) was reported as the most abundant pupal parasitoid in Mexico (Molina *et al.*, 2003). Also in Kenya and Tanzania, Sisay *et al.* (2019a) recorded egg parasitism rates by *T. remus* above 50 per cent.

Magali *et al.* (2015) surveyed the maize fields in Mexico and found parasitoids *viz.*, *Chelonus insularis* Cresson and *Meteorus arizonensis* Muesebeck, *Campoletis sonorensis* Cameron, *Campoletis flavicineta* Ashmead, *Pristomerus* sp., *Euplectrus platyhypenae* Howard and *Lespesia* sp. and *Archytas marmoratus* Townsend. The incidence of parasitism by parasitoids was 8.1 per cent and parasitoids emerged from 5.8 per cent of the larvae. The *Meteorus arizonensis* and *C. flavicineta* were the most

commonly encountered parasitoids, affecting 3 and 1.3 per cent of the total collected larvae, respectively. Also, 2 species of entomopathogenic fungi were found *viz.*, *M. rileyi* (Farlow) and *B. bassiana* (Balsamo) with infection of 8.6 and 0.65 per cent, respectively. Forty-nine nucleopolyhedrosisvirus isolates were obtained, corresponding to an incidence of 0.8 per cent. Further, 34 specimens of the predator *Podisus maculiventris* were found during the surveys.

Maria *et al.* (2015) tested the application of one, two and three releases of *T. pretiosum*. The observation were recorded on plant damage ratings, egg masses parasitized and grain yield. The Result showed that 79.2 per cent of egg masses were parasitized. Maize yields for parasited plots increased of 7.01 q/ha versus control plots.

Varella *et al.* (2015) and Jaraleno *et al.* (2020) reported that *T. pretiosum* Riley and *T. atopovirilia* Oatman & Platner (Trichogrammatidae) regularly found parasitizing FAW egg masses, but natural parasitism remained below 5 per cent. This was partly ascribed to the difficulty to parasitize eggs in the lower layers of egg masses or egg masses covered by a high number of scales and hair (Beserra and Parra, 2005 and Goulart *et al.*, 2011).

Hay *et al.* (2016) recorded more abundant parasitoid species in the corn field of Florida included *Aleiodes laphygmae*, *Meteorus autographae*, *Cotesia* sp., *Euplectrus platyhypenae* and *Ophion flavidus*. Among this, the endoparasitoids *Cotesia* sp. and *Meteorus* sp. were recovered more often in the main corn crop. It was observed that strong seasonality of the predator *Doru* in September-October, wherein eggs and small larvae were predated by this species. *Doru* were found in soil, whorls and leaves; the environmental conditions were favorable for this species. Other predator species included various spider species and Chilopoda all of which were recovered from the PVC traps.

Robert *et al.* (2016) surveyed the fields from South Florida counties and fall armyworm larvae were collected from sweet corn plants (*Zea mays* L) from 2010 to 2015 during the fall and spring seasons. It was identified the common parasitoids emerging from larvae *viz.*, the solitary endoparasitoids *Cotesia marginiventris* (Cresson) and *Chelonus insularis* Cresson whereas parasitism ranged from 1 to 91.7 per cent. Further, parasitoid species that emerged from fall armyworm larvae were *Aleiodes*

laphygmae (Viereck), *Euplectrus platyhypende* Howard, *Meteorus* spp. and *Ophion flavidus* Brulle.

Amadou *et al.* (2018) conducted survey on FAW natural enemies in 2017 and 2018 in maize and sorghum fields in Niger and revealed the occurrence of three egg parasitoids (*Trichogramma* sp., *Trichogrammatoidea* sp. and *Telenomus* sp.), one egg-larval (*Chelonus* sp.) and four larval parasitoids (*Cotesia* sp. *Charops* sp., unidentified ichneumonid and tachinid fly). Among these parasitoids, egg parasitoid *Telenomus* sp. parasitized 34 and 25 per cent of eggs in 2017 and 2018, respectively.

Mallapur *et al.* (2018) studied entomopathogenic fungi *Nomuraea rileyi* was naturally occurring on *S. frugiperda* and its infection ranged between 1.87 and 18.30 per cent in Vijaypur and Dharwad, respectively. Further, three large-scale field evaluation studies conducted on this pathogen against the fall armyworm in maize revealed that 58.91 to 62.87, 62.50 to 66.46, 66.84 to 73.05 per cent reduction of pest infestation, larval and leaf injury, respectively. This is the first report from India with respect to the efficacy of *N. rileyi* against *S. frugiperda* under field conditions.

Miguel *et al.* (2018) surveyed the 190 fields of maize in Northern Sinaloa, Mexico during 2016 and 2017 and showed the average per centages of parasitized *S. frugiperda* larvae in maize fields were 7.0 and 9.3 per cent, respectively. The most common parasitoids were *Meteorus laphygmae* Viereck, *Chelonus insularis* Cresson and *Cotesia marginiventris* Cresson with 9.5 per cent of total parasitism. Idiopathic mortality (2.6 %) was determined throughout the study, but no entomopathogens were found in any larva collected.

Mora and Blanco (2018) tested on efficacy of botanical insecticides and found that the best insecticide to control the immature fall armyworm is Solaris 6 % SC, followed by the insecticide made of garlic extract, neem and detergent. Also, the natural parasitism of the FAW on the area not treated with pesticides reached values of 60 per cent where the *Chelonus* sp. was the parasitoid that was present at all times.

Shylesha *et al.* (2018) reported the natural enemy complex of *S. frugiperda* for the first time from India and studied natural parasitism by egg parasitoids viz., *Telenomus* sp. and *Trichogramma* sp., gregarious larval parasitoid *Glyptapanteles creatonoti* (Viereck) and solitary larval parasitoid *C. chlorideae* Uchida. *S. frugiperda*

was the first host record for *G. creatonoti* across the globe. *G. creatonoti* was well established parasitoid of various noctuids in India and Malaysia; capable of parasitizing *S. frugiperda*. Besides these, other commonly found bioagents viz., *Forficula* sp. and entomopathogenic fungus *N. rileyi* (Farlow) Samson was also collected in large numbers.

Hruska (2019) stated that predatory ants are known to contribute to the biological control of FAW. Similarly, in maize-based cropping systems in Honduras highlands, ants especially *Solenopsis geminata*, *Brachymyrmex* spp., *Camponotus* spp., *Crematogaster* spp. and *Pheidole* spp. were closely associated with FAW (Wyckhuys and O'Neil, 2006). In Benin, Dassou *et al.* (2021) found seven ant species in fields infested by FAW and all preyed on FAW larvae in the laboratory.

Kenis *et al.* (2019) surveyed in South, West and East Africa for the parasitoids of FAW. The parasitized egg masses of *S. frugiperda* were collected and the emerged parasitoids were identified through morphological observations as *T. remus*. It was reported that *T. remus*, was the main egg parasitoid of *S. frugiperda*.

Liao *et al.* (2019) conducted a survey for the detection of egg parasitoids and revealed that *T. remus* parasitized *S. frugiperda* eggs in corn fields in southern China and the parasitism rate was 30 per cent of egg masses from the total number of egg masses and 50 per cent of eggs per egg mass.

Navik *et al.* (2019) identified different species of Trichogramma viz., *T. chilonis*, *T. achaede*, *Trichogrammatoidea bactrae* and *Trichogrammatoidea armigera* from the eggs of different Lepidopteran pests infesting the diverse cropping systems in India and evidenced that in nature, the parasitism rate varied from 5.35 to 82.25 per cent. The per cent adult parasitoid emergence from the sentinel trap cards ranged from 70.59 to 100.00 per cent. The natural parasitism of *Trichogramma* sp, on the eggs of *S. frugiperda* infesting maize was recorded to be 25.64 per cent in Karnataka.

Sharanabasappa *et al.* (2019) reported 5 larval parasitoids, 3 predators and one entomopathogenic fungus from different maize-growing areas of Karnataka and Tamil Nadu. They recorded 2 to 4 per cent parasitism by *C. chlorideae*, *Coccinella transversalis* (0.5–1.00 per plant) and *N. rileyi* (10 -15 % infection)

Sisay *et al.* (2019a) conducted survey in 2018 to determine the distribution of natural enemies of *S. frugiperda* in different African countries and revealed that in

Kenya, *T. remus* was the dominant egg parasitoid and accounted for 69.3 per cent of egg parasitism, followed by *T. chilonis*, which accounted for 20.9 per cent of egg parasitism, whereas *Chelonus curvimaculatus* caused low levels of egg parasitism (4 %). *Cotesia icipe* was the main larval parasitoid which caused 42 per cent parasitism while *Cotesia ater* caused minimum parasitism (2 %).

Agboyi *et al.* (2020) recorded ten species of parasitoids including two egg parasitoids, one egg-larval, five larval and two larval-pupal parasitoids in two western African countries, Ghana and Benin. The two Braconids the egg-larval parasitoid *Chelonus bifoveolatus* and the larval parasitoid *Coccygidum luteum* were the most abundant parasitoids in both countries and average parasitism rates varied from 0 to 75 and 5 to 38 per cent, respectively. It was observed that egg parasitoid *T. remus* Nixon preferred over *Trichogramma* spp. in biocontrol programs in the Americas due to its capability of parasitizing the inner layers of egg masses. The field parasitism by *T. remus* was ranged from 14.5 to 25.9 per cent attack on egg masses of FAW.

Firake and Behere (2020a) showed that the entomopathogenic fungus, *Metarhizium rileyi* (Farlow) Samson and the baculovirus, *Spf*-NPV were observed to be dominant mortality factors throughout the season, responsible for > 50 per cent mortality of FAW larvae. In northeast India, 57 to 73 per cent FAW larval mortality was reported due to natural enemies in maize fields. It was observed that 12 predators were found feeding on FAW eggs and larvae, including predatory bugs, earwigs, spiders, paper wasps and a tiger beetle. The most important predator was pentatomid bug, *Eocanthecona furcellata* Wolf. Various species of ladybird beetles were also found foraging on infested plants.

In ginger fields in Meghalaya state, Firake & Behere (2020b) recorded 74 per cent larval mortality which was mainly due to the egg-larval parasitoid *Chelonus formosanus* Sonan (5 %), mermithid nematodes (10 %), *M. rileyi* (38.01 %) and *SfMNPV* (21 %).

Keerthi *et al.* (2020) recovered parasitoids from the field collected larvae viz., *Aleiodes* sp., gregarious larval parasitoid *Cotesia ruficrus* Haliday, solitary larval parasitoid *Campoletis chlorideae* Uchida and predator *Eocanthecona furcellata* (Wolff).

Koffi *et al.* (2020) conducted the survey of different localities of the 10 regions of Ghana and recorded 18 species of natural enemies in maize field. Among natural enemies recorded, 7 species were parasitoids: *Chelonus bifoveolatus* (Szpligeti), *Coccygidium luteum* (Brull), *Cotesia icipe* (Fernandez), *Meteoridea testacea* (Granger), *Bracon* sp., *Anatrichus erinaceus* Loew and an undetermined tachinid fly whereas, the parasitism rate was 3.58 per cent. Three predator species were collected: *Pheidole megacephala* (Fischer), *Haematochares obscuripennis* (Stal) and *Peprius nodulipes* (Signoret). The two most abundant parasitoids were *C. bifoveolatus* and *C. luteum* with a relative abundance of 29.0 and 23.7 per cent, respectively and a parasitism rate of 1.04 and 0.85 per cent, respectively. However, parasitoids *C. bifoveolatus* and predator *P. megacephala* were the most dispersed in 6.6 and 3.8 per cent, respectively at the inspected sites.

Mwanjia and Maulid (2020) showed that one species of egg larva parasitoids *Chelonus bifoveolatus* and two species of larval parasitoid *Coccygidium luteum* and *Cotesia* sp. were recovered from the sampled fall armyworm eggs and larvae. The per centage of parasitism of *C. bifoveolatus* and *C. luteum* differed significantly among intercropping systems.

Sharma and Sharma (2020) revealed the occurrence of the fall armyworm *S. frugiperda* (J E Smith) for the first time in Himachal Pradesh. Natural enemies like coccinellids, syrphids and lacewings were observed in maize field.

Tang *et al.* (2020) reported that parasitism rates by *T. remus* were significant, with 28.9 per cent of the egg masses parasitized in Hainan province, China. In Hainan, parasitism by the egg-larval parasitoid *C. formosanus*, the larval parasitoid *Microplitis pallidipes* Szepilgeti and the pupal parasitoid *Tetrastichus howardi* Olliff was 12, 7 and 4 per cent, respectively. Whereas, Huo *et al.* (2019) reported that parasitism rate of 30.6 per cent by *T. remus* in Guangdong Province, China.

Abang *et al.* (2021) showed that *T. remus*, *T. chilonis*, *Cotesia icipe* and *Charops* sp. were obtained from both *S. frugiperda* and *S. eridania* whereas, *Cotesia luteum* and *Cotesia sesamiae* from *S. frugiperda*. In the laboratory, *T. remus* showed significantly higher parasitism and shorter development time on egg of *S. frugiperda* than *S. eridania*.

Anandhi and Saminathan (2021) identified four parasitoids on *S. frugiperda* namely *Peribeae* sp, *Euplectrus* sp. nr. *xanthocephalus*, *Temelucha* sp. and *Microplitis demolitor* Wilkinson first time in Tamil Nadu. Two spider species discovered were Jumping spider (Salticidae: Araneae) and striped lynx spider *Oxyopus javanus* (Oxyopidae: Araneae).

Navik *et al.* (2021) found five parasitoids parasitizing the egg, egg-larval, larval and larval-pupal stages of *S. frugiperda* in ten districts of Karnataka. *Trichogramma chilonis* Ishii and *Telenomus remus* Nixon egg parasitism rates were 15.81 - 23.87 and 5.44 - 8.78 per cent, respectively. The larval parasitoids caused 9.18 per cent parasitism of *S. frugiperda* larvae. *T. chilonis* was appeared as a major natural enemy.

Nurkomar *et al.* (2021) found that the predatory insects *Coccinella transversalis*, *Forficula* sp. and *Harmonia octomaculata*. Furthermore, the parasitoid insect found were the *Tachinidae* sp. fly which was only found in one of all samples of *S. frugiperda* larvae. *Archyta marmoratus* was reported as larval parasitoid of *S. frugiperda* larvae.

Otim *et al.* (2021) identified 13 parasitoid species belonging to three families of Hymenoptera: Platygastridae, Braconidae and Ichneumonidae, as well as one Dipteran family (Tachinidae). Among them, the *Coccygidium* spp. and *Chelonus bifoveolatus* were the most abundant and widely distributed parasitoids. Overall, parasitism ranged from 3.1 to 50, 0.8 to 33 per cent in 2017 and 2019, respectively. Parasitism by *Sturmiopsis parasitica*, *Diolcogaster* sp. and *Cotesia flavipes* on FAW in maize crops were reported for the first time.

Tawakkal *et al.* (2021) conducted an extensive survey of parasitoids in Java, Indonesia where FAW egg parasitism was dominated by *Telenomus* sp. and larval parasitism by *Microplitis* sp.

Youssef (2021) conducted on field survey and recorded five parasitoids to of *S. frugiperda* in Egypt at Sohag and Qena governorates. Three of the Hymenopteran parasitoids *Dinarmus basalis* (Rondani), *Cotesia ruficrus* (Haliday) and *Chelonus intermedius* (Thomson) were observed from the samples of FAW. While the fourth was

Microplitis rufiventris (Kokujev) and last the Dipteran parasitoid *Exorista larvarum* (Linnaeus).

Dorji *et al.* (2022) identified 48 natural enemy species associated with the fall armyworm infested maize fields in Bhutan. Parasitism was noted for *Chelonus formosanus*, *Trichogramma* sp., *Winthemia trinitatis*, *Linnaemya* sp. and *Campoletis sonorensis* while predation was observed by *Polistes olivaceus*, *Stenodynerus smilibaroonii*, *Tetraponera allaborans*, *Cremato-gaster rogenhoferi* and *Dolichoderus thoracicus* on the fall armyworm.

Mallapur *et al.* (2022) studied the various natural enemies of fall armyworm on maize in Northern Karnataka. Wherein among insect natural enemies, pupae of *C. chloridae* (2-11 pupae / 20 pls) were more in numbers followed by earwigs (1-8 / 20 pls), spiders (1-7 / 20 pls), coccinellids (1-5 grubs/ 20 pls) and *C. formosanus* (0-2 adults/ 20 pls). Among these, *M. rileyi* infection observed was 8 to 43 per cent and recorded major cause of death of fall armyworm larvae compared to other predators and parasitoids.

Zhang *et al.* (2022) studied eight natural fungal strains were isolated from diseased larvae of FAW and identified as *Cladosporium cladosporioides* (EFNL-1), *M. rileyi* (EFNL-2 and EFNL-8), *Fusarium proliferatum* (EFNL-3 and EFNL-6), *F. equiseti* (EFNL-4 and EFNL-5) and *F. tricinctum* (EFNL-7) using the morphological and molecular tools or methods. However, it was concluded that the *M. rileyi* EFNL-8 (1×10^8 conidia/ml) as a good pathogenic isolate against eggs and first to third instar larvae of FAW.

2.2 Efficacy of biopesticides against *S. frugiperda*

Biopesticides are non-toxic, ecologically friendly pesticides made from naturally occurring animals, plants, microbes, or minerals comprising living organisms (natural enemies), their products (phytochemicals, microbial products), or byproducts (Semiochemicals) originating from animals (e.g., nematodes), plants (*Chrysanthemum*, *Azadirachta*) and microorganisms. Biopesticides are a viable alternative to chemical pesticides in sustainable pest management strategies. Literature reveals that biopesticides were evaluated for their efficacy both in laboratory and field.

Wayne and James (1980) stated that entomopathogens may be used to suppress insect populations in at least three ways like optimization of naturally occurring diseases, introduction and colonization of pathogens into insect populations as natural regulatory and repeated application of pathogens as microbial insecticides.

Lengai and Muthomi (2018) stated biopesticides could take the place of synthetic pesticides. Biopesticides are biodegradable, have multiple modes of action, are less costly and have little toxicity to humans and non-target animals. They are significant in IPM because they reduce the usage of harmful synthetic chemical pesticides that are hazardous to human and environmental health. Thus, the use of biopesticides enriched farming practices to promote food security and agricultural sustainability

2.2.1 Efficacy of biopesticides against *S. frugiperda* under laboratory conditions

Lezama *et al.* (1996) conducted laboratory bioassays and showed *M. anisopliae* to be highly pathogenic to both eggs and neonate larvae of fall armyworm with mortality rates of 100 per cent and LT_{50} values of 2.5 days for the egg stage and 3.1 days for larvae after 48 hr exposure to maize leaves previously immersed into a suspension of conidia ($1 \times 10^8 \text{ ml}^{-1}$). Also, Romero *et al.* (2014) recorded 72.5 per cent mortality of third instar larvae of FAW in the laboratory at 72 hr post-infection when treated with a concentration of 5.3×10^5 conidia ml^{-1} of *M. anisopliae* (strain CP-MA1).

Polanczyk *et al.* (2000) studied the bioefficacy of *B. thuringiensis* to control *S. frugiperda* at Health Plant Department, School of Agronomy, Brazil. Strains of *Bt dendrolimus* HD 37, *Bt aizawai* HD 68, *Bt kurstaki* HD 73, *Bt darmstadiensis* HD 146 and *B. thuringiensis* 4412 were tested against second instar larvae. Suspensions of *Bt aizawai* HD 68 and *B. thuringiensis* 4412 containing 3×10^8 cells/ml and induced the mortality of 100 and 80.4 per cent, respectively.

According to Molina *et al.* (2003) among the pathogens, *B. thuringiensis*, *M. anisopliae* and *B. bassiana* are cause significant level of mortality in FAW population and help to reduce leaf defoliation in crops.

Polanczyk *et al.* (2003) studied a laboratory experiment to verify the susceptibility of *S. frugiperda* to *B. thuringiensis* and this trial was carried out with 58 isolates in Brazil. For each isolate, 20 second instar larvae were used for study. *Bt var*

morrisoni isolate was the most pathogenic with 80 per cent of mortality and in the virulence assay, it showed an LC_{50} of 8.6×10^6 cells /ml. Other 7 isolates caused mortality between 40 and 15 per cent, 3 isolates below 15 per cent and all remainders were not active to this pest.

Bosa *et al.* (2004) studied the biocontrol activity of 10 isolates of *N. rileyi*, isolated under laboratory conditions from the Llanos Orientales, at 1×10^7 conidia ml^{-1} was evaluated by spraying onto "higuerilla" leaves (*Kicinus communis*) infested with second instar larvae. It was reported the efficacy of *M. rileyi* isolates (Nm-07) in Colombia, caused 100 per cent mortality and the lowest lethal times in 2nd instar of *S. frugiperda*.

Chavez *et al.* (2004) evaluated the activity of ten isolates of *M. rileyi* against 2nd instar larvae of FAW by spraying the fungus at a concentration of 1×10^7 conidia ml^{-1} and found one of the most effective isolates Nm-07 caused 100 per cent mortality, with lethal time (LT_{50} and LT_{90}) of 6.2 and 7.9 days, respectively. Whereas, Tigano *et al.* (1995) found that *M. rileyi* isolates obtained originally from FAW were highly virulent to FAW, with mortality rates of 53.3-82.2 per cent and LT_{50} of 4.8 - 8.5 days, following treatments at a concentration of 1×10^8 conidia ml^{-1} .

Sanchez *et al.* (2007) compared the activity of different strains of EPFs (isolated from soil or insects) against FAW larvae by submerging insects in conidial suspension (1×10^8 ml^{-1}). The study demonstrated that the *M. anisopliae* strain UA-12 derived from soil was more active with 90 per cent mortality than the *B. bassiana* insect derived strain with 80 per cent mortality on larvae of FAW.

Dos *et al.* (2009) performed selective bioassays from one hundred strains of *Bt* isolated from soil and water samples from different regions of Brazil showed that only eight strains had toxicity above 70 per cent to fall armyworm larvae on the fifth day. Likewise, Arango *et al.* (2002) reported the *Bt* strain 366-0476 of *sub species kurstaki* exhibited a sub lethal effect observed as wing deformities in 20.8 per cent of the newly emerged FAW adults.

Wraight *et al.* (2010) conducted laboratory assays, in which the second instar larvae of FAW were topically sprayed with conidial suspensions of the commercial *B. bassiana* strain GHA registered in the USA as Botani Gard, showed a median lethal

concentration (LC₅₀) of 1213 conidia mm⁻² while a dose of 4234 conidia mm⁻² caused 95 per cent mortality. Also, in vitro studies showed 30 and 87 per cent mortality when *B. bassiana* and *M. anisopliae* were applied on second instars larvae, respectively. Similarly, Garcia and Bautista (2011) reported that *B. bassiana* (strain Bb42) obtained from field-collected FAW larvae showed the virulence of 96.6 per cent mortality to 2nd instar larvae at a concentration of 1 x 10⁹ conidia ml⁻¹.

Freed *et al.* (2012) revealed that the efficacy of *M. anisopliae* was evaluated against 3rd instar larva of *S. exigua* in the laboratory and semi-field / greenhouse conditions. It was observed that *M. anisopliae* was more effective in laboratory as well as semi-field conditions and showed 87.5 and 81.25 per cent mortality of *S. exigua*, respectively.

Avalos *et al.* (2018) isolated 14 entomopathogenic fungal strains and conducted bioassays on neonate larvae of *S. frugiperda* and reported 100 per cent mortality with strains Mr8, Ma22, Ma41 strains of *M. anisopliae* and Bb9 strain of *B. bassiana* at a spore concentration of 1 x 10⁸ conidia/ml.

Grijalba *et al.* (2018) evaluated the efficacy of *M. rileyi* formulated as an emulsifiable concentrate against FAW larvae on maize plants under glasshouse conditions. The results showed LC₅₀ and LC₉₀ values of approximately 1.2 x 10⁴ and 4.0 x 10⁶ conidia ml⁻¹, respectively and a 57 per cent reduction in damage to plants at the rate of 1.3 x 10¹² conidia ha⁻¹.

Akutse *et al.* (2019) found that fungal pathogens like *M. anisopliae* and *B. bassiana* were effective against the eggs and second instar larvae of fall armyworm. Under laboratory conditions, *M. anisopliae* caused egg mortalities of 79.5 to 87.0 per cent and *B. bassiana* recorded mortality of 30 per cent to second instar larvae. The total mortality of eggs and early stage larval mortality with *M. anisopliae* was as high as 96 per cent with some fungal isolates.

Cruz *et al.* (2019) conducted a laboratory experiment with fourteen fungal entomopathogenic strains of *M. anisopliae*, *B. bassiana* and *N. rileyi* were isolated from soil samples and infected field collected fall armyworm larvae in Guanajuato, Mexico. It was proved that high mortalities on eggs and neonate larvae of FAW when exposed to *M.*

anisopliae isolates. While, Gutierrez *et al.* (2019) reported that *M. anisopliae* Ma-San Rafel-2 caused 68.7 per cent mortality in FAW adults.

Husseini (2019) studied a local isolate of the fungus *B. bassiana* was tested against the beet armyworm, *Spodoptera exigua* (Hubner) larvae reared on artificial diet. Seven successive increased conidiospore concentrations (2×10^1 to 2×10^7 spores/ml) were tested against larvae of L3 and L4. Larval mortality increased by increasing the conidiospore concentrations in laboratory conditions. While applying *B. bassiana* (6×10^7 conidiospore /ml) for controlling *S. exigua* in sugar beet fields in Fayoum Governorate, Egypt, resulted in suppression in its larval populations through 5 applications by 54.5–70 and 66.6–80 per cent in season 2016-2017 and 2017-2018, respectively.

Sufyan *et al.* (2019) investigated the biocontrol potential of *B. bassiana* under laboratory conditions against maize stem borer, *C. partellus*. Three doses of *B. bassiana* (1×10^4 , 1×10^6 and 1×10^8 conidia ml⁻¹) were applied against 2nd and 4th larval instars of *C. partellus*. Mortality of second and fourth instar larva was 58.01 and 51.03 per cent, respectively and pupation per cent was also greatly reduced with 48.81 per cent at 1×10^8 conidia per ml concentration.

Ullah *et al.* (2019) studied effects of *B. bassiana* on the biology of *S. litura* by studying different growth parameters like RGR (relative growth rate). *B. bassiana* proved to be effective in reducing the egg hatchability (71.1 %) compared with the control treatment (92.9 %) and reduced larval survival (53.3 % of larvae survived after 10th day exposure of *B. bassiana* treatment) against 100 per cent survival in control.

Barros *et al.* (2020) studied the pathogenicity of three isolates CG381, CG1312 and new wild isolate of *M. rileyi* against third instar larvae of *S. frugiperda* and *Chrysodeixis includens* (Walker) by treating with the conidial suspension under laboratory condition at Embrapa Agrossilvipastoril, Mato Grosso state, Brazil. The results revealed that both species were susceptible to the isolates of *M. rileyi* with mortality rates of 74-84 per cent for *S. frugiperda* and 53 - 58 per cent for *C. includens*.

Kiruthiga *et al.* (2020) conducted laboratory bioassay by leaf dip method with isolate of *B. bassiana* (TM MH590235) and *Metarhizium* sp. with concentration ranging from 1×10^7 to 1×10^8 conidia /ml against FAW. Results indicated that *B.*

bassiana (TM MH590235) registered LC 50 value of 1.09×10^7 , 1.56×10^7 and 1.43×10^7 spores per ml against first, second and third instar of *S. frugiperda*. Whereas, *Metarhizium* sp. recorded LC₅₀ and LT₅₀ value of 2.9×10^7 spores per ml and 3.5 days against first instar of *S. frugiperda*, respectively.

Patel *et al.* (2020b) determined the bio-efficacy of different strains of entomopathogenic fungi viz., *B. bassiana*, *M. anisopliae* and *N. rileyi* and entomopathogenic bacteria *B. thuringiensis* against *S. frugiperda* under laboratory condition. The result revealed that the AAU strain *M. anisopliae* @ 2×10^9 conidia/ml showed the highest larval mortality i.e., 57.56 and 50.63 per cent against second and third instar larvae, respectively. The same strain registered the larval mortality of 55.50 and 48.45 per cent against second and third instar larvae, respectively @ 2×10^8 conidia/ml. In the case of AAU strain of *B. thuringiensis* @ 3 ml/l showed 64.65 and 59.01 per cent larval mortality against second and third instar larvae, respectively.

Ramos *et al.* (2020) conducted an experiment on endophytic establishment of *B. bassiana* and *M. anisopliae* in maize plants and its effect against *S. frugiperda* larvae. Both entomopathogenic fungi caused 100 per cent mortality on the second instar larvae. In addition, *B. bassiana* and *M. anisopliae* killed 87 and 75 per cent of the fourth larval instars, respectively.

Sagar *et al.* (2020) reported that seed powder of *Azadirachta indica* caused 70 per cent larval mortality of *S. frugiperda* in laboratory whereas *Nicotiana tobacum* and *Lippia javanica* controlled the larvae by 66 per cent in contact toxicity. *M. anisopliae* controlled the egg and neonate larvae by 87 and 96.5 per cent, respectively. Similarly, Tavares *et al.* (2010) reported that the application of 0.25 per cent neem oil extract under laboratory conditions showed 80 per cent larval mortality.

Aarathi *et al.* (2021) evaluated the bioefficacy of six bioagents *M. anisopliae*, *N. rileyi* and *B. bassiana*, *B. thuringiensis*, Nematode *S. carpocapsae* (Weiser) and *azadirachtin* at Department of Entomology, College of Agriculture, Pune, MPKV, Rahuri. The results revealed that *Bt* showed the highest mortality of 85.92, 64.44 and 50.00 per cent against 1st, 3rd and 5th instar larvae, respectively followed by *N. rileyi*, 71.48, 57.04 and 36.68 per cent against 1st, 3rd and 5th instar larvae, respectively.

Ginting *et al.* (2021) performed an experiment on the potential of entomopathogenic fungal culture filtrate of *N. rileyi* in Bengkulu, Indonesia against the *S. frugiperda*. The results showed that the highest mortality was recorded at a concentration of 1 per cent reaching 100 per cent on day 3, while at a concentration of 0.05 and 0.005 per cent, the mortality of *S. frugiperda* larvae was under 10 per cent. The culture filtrate of *N. rileyi* also caused mortality above 50 per cent at concentrations of 0.50 and 0.75 per cent.

Idrees *et al.* (2021) studied the effectiveness of five entomopathogenic fungal isolates viz., *Aspergillus* sp. BM-3 and SE-2-1, *Cladosporium tenuissimum* SE-10, *Penicillium citrinum* CTD-24 and *B. bassiana* ZK-5 against immature stages like eggs, neonates, larvae and feeding efficacy of first to sixth instar *S. frugiperda* larvae at 1×10^6 , 1×10^7 and 1×10^8 conidia/ml. Among the five tested fungal isolates, *C. tenuissimum* SE-10, *P. citrinum* CTD-24 and *B. bassiana* ZK-5 showed significant effects on egg mortality and significantly reduced the early third instar feeding efficacy of FAW larvae at the highest concentration level.

Julius *et al.* (2021) performed the six isolates of *B. bassiana* against fall armyworm. Consequently, all the isolates were showed efficacy against *S. frugiperda* with isolate BCMU6 caused 91.67 per cent mortality. Further, molecular analysis revealed that all the isolates possess the GAS1 gene (glycosyl transferase-like protein 1) which contributed to their virulence against the insect. This was the first report of utilizing native entomopathogenic *B. bassiana* to manage *S. frugiperda* in Thailand with the revelation of GAS1 as a factor in inducing virulence and cuticle penetration.

Kumar *et al.* (2021) evaluated the efficacy of different bio-pesticides against fall armyworm under laboratory condition. The result indicated that the treatment emamectin benzoate @ 0.4 g/l caused the highest mortality (100 %) at 72 hours after treatment application. While, *M. anisopliae* @ 7 ml/l caused 100 per cent mortality followed by the treatment *B. bassiana* @ 7 g/l (95 % mortality) at 96 hr after treatment application. Other treatments caused more than 80 per cent mortality at 96 hr after treatment application. It was concluded that larval mortality increased with an increase in doses of microbial pesticides and time interval.

Lara *et al.* (2021) conducted an experiment on concentration mortality response of Mexican populations fall armyworm to commercial formulations of *Bacillus thuringiensis* such as *Bt sub sp. aizawai* and *Bt sub sp. kurstaki*. The populations were susceptible to both *Bt* formulations but *Bt sub sp. aizawai* (Xentari) was more susceptible than *Bt sub sp. kurstaki* (Dipel).

Melissa and Marcela (2021) reported that *M. rileyi* from *S. exigua* was infective to all larval instars of *S. frugiperda*. Early larval instars (1st - 3rd) were more susceptible than late larval instars (4th - 6th). Higher conidial concentrations caused a higher and faster rate of larval mortality than lower conidial concentrations.

Shahzad *et al.* (2021) evaluated the toxicity of two entomopathogenic fungi such as *M. anisopliae* and *B. bassiana* against second instar larvae of FAW under controlled conditions. The results showed that *B. bassiana* was found more toxic among tested entomopathogenic fungi than *M. anisopliae*, *B. bassiana* caused 79 per cent larval mortality while *M. anisopliae* 59 per cent.

Tulashie *et al.* (2021) assessed the toxicity of neem extracts *viz.*, neem seed oil extract (NSOE) and methanolic neem leaf extract (MNLE) were obtained from neem seeds and leaves by Soxhlet extraction and cold maceration respectively for control of fall armyworm. The estimated LC₅₀ after 2, 6 and 12 hrs for NSOE were 1.78, 0.97 and 0.68 per cent, respectively while LC₅₀ after 2, 6 and 12 hrs for MNLE were 2.67, 2.62 and 1.64 per cent, respectively. The results suggested that both extracts have great potential as a natural insecticide for the management of fall armyworms.

Aarhi *et al.* (2022) assessed bioefficacy of six test bioagents against eggs, second instar larvae and pupae of FAW. The mean egg mortality at 5 DAT revealed that azadirachtin recorded highest egg mortality (81.33 %) followed by *S. carpocapsae* (73.67 %), *N. rileyi* (73.67 %) and *M. anisopliae* (66 %). Against the second instar larvae at 7 DAT, *Bt* (67.78 %) was the most effective treatment which was followed by *N. rileyi* (60.37 %), *M. anisopliae* (57.04 %) and azadirachtin (53.33 %), *S. Carpocapsae* (28.15 %) and *B. bassiana* (24.81 %). Azadirachtin recorded the lowest adult emergence (70 %) from pupae followed by *S. carpocapsae* (73.33 %), *N. rileyi* (83.33 %) and *M. anisopliae* (86.67 %).

Idrees *et al.* (2022) studied the bioassays of *B. bassiana* isolates against the fall armyworm, *S. frugiperda*. The result indicated that the *B. bassiana* isolates QB-3.45, QB-3.46 and QB-3.428 caused the highest egg mortality rates of 87.3, 82.7 and 79.3 per cent, respectively, when applied at a concentration of 1×10^8 conidia/ml and measured at 7 days post-treatment. Neonate mortality rates of 45.6 to 53.6 per cent were observed with the same isolates. The *B. bassiana* isolates caused significant cumulative mortality rates ranging from 71.3 to 93.3 per cent at 14 days post-treatment and reduced larval feeding efficacy from 69.4 to 77.8 per cent at 48 hr post-treatment.

Montecalvo *et al.* (2022) conducted laboratory bioassays to elucidate the virulence of *M. rileyi* to different life stages of *S. frugiperda*. The higher mortalities were observed in early instars of *S. frugiperda* to *M. rileyi*. Mycosed larvae were covered with white fungal growth and light olive-green conidia. The mean time to larval death ranged from 5.10 to 8.67 days depending on conidial concentration and larval instar. Based on t-test, no ovicidal activity, reduced pupation and adult emergence were observed in fungal treated prepupa. However, there was no effect on the adult emergence of fungal treated pupa.

Nonthakorn *et al.* (2022) assessed mortality induced by 11 EPF candidates from Australia, New Zealand and Malaysia that were in CSIRO's fungal collection against the recently established Lepidopteran pest of *S. frugiperda*. Two Australian isolates of *Beauveria* sp. (B-0571 and B-1311) induced the highest mortality in 3rd instar larvae of *S. frugiperda* with mortality induced predominantly in the first day after infection. These two isolates also induced high mortality in *S. frugiperda* moths and 6th instar caterpillars, but not in pupae.

Sharma *et al.* (2022) evaluated seven different treatments such as spinosad 45 % SC, chlorantraniliprole 18.5 % SC, imidacloprid 17.8 % SL, emamectin benzoate 5 % SC, spinetoram 11.7 % SC, azadirachtin 1500 ppm and control. Spinosad and spinetoram were found effective in which > 50 per cent mortality of the larva was obtained in twelve hours and > 90 per cent mortality in twenty four hours. Azadirachtin and imidacloprid were not as effective as other pesticides that caused only 17 per cent larval mortality in the first twelve hours and 68 per cent mortality in sixty hours.

2.2.2 Efficacy of biopesticides against *S. frugiperda* in field condition

Kubo and Klocke (1981) worked on a biorational insecticide azadirachtin. The trial was conducted at college of natural resources, University of California, United States of America for determining the antifeedant activity against *S. frugiperda*. The results revealed that azadirachtin showed 95 per cent antifeedant activity which helped in controlling the fall armyworm.

According to All *et al.* (1996) genetically modified *B. thuringiensis* strain EG1999, from EG2348 (the active ingredient of the bioinsecticide condor), showed good control of FAW infestations in whorl stage field corn in 1994 and sweet corn in 1995 as compared with Javelin (WG), an insecticide derived from a naturally occurring *B. thuringiensis* strain and methomyl. Leaf samples were taken 1 hr, 1, 2, 3, 5 and 7 days after spraying and assayed in the laboratory with FAW it was observed that the *B. thuringiensis* products had less than 48 hr residual toxicity to first instar larvae.

Capalbo *et al.* (2001) evaluated solid-state fermentation of active *Bt* var. *tolworthi* @ 2×10^6 spores/ml against *S. frugiperda* in maize. The results showed that 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. During one maize crop cycle, two applications were made and up until 70 days after emergence, it was not necessary to apply any other insecticide for fall armyworm control.

According to Lezama *et al.* (2001) the use of microbial control is a potentially valuable alternative to chemical pesticides with their high cost, possible pest resurgence, development of resistance and environmental contamination.

Lingappa *et al.* (2002) conducted experiment on the field performance of *N. rileyi* at 2×10^8 conidia /litre against soybean pests (*Spodoptera litura*, *Helicoverpa armigera* and *Thysanoplusia orichalcea*) was compared with that of monocrotophos at 1 ml/litre and lambda cyhalothrin at 0.6 ml/litre in 2001-02 in Karnataka, India. Larval population was reduced by 28 and 62 per cent in 10 days by *N. rileyi* after the first and second applications, respectively. Population reduction in pests in the chemical insecticide treated soybean was 42 and 65 per cent after the first (monocrotophos) and second (lambda cyhalothrin) sprays.

Tang and Hou (2002) studied the effects of the entomopathogenic fungus *N. rileyi* on maize earworm *H. armigera*. When administered at 10^7 conidia/ml the fungus killed 95 to 100 per cent of 4th instar larvae. When the soil surface was sprayed with 10^8 conidia/ml solution, the fifth instar larvae showed mortality of 94.6 per cent on soil with 20 per cent water content and 41.7 per cent on soil with 10 per cent water content.

Lima *et al.* (2010) reported that the lowest per centage of fall armyworm damage (56 %) and damage rating (1.3) was observed in neem leaf extract @ 5 % treated plot compared to the control plot in the maize.

Wraight *et al.* (2010) reported that *B. bassiana* (Vuill), *M. anisopliae* (Metchnikoff) and *N. rileyi* (Farlow) were common fungi with potential uses against insect pests including fall armyworm.

Ruiz *et al.* (2013) demonstrated the natural occurrence of *M. rileyi* fungus in the area of origin in Mexico with about 3 per cent of FAW larval mortality was observed in the third to sixth instar larvae at whorl stage of maize.

Suganthy and Sakhivel (2013) studied the field evaluation of bio-pesticides against *S. litura* on *Gloriosa superba*. The result indicated that seven days after treatment 100 per cent reduction in larval population was observed in flavonoids and quinalphos. Next best treatments were neem oil, neem seed kernel extract and *Bt* with 0.90, 1.43 and 1.47 larvae per plant, respectively. Significant reduction in larval population was observed in *Bt* treated plots (0.70 larvae /plant) at 14 days after treatment.

Alves *et al.* (2014) reported that entomopathogenic fungi have a broad spectrum action with the ability to infect several species of insects and different stages caused epizootics under natural conditions. Similarly, Lacey and Shapiro, (2008) proved that the application of EPF gained increased attention as a sustainable control in reducing insect pest population without affecting the non-target insects. It was reported that the fungus multiplies rapidly using its host nutrients, leading to physiological disruption and insect death.

Manu *et al.* (2014) tested the efficacy of insecticides, biopesticides and poison baits against leaf eating caterpillars of soybean. Among the biopesticides, the highest population reduction of tobacco caterpillar was observed in the plots treated with

N. rileyi 2 x 10 cfu @ 2 g /l followed by SL NPV 250 LE/ ha, nimbecidine @ 3 ml /l and neem leaf extract @ 5 %.

Chandrayudu *et al.* (2015) evaluated the field efficacy of botanical and microbial insecticides against tobacco caterpillar, *S. litura* in groundnut and reported that minimum per cent leaf damage was observed in plots treated with *SINPV* @ 250 LE ha (24.26 %) followed by *B. thuringiensis* @ 1.0 g l (24.74 %), *N. rileyi* @ 1.5 x 10 spores /ml (26.60 %), *B. bassiana* @ 1.5x10¹ spores ml (28.19 %) and NSKE @ 5.0 % (34.45 %) whereas, the highest per cent reduction of larval population was observed in plot treated with *SINPV* (97.26 %) followed by *Bt* (94.38 %), *N rileyi* (91.90 %), NSKE (86.58 %) and *B. bassiana* (68.64 %).

Rodriguez and Sergio (2016) evaluated the bioefficacy of *B. bassiana* against fall armyworm larvae *S. frugiperda* at the Department of Parasitology, Coahuila. Results showed that 3rd instar larvae inoculated with *B. bassiana* entophytic strain caused the per cent mortality of 4.10, 26.60, 48.30 and 75.00 at 4, 7, 10 and 14 days after treatment, respectively.

Darabian and Yarahmadi (2017) conducted field experiments for testing the efficacy of *azadirachtin*, emamectin benzoate and *B. thuringiensis* against the *S. exigua* population at Lorestan province, west of Iran. The results revealed that one day after treatment (DAT), emamectin benzoate significantly decreased the pest eggs and larvae densities whereas at 5 and 7 DAT performance of *azadirachtin* and *Bt* reduce the larval population. Similarly, Yubak *et al.* (2020) assessed 12 biopesticides against *S. frugiperda* in Nawalparasi District of Nepal. It was reported that neem based pesticides and *Bt* were most effective.

Mahmoud (2017) reported that the development of resistance to synthetic insecticides is one of the driving forces for changes in insect pest management. Government's regulatory bodies are in favour of environmentally safe chemicals with low toxicity, short-term persistence and limited effects on non-target organisms as predominantly requirements for pesticides registration. Biological control can be considered as a powerful tool and one of the most important alternative control measure providing environmentally safe and sustainable plant protection. The success of biological control will depend on understanding the adaptation and establishment of

applied biological control agents in agricultural ecosystems. Microbial pathogens and arthropod biocontrol agents, entomopathogenic nematodes have been successfully used in agricultural systems.

Bateman *et al.* (2018) studied on assessment of potential biopesticides options for managing fall armyworm in Africa. By using data, they were identified fifty biopesticide which have been registered in one or more of the 30 countries for FAW management. Twenty-three of these are recommended for follow-up and field trials or bioassays.

Mallapur *et al.* (2018) studied three large scale field evaluation of *N. rileyi* against *S. frugiperda* revealed that 58.91 to 62.87 per cent reduction of pest infestation was observed in these localities in maize. Similarly, the larval and leaf injury reduction after 15 days of spraying *N. rileyi* ranged from 62.50 to 66.46 and 66.84 to 73.05 per cent, respectively.

Liu *et al.* (2019) conducted field trials using the *Bt* strain KN50 at 32,000 IU mg⁻¹ and demonstrated a controlled efficacy of 72.6 and 86.6 per cent for 0.3 and 0.6 g m², respectively against larval populations of mixed instars at seven days post-treatment. According to Prasanna *et al.* (2018), seven *Bt* strains were recorded highly effective and caused 100 per cent mortality of FAW larva on 7 days post-treatment of a lethal concentration. On the report of Prasanna *et al.* (2021) *Bt* was most efficient against early larval instars of *S. frugiperda*.

Shaiba *et al.* (2019) assessed the impact of neem based bioinsecticides on fall armyworm infestation in maize and reported that lowest fall armyworm damage (10 %) and highest yield (6.0 kg plot) was observed in neem oil treated plot.

Sindhu and Shekharappa (2019) concluded that NSKE @ 5 % was found effective against defoliator complex on cowpea followed by garlic chilli extract @ 0.5 %. The yield in these treatments was 10.97 and 10.61 q/ha, respectively.

Babendreier *et al.* (2020) reported that neem based pesticides show an equal effect to control FAW damage with respect to emamectin benzoate which is widely used as a safe chemical pesticide for the control of pests.

Dhobi *et al.* (2020) reported that the plot treated with *N. rileyi* 1 % WP @ 40 g/10 lit of water was recorded lowest larval population of *S. frugiperda* (1.81 larvae

/10 plants), minimum plant damage (15.34 %) and cob damage (15.19 %). It was at par with *B. thuringiensis* var. *kurstaki* 1 % WG @ 20 g/10 lit water with minimizing larval population, plant damage and cob damage by 2.03 larvae per 10 plants, 17.70 and 15.20 per cent, respectively. Among the tested biopesticides, the highest grain and fodder yield recorded from the plot treated with *N. rileyi* 1 % WP (29.57 and 40.69 q/ha) and followed by *B. thuringiensis* (29.32 and 40.33 q/ha).

Harika *et al.* (2020) carried out a field experiment to know the efficacy of selected microbial biopesticides comprising three fungi (*M. anisoplae*, *B. bassiana*, *M. rileyi*) one commercial *Bt* (Dipel) and five native *Bt* isolates along with a check (HD 1). Among all the treatments, *M. rileyi* showed the highest per cent mortality over the control with lowest leaf damage.

Mohan *et al.* (2020) conducted surveys on natural enemies of fall armyworm in Karnataka. They collected fungi infected larvae from the field and identified it as *Beauveria feline*. They recorded 20 to 30 per cent of FAW larvae infected with *B. feline*. Bioassay of the *B. feline* was conducted on second instar fall armyworm in laboratory which resulted in 10 per cent of the tested larvae.

Ramanujam *et al.* (2020) evaluated ten strains of *B. bassiana*, *M. anisoplae* and *M. rileyi*. Field trial results showed that *B. bassiana* ICAR-NBAIR Bb-45 strain demonstrated the greatest reduction in per cent infestation (76 %) and increase in yield (55 %) followed by *M. anisoplae* ICAR-NBAIR Ma 35 strain with 70 per cent reduction in per cent infestation and 44 per cent increase in yield.

Tambo *et al.* (2020a) stated that *Bt* based biopesticides are among the most commonly used products against FAW in countries such as Ghana. Also, *Bt* is registered against fall armyworm and commercially available in several newly invaded countries, alone or mixed with other biopesticides or pesticides (Bateman *et al.*, 2021).

Varshney *et al.* (2020) modulated biocontrol based IPM strategy and examined during *rabi* and *kharif* 2018-19. The IPM strategy having FAW pheromone traps, four release of *T. pretiosum*, two sprays of neem oil, one spray each *B. thurengiensis* (NBAIR-BT25), *M. anisoplae* (NBAIR-MA35) gave the best results. This module showed a reduction in egg masses of 76.00 and 71.64 per cent and a larval population reduction of 80 and 74.40 per cent in the *rabi* and *kharif* seasons, respectively.

Crepin *et al.* (2021) evaluated the efficacy of household soaps in lab and field conditions along with plant neem (neem oil), dezone (diatomaceous earth) and emacot 19 EC (emamectin benzoate). In field conditions, the biorational insecticides produced similar or better control than Emacot 19 % EC. It was concluded that the use of Palmida soap at 0.5 % concentration, neem oil at 4.5 L/ha and Dezone at 7.5 kg/ha could provide effective, environment friendly and sustainable management of *S. frugiperda* in maize.

Sowmya *et al.* (2021) conducted a field evaluation with six promising strains of *M. rileyi* against maize fall armyworm and *S. litura* during 2020 at UAS Raichur, Karnataka, India. Highest per cent reduction was recorded in *M. rileyi*, UASRBC-Mr 2 (91.34 %) followed by *M. anisopliae* UASRBC-Ma 2 (86.89 %) on 30 days after spraying. Maximum yield was recorded in *M. rileyi*, 92.57 q/ha) treated plot followed by *M. anisopliae* (89.87 q/ha).

Wayal *et al.* (2021) conducted an experiment on biorational management of *S. frugiperda* on maize. Four sprays were applied at 12 days interval and the treatments included *N. rileyi* 1×10^8 cfu/g @ 30 g/10 l, *M. anisopliae* 1×10^8 cfu/ g @ 50 g/ 10 l, *B. bassiana* 1×10^9 cfu/ g @ 40 g/ 10 l, NSKE 5 %, *Bt* 85 % @ 20 g/ 10 l, SLNPV 1×10^9 POB/ ml (500 LE), azadirachtin 1500 ppm @ 50 ml/ 10 l and untreated control. The results revealed that *Bt* was the most effective treatment (67.78 %) however it was at par with *N. rileyi* (60.37 %), *M. anisopliae* (57.04 %) and azadirachtin (53.33 %) followed by *S. carpocapsae* (28.15 %) and *B. bassiana* (24.81 %).

Cab *et al.* (2022) evaluated commercial formulations of two entomopathogenic fungi *M. anisopliae* Metschnikoff and *B. bassiana* Balsamo against *S. frugiperda* and emamectin benzoate against *H. zea* in two localities in the Yucatan Peninsula, Mexico. In both locations, *M. anisopliae* and *B. bassiana* had similar efficacy to that of emamectin benzoate on suppressing leaf damage by *S. frugiperda*. The grain yield of plots treated with these fungal based insecticides (59.00-75.00 q/ha) was similar to that treated with (74.00-75.00 q/ha).

Gomez *et al.* (2022) investigated the fungal and viral entomopathogens as a combined strategy for the biological control of fall armyworm larvae in maize. The results indicated that the combined use of NPV: *M. rileyi* caused higher larval mortality

than the biocontrol agents used separately. Under field conditions, the individual or sequential application of NPV and *M. rileyi* using 100 per cent of their recommended doses and the simultaneous application of both entomopathogens at 50 per cent of their recommended doses, significantly reduced the foliar damage.

Jahan (2022) evaluated different microbial pesticides against fall armyworm, *S. frugiperda* during *rabi* season in Chuadanga. Results revealed that the highest per cent reduction of leaf infestation was 52.02 per cent with *M. anisopliae* @ 8 g/ l followed by 39.95 % with SNPV @ 0.2 g/l and 30.80 per cent with *B. thuringiensis* @ 0.4 g/l, whereas the lowest reduction of leaf infestation was recorded in *B. bassiana* @1 ml/l treated plants.

Joseph *et al.* (2022) reported that oil-based *M. anisopliae* ICIPE 41 was effective in a high susceptibility of second instar larvae of *S. frugiperda* under laboratory and field conditions. Oil-formulated conidia of *M. anisopliae* ICIPE 41 was effective against FAW which could be used sustainably to manage the invasive FAW in maize cropping systems.

Ramesh and Tayde (2022) evaluated the efficacy of synthetic insecticides, neem oil and NPV based on per centage incidence of maize fall armyworm. Spinetoram 11.7 % SC (4.93 %) was the most effective treatment followed by chlorantraniliprole 18.5 % SC (6.24 %), flubendiamide 39.35 % SC (6.42 %), emamectin benzoate 5 %SG (6.90 %), novaluron 10 % EC (8.13 %), NPV (8.28 %) and neem oil 2 % (8.37 %). Spinetoram 11.7 % SC recorded the highest yield of (41.10 q/ha) with ICBR 1:1.79 as against the untreated control.

2.3 Evaluation of efficacy and economics of the poison baits against *S. frugiperda* in maize

Currently, chemical pesticides are being used to control this pest; however, they are not ideal because they cause environmental pollution. This technique may be useful to manage fall armyworm on maize which is an alternative to synthetic insecticide spray and safe for natural enemies. Hence, the present investigations were carried out to evaluate different whorl applications for the management of fall armyworm on maize.

Bhusal and Chapagain (2020) stated that in fall armyworm management, the application of poison bait in the whorls at vegetative and broadcasting in the mature crop has also shown a good response to controlling an infestation. Also, Latchininsky and Vandyke (2006) mentioned that baits were safer than sprays for non-target organisms and the applicator, but sprays were more cost efficient on a larger scale. Bait formulations were cheaper than sprays for small-scale operations and baits have high potential because they may be improved in the future with added attractants and chemicals that protect the spores from UV exposure.

Lima *et al.* (2010) reported severe yield losses only when the whorl was destroyed. According to Dakhel *et al.* (2019) baits were specific to the target organism or at least more selective than liquid and dust treatments.

Duraimurugan and Srinivas (2017) studied field experiments to evaluate the efficacy of five poison baits against tobacco caterpillar, *S. litura* in castor. It was reported that wheat bran + sugarcane jaggery + chlorpyrifos 20 % EC bait found effective and resulted in maximum larval mortality of 51.1 to 53.3 per cent as compared to 45.6 to 50 per cent mortality in standard check of rice bran + sugarcane jaggery + monocrotophos 36 % SC.

Sharma *et al.* (2019) conducted an experiment on the evaluation of poison baits and *B. thuringiensis* var. *kurstaki* against *S. litura* in tomato and the result revealed that the per cent mortality of baits with insecticide (ranging from 10.24 to 83.24 %), baits with *Bt* formulation (15.64 to 81.06 %) and a spray of *Bt* formulations (14.10 to 85.60 %) in fields did not differ significantly at the respective days.

Dileep Kumar *et al.* (2020) revealed that whorl application of different poison baits using spinetoram 5 ml/kg, 2.5 ml/kg, novaluron 5 ml/kg and chlorantraniliprole @ 3 ml/kg bait were recorded maximum larval mortality of 97.20, 93.15 and 92.46 per cent, respectively and minimized the leaf damage by the fall armyworm at 14 days after the second application over untreated control. There was a substantial reduction in the cost of plant protection ranging from 22 to 44 per cent in bait application over foliar spray involving the same insecticide.

Lunagariya *et al.* (2020) carried out an experiment on the efficacy of poison baits against *S. frugiperda* infesting maize. Among the different poison baits

evaluated, rice bran 25 kg + jaggery 5 kg + thiodicarb 75 % WP 250 g/ha, maize flour 25 kg + jaggery 5 kg + thiodicarb 75 % WP 250 g/ha, rice bran 25 kg + jaggery 5 kg + emamectin benzoate 5 % SG 125 g/ha, maize flour 25 kg + jaggery 5 kg + emamectin benzoate 5 % SG 125 g/ha were found more effective in managing the population of FAW which reflected plants and cob damage and ultimately on grain and fodder yield of maize.

Shinde *et al.* (2021) tested nine whorl applications against the *S. frugiperda* in maize such as carbofuran 3G @ 33 Kg/ha, ash @ 35 kg/ha, sand + lime (9:1) @ 62 kg/ha, entomopathogenic nematode @ 5 Kg/ha, poison bait (wheat bran 10 Kg + jaggery 2 Kg + 3 lit. water + thiodicarb 100 g) @ 44 kg/ha, *B. bassiana* @ 2.5 kg/ha, *M. anisopliae* @ 2.5 kg/ha, *N. rileyi* @ 2.5 kg/ha along with untreated control. The result indicated that the *N. rileyi* was superior in managing the population of fall armyworm and safer to natural enemies i.e., lady beetle, predatory bug and earwig. It was followed by *M. anisopliae*, *B. bassiana*, poison bait and sand + lime.

Divya *et al.* (2022) evaluated whorl application of insecticides mixed in river sand for its efficacy. Sand mixed with chlorantraniliprole 18.5 % SC @ 0.4 ml/ kg, emamectin benzoate 5 % SG @ 0.4 g/ kg and spinosad 45 % SC @ 0.4 ml/ kg sand were found to be effective, with a significant reduction in leaf damage. The quantity of insecticide required/ unit area was 50 per cent less than the spray while the maximum grain yield/cost benefit ratio was obtained.

Jindal *et al.* (2022) carried out an experiment on targeted delivery of soil-insecticide mixture in maize whorls to manage fall armyworm, *S. frugiperda*. The result indicated that the whorl application of chlorantraniliprole 18.5 % SC and emamectin benzoate 5 SG @ 5 ml/kg soil effective followed by spinetoram 11.7 SC @ 5 ml/kg soil in reducing the damage by FAW.

Yeddula *et al.* (2022) revealed that poison bait with thiodicarb 75 SP (50 kg rice bran + 5 kg jaggery + 500 g thiodicarb 75 % SP @ 50 kg/ha) was effective in the management of fall armyworm compared to treatment of spinosad 45 % SC @ 175 ml/ha and spinetoram 11.7 % SC @ 250 ml/ha. Least cob damage of 8.5 per cent and a higher yield of 73.44 q/ha was observed in the poison bait treatment. It was concluded

from the field experiment that poison bait followed by spinosad 45 % SC and spinetoram 11.7 % SC were effective in the management of fall armyworm in Maize.

2.4 Scientific validation of different fall armyworm management practices adopted by the farmers

Locally, farmers use different management practices across countries, regions and places which have no negative impact on the environment and human health. However, these farmers' best practices and experiences were not systematically documented and made available to farmers in different countries. Currently, FAW is major maize production limiting constraint in major parts of Africa where farmers are attempting to adopt various cultural practices. Therefore, this review aims to search, document, summarize and select the best indigenous knowledge and practices available to farmers and farming stakeholders at large.

The use of locally adopted practices by farmer is considered as a substitute to hazardous synthetic pesticides such as pyrethroid and organophosphorus pesticides due to the disturbance in the environment, increasing user cost, pest resurgence and pest resistance to pesticide.

Indian agriculture is at least 10,000 years old. Over millennia, farmers developed innumerable practices to successfully grow crops and raise animals in the highly diversified agro ecological regions of the Indian subcontinent. The last 170 years have brought in new techniques, some useful and some harmful. The development of indigenous technical knowledge (ITK) systems, including the management of natural environment, has been a matter of survival to the people who generated these systems long back (George *et al.*, 2000). Most ITK's were based on the local availability of material and human resources to ensure minimal livelihoods for local people.

According to Warren *et al.* (1993) a majority of farmers in most developing countries are small scale farmers and their knowledge systems have never been recorded systematically in written form; hence they are not easily accessible to agricultural researchers, extension workers and development practitioners.

Abate *et al.* (2000) reported that most subsistence farmers in Africa deter or kill pests via maize intercropping, handpicking and killing of caterpillars, application of wood ashes, tobacco extracts and soils to leaf whorls. Also, Maredia *et al.* (1992)

reported that neem seed powder was very effective to control fall armyworm which can cause over 70 per cent larval mortality.

Oparaeke *et al.* (2006) reported that ashes from burnt palm fronds and bunches have been traditionally used in the eastern parts of Nigeria to dust the leaves of okra to protect against leaf eating beetles, *Podagrica* spp. It was stated that a thick layer of ash is either spread on the soil around plants or sprinkled on foliage to protect it against a variety of pests. Besides acting as physical poison ash on crop foliage interferes with the chemical signals emanating from the host plants thus obstructing the initial host location by pests.

Bissdorf (2008) studied chili extract and recommended that 500 g of chopped the whole plant and 10 hot chili pods, soaked overnight in 15 liters of water, dilute the filtrate with water at 1:2 ratios and added soap @ 1tsp per litre of extract. This treatment controlled most agricultural pests.

Ahmed *et al.* (2009) studied the efficacy of plant extracts against the insect pests of cowpea and reported that a significant reduction in the population of *Clavigralla tomentosicollis* (Stal) and *Maruca virrata* (Fabricus) was observed in plots treated with the crude extract of chilli pepper compared to untreated control.

Chandola *et al.* (2011) stated that indigenous practices of pest management are effective without having a deteriorating effect on the environment and cheap. Similarly, Kumela *et al.* (2019) reported that the use of other non-chemical practices such as ash, soil and plant extracts were shown potential concerning fall armyworm management, besides providing low-cost options for smallholder farmers. Also, in Ethiopia 15 per cent of the farmers used different practiced against FAW like, handpicking and killing of the larvae. The farmers of Kenya added soil to plant whorl, drenching tobacco extracts to damage plants, handpicking and killing of larvae.

Sakhinetipalli (2012) conducted field testing of ITK and insecticide based strategies for the control of brinjal fruit and shoot borer, *Leucinodes arbonalis* Guenee in brinjal. Result revealed that the application of ash @ 50 kg/ha, kerosene 5 % and spinosad 45 % SC recorded a maximum benefit cost ratio of 4.8:1 in brinjal.

Bergmann and Raupp (2014) stated that capsicum was a common and necessary component of almost every Nepalese farmer's field and its bio-pesticidal

activity can be employed to control a wide range of insect pests. Because it's insecticidal and repellent, it's used to manage Hemipteran pests and Lepidopteran pests. Also, Belmain *et al.* (1999), chili pepper was an effective deterrent and bio-pesticide for reducing the number of weevil species attacking stored grains. Similarly, Morgan (2004) described that the leaves, bark, root and seeds of the neem plant was used as botanical insecticides for a range of pests.

Oben *et al.* (2015) reported that the farmers practiced the combination of ash with conventional insecticides such as Mocap (ethopropos), Sevin, Gamalin, or Kerosene and ash with water or Kerosene. It was applied in the leaf whorl of the plant. Also, Silva *et al.*, (2015) showed that aqueous extracts of neem seed cake were effective for control of fall armyworm on maize in Brazil.

Abrahams *et al.* (2017) suggested that handpicking of egg masses and larvae, deep ploughing to kill pupae in the soil and placing sand or ash in the whorls reduced the yield losses that occurred in the infested farms by the fall armyworm.

CABI (2017) report showed that smallholder farmers practice handpicking, destroying egg masses and larvae and putting sand mixed with lime or ash in the whorl of infested maize to kill the larvae. On the same line, Stevenson *et al.* (2017) reported that the botanical pesticides used by farmers against *S. frugiperda* were usually made from neem leaves or seeds, vernonia leaves, pepper and ash.

Kushram *et al* (2017) reported that the highest per cent reduction of *S. litura* larval population over untreated control in soybean was observed in the plots treated with garlic + green chilli extract @ 8.75 kg ha (63.56 %) however, 34.75 per cent larval population reduction over control was observed in green chilli pod @ 9 kg /ha.

Adeye *et al.* (2018) found that neem oil at 4.5 l/ ha reduced the incidence of pest attacks, the severity of damage and the loss of maize yield by 42.80 and 57.00 per cent. Some of the farmers also added soaps, detergents, or petroleum to botanical pesticides.

Hruska (2019) stated that many smallholder farmers around the world used locally available substances to control FAW. These include local botanical extracts, soil, sand, wood ash, lime, oils, detergents, salt, soaps, urine and others. Similarly,

Wyckhuys and O'Neil (2007) reported that soil and ash were used for control of FAW for a long time by small holder farmers in the Americas.

Kansiime *et al.* (2019) studied farmers' perception of fall armyworm and farm-level management practices in Zambia. It has been reported that the majority of farmers (60 %) used pesticides for fall armyworm control, along with other cultural/physical practices like hand picking and crushing egg masses/caterpillars (36 %) and application of ash/sand in the funnel (19 %). It concluded that research into cultural and indigenous practices used by farmers will offer opportunities for alternative and sustainable management practices.

Babendreier *et al.* (2020) conducted field trials that tested maltodextrin, neem-based products, ash and soil, as well as the locally produced alata samina soap, in the Upper West and Greater Accra regions, Ghana. Ash, soil and alata samina soap treatments were not efficiently reduce FAW larval numbers or crop damage at the dosages tested.

Dhobi *et al.* (2020) reported that green chilli water extract @ 10 % was effective against fall armyworm in maize and the larval population and plant damage in the treatment was 2.08 larvae per 10 plants and 37.93 per cent, respectively which was significantly superior over control.

Gebissa and Mulatu (2020) studied and review on local and indigenous knowledge of farmers against FAW. The farmers applied different locally available knowledge such as handpicking, killing of larvae, adding soil to plant whorls, drenching tobacco extracts, destroying ratoon host crops, early planting, deep ploughing to kill pupae, placing sand or ash in the whorls, burning stubbles after harvesting of infested crops, intercropping and sowing multiple varieties and rotation of maize with non-host crops.

Houngbo *et al.* (2020) worked on farmers' knowledge and management practices of *S. frugiperda* in Benin, West Africa. About 16 per cent of farmers identified the francolin (*Francolinus bicalcaratus*), village weaver (*Ploceus cucullatus*) and the common wasp (*Vespula vulgaris*) as natural enemies. Also, 5 per cent of farmers identified yellow nutsedge, chan, shea tree, neem, tamarind and soybean as repellent plants of *S. frugiperda*. Most farmers (91.4 %) used synthetic pesticides and 1.9 per cent

used botanical pesticides, it was found more effective than synthetic ones. It was concluded that more research is required to further understand the effectiveness of botanical pesticides made by farmers against *S. frugiperda*.

Tambo *et al.* (2020b) reported that farmers in five African countries and found that between 2.5 and 17.7 per cent of farmers apply ash or sand to the whorl, of which 48 -77 per cent responded positively that they were efficacious compared to 92 -97 per cent responding positively for synthetic insecticides. Likewise, Tambo *et al.* (2020a) showed that less than one per cent of farmers in Ghana and about 5 per cent of farmers in Zambia use ash for FAW control.

Bhandari *et al.* (2021) reported that some of the farmers in Nepal used locally available materials toxic to FAW for its control such as sand, lime powder and neem products. They used to apply ash and lime powder by dusting and neem oil by spraying into the infested plants.

Mugwanya (2021) evaluated the potential of chili pepper and neem leaf aqueous extracts to control *S. frugiperda* on maize plants. The results revealed that the application of neem leaf extract and chili pepper extract plus their combination caused significant death of 3rd instars larvae of fall armyworm compared to untreated control experiment irrespective of the method of application.

Parajuli *et al.* (2022) described a group of botanicals either their parts or the whole as extracts having pungent smell such as Neem (*Azadirachta indica*), Chili pepper (*Capsicum annuum*), Garlic (*Allium sativum*), Moringa (*Moringa oleifera*), Clove basil (*Ocimum gratissimum*), China berry (*Melia azedarach*), Biter leaf (*Vernonia amygdalina*), etc. can be used for pest control. A number of members of Hemipteran, Lepidopteran, Thysanopteran, Coleopteran and Dipteran insects have been successfully controlled by using bio-pesticides.

2.5 Evaluation of different IPM strategies against fall armyworm, *S. frugiperda* in maize

Management of this pest should be done in such a way that sustains for eco-friendly environment, causes a low risk to the human environment and also should be cost-effective. Control of this pest is possible through many physical, biological, chemical and cultural means. Proper timing, selection of crop variety, crop management

and proper use of bio-pesticides and synthetic pesticides are the important parameters of IPM. Therefore, it is essential to optimize IPM of FAW packages that will prioritize non-chemical uses over chemical ones.

Noor *et al.* (2015) evaluated different integrated pest management modules to control *Helicoverpa* sp. for adaptation to climate change. The result indicated that among different modules tested the module-15 involving integrated implementation of spinosad, neemosal, *C. carnea* and *H. hebetor* explained the highest yield (16.39 q/ha) with ICBR (1: 6.15) and proved economical and effective IPM module.

Badhai *et al.* (2020) studied the integrated management of *S. frugiperda* in maize crops. Studies revealed that deep ploughing before the onset of rains and wide sowing practices was the best cultural practices for the management of all armyworm. Using sex pheromone traps @ 2 traps/acre at the time of sowing & hand picking and squashing of eggs was found effective to control fall armyworm. Spraying of azadirachtin 1 EC @ 2 ml/l of water, emamectin benzoate 5 % SG @ 0.5 g/l of water, chlorpyrifos 50 % + cypermethrin 5 % EC @ 2ml/l of water, lambda-cyhalothrin 5 % EC @ 2ml/l of water were found effective against fall armyworm.

Deshmukh *et al.* (2020) conducted a field experiment on the efficacy of different insecticides against fall armyworm for two planting dates (June sown crop and September sown crop, 2018). The results revealed that the effective insecticides were chlorantraniliprole 18.5 SC followed by emamectin benzoate 5 SG, spinetoram 11.7 SC, flubendiamide 480 SC, indoxacarb 14.5 SC, lambda-cyhalothrin 5 EC and novaluron 10 EC. Higher efficacy also was correlated with higher grain yield in comparison with the control. Chlorantraniliprole, emamectin benzoate and spinetoram were suitable as one of the components of IPM of FAW in India.

Neelima *et al.* (2020) gave a review on the invasive fall armyworm in maize, status and infestation took control under sustainable management. From this review, it was reported that integrated pest management approaches like the combination of the physical, chemical and biological methods adopted by the majority of the corn producers to reduce the impact of the pest on the crops. These practices were safe for the environment and human health. The management practices of this pest by synthetic pesticides also affected human health, natural enemies and the environment negatively.

Omprakash *et al.* (2020) evaluated four different modules for the management of fall armyworm *S. frugiperda* in maize during *rabi* 2018-2019. Among different modules, module IV includes the seed treatment with imidacloprid 600 FS, 20 DAG- chlorantraniliprole 18.5 % SC @ 0.3 ml/l, 30 DAG - spinetorum @ 0.5 ml/l, 40 DAG - poison bait with thiodicarb @ 100 g/acre) recorded the lowest per cent plant damage (3) and per cent severity (1.57) with 95.45 and 96.08 per cent reduction over control.

Thilagam *et al.* (2020) evaluated of IPM technology capsule against *S. frugiperda* developed by Tamil Nadu Agricultural University, Coimbatore along with farmers' and zero practice during the *rabi* season 2019 at Agricultural Research Station, Virinjipuram and in farmers field. The results revealed that the vegetative stage at 15 days after sowing (DAS), the leaf damage was found to be lowest in the technology capsule (16.6 %) followed by farmers' practice (30.0 %) and the highest was recorded in zero practice (43.3 %). At 60 DAS, the lowest tassel damage was reported in the technology capsule (6.6 %) and zero practice was reported with the highest damage (56.6). The results on the leaf grade revealed that the lowest scale (3) was observed in the technology capsule at 30 DAS followed by farmer's practice (6) as compared to zero practice(9). The reduction in the larval population was reflected in the highest grain yield in the technology capsule (42.00 q/ha) followed by farmers' practice (29.90 q/ha) and zero practice (17.00 q/ha).

Balabantaray and Samal (2021) studied threats of *S. frugiperda* incidence in India and its integrated management approach. It was concluded that the integrated management approach *viz.*, physical, chemical, botanical and biological methods was an effective measure to reduce the menace of this pest. The biological approach of management was most effective as it used different parasitoids, pathogens and predators to control the pest. Though the chemical method of control was expensive and non-environmentally friendly, it was practiced for effective control of pest this pest. Awareness among farmers for adopting field sanitation, crop rotation and intercropping, proper dose of fertilizer application, use of botanicals, predators, or promoting natural control must be created.

Chitti *et al.* (2021) conducted a field experiment on integrated pest management of an invasive pest on maize, *S. frugiperda* in the Srikakulam district of Andhra Pradesh. The pest incidence was 11-12 per cent in IPM plots in *kharif* and 4-5 per cent during *rabi*. Whereas the pest incidence was 30-32 per cent in *kharif* and 16-17 per cent during *rabi* in non-IPM followed fields. There was 8-10 per cent yield increase observed and the incremental cost-benefit ratio was 1: 5.2. The results indicated that evaluated IPM against fall armyworm gave efficient pest control and reduced the economic loss to the farmers.

In India, Varshney *et al.* (2021) integrated *T. pretiosum* into biocontrol based integrated pest management comprising pheromone traps, the fungi *M. rileyi* and *M. anisopliae*, neem oil and *B. thuringiensis*. These treatments resulted in 71 to 76 per cent egg mass reduction, 74 to 80 per cent larval population reduction and 38 to 42 per cent gain in yield than farmer practice.

Warkad *et al.* (2021) tested four IPM modules for the fall armyworm on maize during *rabi* 2019- 20. Modules were IPM excluding seed treatment, IPM including seed treatment, bio-intensive control and chemical control. The result revealed that IPM including seed treatment was found superior to other modules by recording the lowest plant damage (10.30 %).

3. MATERIALS AND METHODS

The present investigation was conducted on the eco-friendly management of fall armyworm *S. frugiperda* (J. E. Smith) in Maize. Studies were conducted during the *kharif* and *rabi* seasons of the year 2021-22 and 2022-23. Laboratory experiments were conducted at the eco-friendly laboratory, Department of Entomology MPKV, Rahuri and the field experiments were conducted at Maize Improvement Project, MPKV, Rahuri. The material and methods employed for these investigations are presented below.

3.1 Studies on the natural enemy complex of *S. frugiperda* infesting maize

3.1.1 Materials

3.1.1.1 Laboratory materials

Different laboratory instruments used during the course of investigations were autoclave with (Equitron make), laminar airflow (Filtrox), BOD incubator (Steelment Novatech), refrigerator, electronic weighing balance (capacity 1.5 kg), gas burner, spirit lamp, inoculating needles, forceps, blades, marker pen, cork borer etc. The glassware of borosil make were utilized for the conduct of experiments *viz.*, petri plates, test tube, conical flask, beakers of various capacities, glass rods, volumetric flasks, glass slides, measuring cylinders of 100 200, 500 and 1000 ml capacity and pipette (10 ml capacity). Each Glassware were cleaned before utilization with soap followed by sterilization in 1 % formalin solution. Then these were cleaned by washing with detergent soap solution followed by rinsing several times in tap water and finally with distilled water. The glassware were autoclaved at 121°C temperature for 15 lbs pressure for 20 minutes and then were kept in laminar air flow for sterilization. The culture media was sterilized at 121°C temperature for 15 lbs pressure.

3.1.1.2 Other materials

Plastic sample container, camel hair brush, surgical cotton, 10 % honey solution, test tube stand, spirit lamp, spirit, iron racks, rubber, parafilm wax, autoclave polythene, eppendorf tubes, tissue paper, muslin cloth, rearing cages, plastic vials, mechanical blender, aluminum trays, etc. were made available in the Biocontrol Laboratory, Department of Entomology, Post Graduate Institute, MPKV, Rahuri.

3.1.1.3 Media

Saboraud's maltose agar fortified with one per cent yeast extract (SMAY) media (Bell, 1981) was used to isolate fungus in the laboratory. The media was composed of 40g maltose, 10g neopeptone, 15g agar and 10g yeast in 1000 ml distilled water. Petriplates and culture tubes (15.0 x 1.4 cm) were plugged with sterile cotton and autoclaved under 15 psi pressure at 121°C for 30 minutes. Medium was poured in sterile petri plates and culture tubes under laminar airflow.

Petri plates containing SMAY medium were inoculated with fungal spores from cadavers under aseptic conditions. The inoculated plates were incubated at 25 ±1°C in a BOD incubator for seven days. The spores thus produced in petriplates are further utilized in the identification of the fungus. Sub-culturing was done once in two months. The procedure for preparation of the media was followed which was given by Chaudhari *et al.* (2016).

3.1.2 Methods

3.1.2.1 Raising of the crop

Maize variety 'Parmeshwar (P 3302)' was sown with the spacing of 75 cm x 25 cm with size of 1000 meter square plot during the *kharif and rabi* season of the year 2021-2022. All the agronomic package of practices was adopted except plant protection in raising the crop.

3.1.2.2 Method of recording natural enemy's complex:

Observations were recorded weekly starting from 10 days after sowing. The observations were recorded on randomly selected ten plants from the unsprayed maize experimental fields in five quadrates. The population of natural enemies and their activity during the period was recorded at weekly interval on randomly selected plants up to tassel emergence stage of crop at Maize Improvement Project, MPKV, Rahuri. The roving survey was carried out at Rahuri Tahsil in the fields of fodder maize.

For parasitism studies, samples of various life stages of FAW (egg masses and larvae) were collected randomly from each quadrate during the observations. Egg masses present on plant parts were detached carefully, placed inside polythene bags and brought to the laboratory where they were held separately in rearing containers until the emergence of parasitoids or FAW larvae. Feeding injury in the leaf whorl and the

presence of fresh frass were used to locate FAW larvae. FAW caterpillars (L2-L4 instar) were collected from the whorl or unopened leaves of maize and placed individually into the sterilized plastic containers (Dimensions: 7 cm x 6 cm, Type: Vial) for further development. Every alternate day larvae were provisioned daily with fresh leaves of maize collected from the fields at the maize improvement project farm. These were surface-sterilized with an aqueous solution of sodium hypochlorite (0.05 %) followed by rinsing with distilled water. All specimens collected for retrieval were held in the eco-friendly laboratory (at $27 \pm 1^\circ\text{C}$ and 12:12 (L: D) photoperiod until completion for development of all life stages and the mortality was observed to get natural enemies. The containers were cleaned or replaced as needed to maintain sanitary conditions. After the emergence, parasitoids from different life stages of fall armyworm were stored each in 15 ml vial containing 70 % alcohol. During the record of observations on natural enemies visual counts of predators were taken from each quadrat (Firake *et al.* 2020a). For identification of parasitoids and predators expertise of advisory committee member and available literature was utilized.

3.1.2.3 Statistical analysis

The data of field experiments were analysed in FRBD. The per cent data was transformed into arc sine values and the number data was transformed in the square root of $n + 1$. The data obtained in the present investigation was subjected to statistical analysis as described by Gomez and Gomez (1984). Transformed data were subjected to design to get ANOVA for the comparison within the treatments.

3.2 Evaluation of the efficacy of biopesticides against *S. frugiperda*.

3.2.1 Materials

3.2.1.1 Laboratory materials

Different laboratory instruments used during the course of investigations were refrigerator, electronic weighing balance (capacity 1.5 kg), inoculating needles, forceps, blades, marker pen, cork borer etc. The glassware of borosil make were utilized for the conduct of experiments *viz.*, petri plates, test tube, conical flask, beakers of various capacities, glass rods, volumetric flasks, glass slides, measuring cylinders of 100 200, 500 and 1000 ml capacity and pipette (10 ml capacity). Each Glassware were cleaned before utilization with soap followed by sterilization in 1 % formalin solution.

Then these were cleaned by washing with detergent soap solution followed by rinsing several times in tap water and finally with distilled water.

The glassware were autoclaved at 121°C temperature for 15 lbs pressure for 20 minutes and then were kept in laminar air flow for sterilization. The culture media was sterilized at 121°C temperature for 15 lbs pressure.

3.2.1.2 Other materials

Plastic sample container, camel hair brush, surgical cotton, 10 % honey solution, test tube stand, spirit, iron racks, rubber, parafilm wax, autoclave polythene, eppendorf tubes, tissue paper, muslin cloth, rearing cages, plastic vials, mechanical blender, aluminum trays, etc. were made available in the Biocontrol Laboratory, Department of Entomology, Post Graduate Institute, MPKV, Rahuri.

Formulation of different commercial bio pesticides, chemical pesticides and other materials required for research purpose were obtained from various sources. The source details of all insecticides and bio-pesticides used for the research are given in the Table 1.

Table 1. Source of materials required for experiment on evaluation of the efficacy of biopesticides against *S. frugiperda*

Sr. No.	Name of the material	Source
1	<i>Metarhizium anisopliae</i>	Bio-control Lab, MPKV, Rahuri
2	<i>Beauveria bassiana</i>	Bio-control Lab, MPKV, Rahuri
3	<i>Metarhizium rileyi</i>	Department of Entomology, UAS, Dharwad
4	<i>Bacillus thuringiensis</i> var. <i>kurstaki</i>	M/s Margo Biocontrols Pvt. Ltd, Bengaluru, Karnataka
5	Azadirachtin 1500 ppm	M/s T Stanes and Company limited, Coimbatore, Tamil Nadu
6	Karanj oil 3 %	M/s Saiee Pharmachem, Pune
7	Chlorantraniliprole 18.5 % SC	M/s FMC India Pvt. Ltd, Bandra kurla complex(E),Mumbai

3.2.2 Methods

3.2.2.1 Laboratory experiment

The experiment was laid out in a complete randomized design (CRD) with three replications and seven treatments viz. *Metarhizium anisopliae*, *Beauveria bassiana*, *Metarhizium (Nomuraea) rileyi*, *Bacillus thuringiensis* v. *kurstaki*, azadirachtin and

karanj oil. Distilled water was used in the control treatment. Details of evaluated biopesticides are given in Table 2.

Table 2. Details of Biopesticides against fall armyworm

Tr. No.	Treatment	Formulations	Dose/l	Dose (per ha)
T ₁	<i>Metarhizium anisopliae</i>	1.15 %WP	5 g	2500 g
T ₂	<i>Beauveria bassiana</i>	1.15 %WP	5 g	2500 g
T ₃	<i>Metarhizium (Nomuraea) rileyi</i>	1.15 %WP	5 g	2500 g
T ₄	<i>Bacillus thuringiensis var. kurstaki</i>	0.5 %WP	2 g	1000 g
T ₅	Azadirachtin	1500 ppm	5 ml	2500 ml
T ₆	Karanj oil 3 %	Crude oil	3 ml	1500 ml
T ₇	Untreated control	-	-	-

3.2.2.1.1 Rearing of fall armyworm

The laboratory culture of fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Noctuidae : Lepidoptera) was initiated by collecting without damaged and disease free larvae (late instar) from the infested host plant of unsprayed maize fields at the Maize Improvement Project, MPKV, Rahuri during 2020-2021. Larvae were brought to the laboratory for rearing and placed individually in clean round plastic vials (measuring diameter 3.5 cm and height 4 cm) and provided with fresh maize leaf discs or maize leaf whorls as food. The rearing were performed in a room at $27 \pm 1^{\circ}\text{C}$ under a 14:10 h light/dark condition (Su *et al.*, 2019). The foods were changed at every 48 hr and the maize leaf whorls were sterilized in 0.05 % sodium hypochlorite followed by two rinses in distilled water. The pre-pupal stages were transferred for pupation to a plastic jar one-third filled with sterilized soil. After completion of pupal period (7 - 8 days) the pupae were observed daily until moths emerged. After the emergence of moths, single male-female were coupled and placed in a moistened petri dish in an oviposition cage. A small piece of absorbent cotton wool hanging in cage by rubber band previously soaked in 50 % honey solution placed in an oviposition cage as a food source for emerging adults. The cup cultured seedlings of maize were kept in egg laying cage as medium for egg laying. After 2–3 days, egg masses along the seedlings were collected from the oviposition cages and placed in sterile separate plastic jars. Eggs were monitored daily for hatching. As soon as the first instar larvae was emerged then they were provided with

tender and fresh maize leaves and seedlings of egg laying were removed once the larvae shifted on fresh leaves using camel hair brush. The second instar larvae were reared separately in the plastic vials on the spirals of maize whorls till the pupation to avoid cannibalism. The rearing of fall armyworm was carried out as per methods suggested by Kumar *et al.* (2021) and Ramzan *et al.* (2021).

3.2.2.1.2 Methodology

The leaf dip method was employed to assess the efficacy of various biopesticides against FAW (Ahmad *et al.*, 1995). Laboratory reared second instar larvae were used for the experiment. A fresh, uniform-sized maize whorl spirals of 2 cm in length were immersed in an aqueous biopesticides solution for 10 seconds and fed to the larvae up to 48 hrs. Treated leaf spirals were placed in plastic vials after rinsing the excess solution and ten second instar larvae were released in each vial. An untreated control was maintained with the leaf spirals dipped in distilled water. At every 48 hr larvae were shifted to sterilised vials and fresh maize whorl spirals were provided to avoid other infections. Larval mortality was recorded at 2, 4, 6, 8, 10 and 12 days after release of larvae to treated whorls. A larva was considered dead once the feeding was ceased. The larval mortality was calculated in each treatment and it was corrected by using Abbott's (1925) formula. The formula is given below.

$$\text{Per cent of mortality} = (\text{Number of dead larvae} / \text{Number of larvae introduced}) \times 100$$

$$\text{Corrected per cent mortality} = T - C / 100 - C \times 100$$

Where,

T = Per cent mortality of the test insect in treatments

C = Per cent mortality of the test insect in the control

3.2.2.1.3 Statistical analysis

The data of laboratory experiment were analysed in CRD. The per cent data was transformed into arc sine values and the number data was transformed in the square root of $n + 1$. The data obtained in the present investigation was subjected to statistical analysis as described by Gomez and Gomez (1984). Transformed data were subjected to design to get ANOVA for the comparison within the treatments.

3.2.2.2 Field Experiment

The field efficacy of commercial biopesticides against *S. frugiperda* on maize was evaluated in a randomized block design (RBD) with three replications and eight treatments including untreated control. The treatment details are mentioned in Table 3. The experiment was conducted at Maize Improvement Project, MPKV, Rahuri during *kharif* 2021 and *rabi* 2021. All the recommended agronomic practices given by MPKV, Rahuri were followed to raise the crop. Observations were recorded after infestation was noticed in Maize.

Table 3. Treatment details of biopesticides against fall armyworm under field experiment

Tr. No.	Treatment	Formulations	Dose/l	Dose (per ha)
T ₁	<i>Metarhizium anisopliae</i>	1.15 % WP	5 g	2500 g
T ₂	<i>Beauveria bassiana</i>	1.15 % WP	5 g	2500 g
T ₃	<i>Metarhizium rileyi</i>	1.15 % WP	5 g	1500 g
T ₄	<i>Bacillus thuringiensis</i> var. <i>kurstaki</i>	0.5 % WP	2 g	1000 g
T ₅	Azadirachtin	1500 ppm	5 ml	2500 ml
T ₆	Karanj oil 3 %	Crude oil	3 ml	1500 ml
T ₇	Chlorantraniliprole	18.5 % SC	0.4 ml	25 ml
T ₈	Untreated control	-	-	-

3.2.2.2.1 Methodology

The spraying was done manually by a hand-operated knapsack sprayer with a hollow cone nozzle. Two foliar sprays of each treatment were given at an interval of 14 days. The first spray was given after the incidence was noticed. The spray pump was washed with water, in the beginning and while switching over from one treatment to another to avoid mixing of insecticides during spraying. Sprays were given during the morning hour to avoid drift due to heavy winds. Untreated control was maintained by spraying water in the plot.

The observation of plant damage, larval population and leaf damage score were recorded from each treatment. The data was recorded one day before spraying as a pre-count while post-treatment counts were taken at 5, 10 and 14 days after spraying (DAS). Spraying was done at 14 days intervals and observations were recorded at pre

and post-sprays per plot. The per cent damage was calculated by the formula given below by Mallapur *et al.* (2018)

$$\text{Per cent damage} = N/T \times (100)$$

Where,

N = Total Number of damaged plants per plot,

T = Total number of plants per plot

Leaf damage score was done before and after sprays at 5, 10, 14 days per plot based on the fresh leaf damage. The data (Table 4) was recorded in a rating scale of 0-9 (Davis and Williams, 1992).

Table 4. Visual rating scale for maize leaf damage assessment

Rating score	Description of damage
0	No visible leaf damage
1	Only pin-hole damage
2	Pin-hole and small circular hole damage to leaves
3	Small elongated lesions of up to 13 mm on 1-3 leaf
4	Mid-sized elongated lesions (13 to 25 mm in length)
5	Large elongated lesions (>25 mm) and small portion eaten on 3-5 leaves
6	Elongated lesions (>25 mm) and large portion eaten on 3-5 leaves
7	Elongated lesions (>25 mm) and 50 % leaf eaten
8	Elongated lesions (>25 mm) on leaf whorl and 70 % leaf eaten
9	Most leave with long lesions and whorl completely defoliated

3.2.2.2.2 Details of a field experiment on efficacy of biopesticides during *kharif* and *rabi* 2021

Location	:	Maize Improvement Project, MPKV, Rahuri.	
Year	:	2021	
Design	:	Randomized Block Design	
Treatments	:	8	
Replication	:	3	
Crop	:	Maize	
Variety	:	P 3302	
Seed rate	:	20- 22 kg/ha	
Spacing	:	75 cm × 25 cm	
Plot size	:	4 × 3 m ²	
Season	:	<i>kharif</i>	<i>rabi</i>
Date of Sowing	:	07/08/2021	10/12/21
First Spray	:	02/09/2021	07/01/22
Second Spray	:	17/09/2021	22/01/22

3.2.2.2.3 Layout of field experiment during *kharif* and *rabi* 2021

Experiment Plot N ↑ ↓ S	Field Border			Farm Road
	R I	R II	R III	
	T ₁	T ₇	T ₂	
	T ₄	T ₃	T ₆	
	T ₇	T ₂	T ₄	
	T ₈	T ₅	T ₇	
	T ₃	T ₄	T ₁	
	T ₆	T ₈	T ₅	
	T ₂	T ₁	T ₃	
	T ₅	T ₆	T ₈	
Field Border				

Matured cobs were harvested from each treatment and dried in the shed for 7 days. Grains were manually removed from the crop using iron grain harvester. The yield kg/plot was recorded and converted into q/ha for statistical analysis. Per cent increase in yield over untreated control was also calculated by using the following formula (Gomez and Gomez, 1984).

$$\text{Per cent increase in yield over control} = \frac{T - C}{C} \times 100$$

Where,

T = Yield from the treated plot

C = Yield from the control plot

The cost incurred on the protection of the pest was summed up with the addition of the cost of treatments and labour charges. The net profit/returns were calculated based on the minimum support price.

$$\text{Incremental Cost Benefit Ratio} = \frac{\text{Net returns}}{\text{Total cost of protection}}$$

3.2.2.2.4 Statistical analysis

The data of laboratory and field experiment were analysed in CRD and RBD, respectively. The per cent data was transformed into arc sine values and the

number data was transformed in the square root of $n + 1$. The data obtained in the present investigation was subjected to statistical analysis as described by Gomez and Gomez (1984). Transformed data were subjected to design to get ANOVA for the comparison within the treatments.

3.3 Evaluation of efficacy and economics of poison baits against *S. frugiperda* in maize

3.3.1 Materials

Formulation of different commercial bio pesticides, chemical pesticides and other materials required for research purpose were obtained from various sources. Jaggary, rice bran and hand gloves were procured from local market. The source details of all insecticides and bio-pesticides used for the research are given in the Table 5.

Table 5. Source of materials required for experiment on evaluation of efficacy and economics of poison baits against *S. frugiperda* in maize

Sr. No.	Name of the material	Source
1	<i>Bacillus thuringiensis</i> var. <i>kurstaki</i>	M/s Margo Biocontrols Pvt. Ltd, Bengaluru, Karnataka
2	Bait GF-4867-0.01 % w/w RB containing spinetoram	Modern Pesticide Testing Scheme Department of Entomology, MPKV, Rahuri
3	Chlorantraniliprole 18.5 % SC	M/s FMC India Pvt. Ltd, Bandra kurla complex(E),Mumbai
4	Emamectin benzoate 5 % SG	M/s Sumil Chemical Industries Pvt. Ltd, Mumbai
5	Thiodicarb 75 % WP	M/s Bayer CropScience Ltd, Thane

3.3.2 Methodology

Five baits (Table 6) were formulated using the four different poisons *viz*; *Bacillus thuringiensis* var. *Kurstaki* (two doses), thiodicarb, emamectin benzoate, chlorantraniliprole. The efficacy of these formulations was evaluated along with a standard check of readily formulated bait of GF-4867-0.1 % w/w RB and untreated control.

The field experiment was laid in a randomized block design with three replications and 7 treatments including untreated control. Variety P 3302 was sown with a spacing of 75 cm x 25 cm and the plot size was 4 m x 3 m. The whorl applications were

done after 15 and 30 days after germination or when the incidence was noticed. The observations on plant damage, larval population and leaf damage score were recorded from each treatment. The data was recorded one day before application of treatments as a pre-count while post-treatment counts were taken at 5, 10 and 14 days after application (DAA). The observations were recorded on randomly selected 10 plants with a larval population in each plot. The damaged plant from each plot was recorded and the per cent of plant damage was calculated with the following formula given by Mallapur *et al.* (2018)

$$\text{Per cent damage} = N/T \times (100)$$

Where,

N = Total Number of damaged plants per plot,

T = Total number of plants per plot

Leaf damage score was recorded in each plot on randomly selected 10 plants based on the fresh leaf damage. At harvest, the yield per plot was recorded and converted into q/ha for comparison. On the basis of yield parameters of maize ICBR of treatments of poison baits were computed.

The yield data (kg/ha) of each treatment was recorded according to replications and after conversions into q/ha it was subjected to statistical analysis to test the significance of mean yield in different treatments. Per cent increase in yield over untreated control was also calculated by using the following formula (Gomez and Gomez, 1984).

$$\text{Per cent increase in yield over control} = \frac{T - C}{C} \times 100$$

Where,

T = Yield from the treated plot

C = Yield from the control plot

The economics of various baits was worked out to get the Incremental Cost Benefit Ratio. The cost incurred on the protection of the pest was summed up with the addition of the cost of treatments and labour charges. The net profit/returns were calculated based on the minimum support price.

$$\text{Incremental Cost Benefit Ratio} = \frac{\text{Net returns}}{\text{Total cost of protection}}$$

Table 6. Treatment details of poison baits against fall armyworm

Tr. No.	Treatment	Dose in gm or ml /kg
T ₁	Rice bran 10 kg + jaggery 2 kg + <i>B. thuringiensis</i> var. <i>Kurstaki</i>	12.50 gm/kg
T ₂	Rice bran 10 kg + jaggery 2 kg + <i>B. thuringiensis</i> var. <i>Kurstaki</i>	25.00 gm/kg
T ₃	Rice bran 10 kg + jaggery 2 kg + Thiodicarb 75 WP w/w 8 % (750 g.a.i/ha)	12.50 gm/kg
T ₄	Rice bran 10 kg + jaggery 2 kg + Emamectin benzoate 5 % SG w/w 8 % (200 g.a.i/ha)	2.50 gm/kg
T ₅	Rice bran 10 kg + jaggery 2 kg + Chlorantraniliprole 18.5 % SC w/w 8 % (40 g.a.i/ha)	1.88 ml/kg
T ₆	GF-4867-0.1 % w/w RB (Ready to use Bait) (5.00 g a.i./ha)	1.00 gm /whorl
T ₇	Untreated control	-----

3.3.2.1 Details of field experiment on bait evaluation during *kharif and rabi* 2021

Location	:	Maize Improvement Project, MPKV, Rahuri.	
Year	:	2021	
Design	:	Randomized Block Design	
Treatments	:	7	
Replication	:	3	
Crop	:	Maize	
Variety	:	P 3302	
Seed rate	:	20- 22 kg/ha	
Spacing	:	75 cm × 25 cm	
Plot size	:	4 × 3 m ²	
Season	:	<i>kharif</i> , 2021	<i>rabi</i> , 2021
Date of Sowing	:	07/08/2021	10/12/21
First Spray	:	15/09/2021	15/01/22
Second Spray	:	30/09/2021	30/01/22

3.3.2.2 Layout of field experiment on bait evaluation during *Kharif* and *Rabi* 2021

Experiment Plot	Field Border			Experiment Plot
	R I	R II	R III	
	T ₄	T ₃	T ₆	
	T ₇	T ₂	T ₄	
	T ₁	T ₅	T ₇	
	T ₃	T ₄	T ₁	
	T ₆	T ₇	T ₅	
	T ₂	T ₁	T ₃	
	T ₅	T ₆	T ₂	
Field Border				

3.3.2.3 Statistical analysis

The data of field experiment was analysed in RBD. The per cent data was transformed into arc sine values and the number data was transformed in the square root of $n + 1$. The data obtained in the present investigation was subjected to statistical analysis as described by Gomez and Gomez (1984). Transformed data were subjected to design to get ANOVA for the comparison within the treatments.

3.4 Validation of different fall armyworm management practices adopted by the farmers

Fall armyworm in maize used to manage by the farmers using their own techniques which include local botanical extracts, soil, sand, wood ash, lime, oils, soaps, detergents, etc. These techniques were validated through the evaluation of their efficacy against FAW in the field.

3.4.1 Materials

Formulation of different commercial bio pesticides, chemical pesticides and other materials required for research purpose were obtained from various sources. Ash, chlorine water, sand, chillies, detergent powder, hand gloves and lime were procured from local market. The neem seed powder and chlorantraniliprole 18.5 % SC were procured from M/s Liebig's Agro Chem Pvt.Ltd, Kolkata and M/s FMC India Pvt. Ltd, Bandra kurla complex (E), Mumbai, respectively.

3.4.2 Methodology

The field efficacy of farmer's practices were evaluated in a randomized block design with three replications and ten treatments (Table 7) including a standard check of chlorantraniliprole and untreated control for comparison. The variety P- 3302 was sown with a spacing of 75 cm x 25 cm and the plot size was 4 m x 3 m. The whorl applications were done after 15 days and 30 days after germination or when the incidence was noticed. The observations on plant damage, larval population and leaf damage score were recorded from each treatment. The data was recorded one day before application of treatments as a pre-count while post-treatment counts were taken at 5, 10 and 14 days after application (DAA). The observations were recorded on randomly selected 10 plants with a larval population in each plot. The damaged plant from each plot was recorded and the per cent of plant damage was calculated with the formula given by Mallapur *et al.* (2018).

$$\text{Per cent damage} = N/T \times (100)$$

Where,

N = Total Number of damaged plants per plot,

T = Total number of plants per plot

Leaf damage score was recorded in each plot on randomly selected 10 plants based on the fresh leaf damage. At harvest, the yield per plot was recorded and converted into q/ha for comparison. The yield data (kg/ha) of each treatment was recorded according to replication and after conversions into q/ha, it was subjected to statistical analysis to test the significance of mean yield in different treatments. Per cent increase in yield over untreated control was also calculated by using the following formula (Gomez and Gomez, 1984).

$$\text{Per cent increase in yield over control} = \frac{T - C}{C} \times 100$$

Where,

T = Yield from the treated plot

C = Yield from the control plot

Table 7. Details of the experiment on validation of farmer's practices

Tr. No.	Treatment	Dose /whorl or lit
T ₁	Wood Ash	5 gm/whorl
T ₂	Soil	5 gm/whorl
T ₃	Sand	5 gm/whorl
T ₄	Neem seed powder	2 gm/whorl
T ₅	Lime	5 gm/whorl
T ₆	Chilli extract spray 10 %	10 ml/l
T ₇	Chorine water 0.5 %	10 ml/whorl
T ₈	Chlorantraniliprole 18.5 SC	0.4 ml/l
T ₉	Detergent water	10 ml/ whorl
T ₁₀	Untreated control	Water spray

3.4.2.1 Details of a field experiment on validation of farmer's practices during *kharif* and *rabi* 2021

Location	:	Maize Improvement Project, MPKV, Rahuri.	
Year	:	2021	
Design	:	Randomized Block Design	
Treatments	:	10	
Replication	:	3	
Crop	:	Maize	
Variety	:	P-3302	
Seed rate	:	20- 22 kg/ha	
Spacing	:	75 cm × 25 cm	
Plot size	:	4 × 3 m ²	
Season	:	<i>kharif</i> , 2021	<i>rabi</i> , 2021
Date of Sowing	:	09/08/2021	13/12/21
First application	:	03/09/2021	15/01/22
Second application	:	18/09/2021	24/01/22

3.4.2.2 Layout of field experiment on validation of farmers practices

Experiment Plot	Field Border			Experiment Plot
	R I	R II	R III	
	T ₁	T ₈	T ₁₀	
	T ₂	T ₄	T ₉	
	T ₃	T ₁₀	T ₈	
	T ₄	T ₁	T ₇	
	T ₅	T ₂	T ₆	
	T ₆	T ₃	T ₅	
	T ₇	T ₉	T ₄	
	T ₈	T ₆	T ₃	
	T ₉	T ₇	T ₂	
	T ₁₀	T ₅	T ₁	
Field Border				

3.4.2.3 Statistical analysis

The data of field experiment was analysed in RBD. The per cent data was transformed into arc sine values and the number data was transformed in the square root of $n + 1$. The data obtained in the present investigation was subjected to statistical analysis as described by Gomez and Gomez (1984). Transformed data were subjected to design to get ANOVA for the comparison within the treatments.

3.5 Evaluation of different IPM strategies against fall armyworm, *S. frugiperda* in maize

3.5.1 Materials

Formulation of different commercial bio pesticides, chemical pesticides and other materials required for research purpose were obtained from various sources. Coriander seeds, marigold seedlings, jaggary, rice bran and hand gloves were procured from local market. The source details of all insecticides and bio-pesticides used for the research are given in the Table 8.

Table 8. Source of materials required for experiment on evaluation of different IPM strategies against fall armyworm, *S. frugiperda* in maize

Sr. No.	Name of the material	Source
1	<i>Metarhizium anisopliae</i>	Bio-control Lab, MPKV, Rahuri
2	<i>Metarhizium rileyi</i>	Department of Entomology, UAS, Dharwad
3	<i>Bacillus thuringiensis</i> var. <i>kurstaki</i>	M/s Margo Biocontrols Pvt. Ltd, Bengaluru, Karnataka
4	Azadirachtin 1500 ppm	M/s T Stanes and Company limited, Coimbatore, Tamil Nadu
5	Pheromone traps and lures	M/s Gaiagen Technologies Private Limited, Bengaluru, Karnataka.
6	Chlorantraniliprole 18.5 % SC	M/s FMC India Pvt. Ltd, Bandra kurla complex(E), Mumbai
7	Emamectin benzoate 5 % SG	M/s Sumil Chemical Industries Pvt. Ltd, Mumbai
8	Spinetoram 11.7 % SC	M/s Corteva Agriscience Pvt. Ltd., Hyderabad
9	Thiodicarb 75 % WP	M/s Bayer CropScience Ltd, Thane

3.5.2 Methodology

The comparative evaluation on three modules was carried out in this experiment (Table 9). The first module was formulated on common farmer's practices which includes three treatments. The second module was formulated based on the outcomes of the studies carried on field bioefficacy of biopesticides (3.2), poison bait (3.3), farmer's practices (3.4) and intercropping of marigold and use of pheromone traps from the IIMR IPM module for FAW. The third module was formulated by selecting some components of the IPM module recommended by IIMR, Ludhiana. The sowing of each module was carried out over an area of 1400 m² during the *kharif* and *rabi* 2022. Each module was further divided into seven regions to serve as replications for taking observations and further statistical analysis (Bhavya, 2006). The variety P-3302 was grown following the package of practices recommended by MPKV, Rahuri. The observations on damaged plants, larval population and natural enemies were recorded at 10, 20, 30, 40, 50 and 60 days after emergence of crop on randomly selected ten plants at five locations in "W" pattern from each module. ETL level based on trapping of moths in

pheromone trap i.e. 1 moth per trap per day. The data were calculated on per cent damaged plants infesting *S. frugiperda* (Mallapur *et al.*, 2018).

Table 9. The details treatment of each module

Tr. No.	Treatment	Dose/ l /whorl
A	Farmers Practice module	
1	Emamectin benzoate 5 % SG @ 0.4 gm /l at 20-25 DAS	0.4 g/l
2	Chlorantraniliprole 18.5 SC @ 0.3 ml/l 30-35 DAS	0.4 ml/l
3	Spinetoram 11.7 SC 0.4 ml/lit 45-50 DAS	0.4 ml/l
B	Proposed IPM module	
1	Intercropping with marigold	6:2 (Maize : Marigold)
2	Install pheromone trap	4 /acre
3	Spraying Azadirachtin 1500 ppm 0.03 % at ETL	5 ml /lit
4	Spraying <i>Metarhizium rileyi</i> 10 days after first application	5 g /lit
5	Spraying of <i>Bacillus thuringiensis</i> var. <i>kurstaki</i> 10 days after the second application	2 g /l
6	Bait of chlorantraniliprole 18. 5 % SC @ 1.88 ml/kg after third application	2 g /whorl
7	Spraying of chlorantraniliprole 10 days after fourth application	0.4 ml/lit
C	Existing IPM module	
1	Intercropping with coriander	6:2 (Maize: Coriander)
2	Install pheromone trap	4 /acre
3	Spraying of 5 % NSKE at 5 % infestation of FAW	5 ml /lit
4	Spraying of <i>Metarhizium anisopliae</i> at 10 % infestation of FAW	5 g/lit
5	Spraying of <i>Bacillus thuringiensis</i> var. <i>kurstaki</i> at 10 % infestation of FAW	2 g/lit
6	Poison bait of thiodicarb at 20 % infestation	5 g -10 g pellet/ whorl
7	Spraying of chlorantraniliprole 18.5 % SC at 20 % infestation	0.4 ml /lit

$$\text{Per cent damage} = N/T \times (100)$$

Where,

N = Total Number of damaged plants per plot,

T = Total number of plants per plot

The observations on yield were recorded at harvest as kg/plot and were converted into q/ha for comparison. The details of treatment in each module are given in Table 7. The economics of different modules were worked out to get the Incremental Cost Benefit Ratio for comparing economic feasibility. The cost incurred on the protection of the pest was summed up with the addition of the cost of treatments and labour charges. The net profit/returns were calculated based on the minimum support price.

$$\text{Incremental Cost Benefit Ratio} = \frac{\text{Net returns}}{\text{Total cost of protection}}$$

3.5.2.1 Details of Field Experiment on validation of IPM during *kharif* and *rabi* 2022

Location	:	Maize Improvement Project, MPKV, Rahuri.		
Year	:	2022		
Crop	:	Maize		
Variety	:	P-3302		
Seed rate	:	20- 22 kg/ha		
Spacing	:	75 cm × 25 cm		
Plot size	:	0.14 ha (each)		
Season	:			
<i>Kharif, 2022</i>				
IPM modules	:	Farmers Practice	Proposed module	Existing module
Date of Sowing	:	08/08/22	08/08/22	09/08/22
First application	:	28/08/22	23/08/22	26/08/22
Second application	:	09/09/22	01/09/22	06/09/22
Third Application	:	21/09/22	14/09/22	16/09/22
Fourth application	:	-	24/09/22	26/09/22
Fifth application	:	-	--	07/10/22
<i>Rabi, 2022</i>				
Date of Sowing	:	18/11/22	18/11/22	18/11/22
First application	:	08/12/22	03/12/22	05/12/22
Second application	:	20/12/22	13/12/22	15/12/22
Third Application	:	03/01/23	23/12/22	25/12/22
Fourth application	:	--	No infestation	06/01/23
Fifth application	:	--	--	

3.5.2.2 Statistical Analysis

The data of field experiment was analysed in FRBD. The per cent data was transformed into arc sine values and the number data was transformed in the square root of $n + 1$. The data obtained in the present investigation was subjected to statistical analysis as described by Gomez and Gomez (1984). Transformed data were subjected to design to get ANOVA for the comparison within the treatments.

4. RESULTS AND DISCUSSION

The studies on “Eco-friendly management of fall armyworm *S. frugiperda* (J. E. Smith) in Maize” were conducted at Maize Improvement Project, MPKV, Rahuri during *kharif* and *rabi* seasons of the year 2021-22 and 2022-23. The results obtained during the course of investigations are presented and discussed under the following heads.

4.1 Studies on natural enemy complex of *S. frugiperda* infesting maize

In this experiment, natural enemies were documented from 33th SMW to 52nd SMW in five quadrates. The observations recorded on natural enemies during *kharif* and *rabi* 2021 are presented and discussed below.

4.1.1 Natural enemies (*kharif* 2021)

4.1.1.1 Per cent parasitism by parasitoids and entomopathogens

The data pertaining to per cent parasitism of egg parasitoids, larval parasitoids and entomopathogens (*T. remus*, *Trichogramma* spp., *C. chlorideae*, *M. rileyi*) observation during *kharif* 2021 are presented in Table 11.

In the 33th meteorological standard week (SMW), no parasitism of natural enemies was observed. In the 34th SMW, *T. remus* showed the highest parasitism (26.67 %) followed by *Trichogramma* spp. (6.67 %). During the 35th SMW, *T. remus* recorded the highest parasitism (46.44 %) followed by *Trichogramma* spp. (18.45 %). This was followed by *M. rileyi* (11.39 %) and *C. chlorideae* (6.32 %). However, they were, at par with each other.

T. remus continued to dominate with 65.33 per cent parasitism during 36th SMW. The parasitism by *Trichogramma* spp. (20.67 %) was at par with *M. rileyi* (19.24 %). The next to follow was *C. chlorideae* which recorded 12.53 per cent larval parasitism. In the 37th SMW, *T. remus* maintained the highest parasitism of 48.36 per cent followed by *Trichogramma* spp. (15.91 %). The next to follow were *M. rileyi* and *C. chlorideae*, being at par, which recorded 20.90 and 16.15 per cent parasitism, respectively.

T. remus recorded the highest parasitism (29.00 %) during 38th SMW followed by *M. rileyi* (23.03 %) to which it was on par. *C. chlorideae* and *Trichogramma* spp. were next to follow which recorded parasitism of 17.79 and 2.86 per cent, respectively. In the 39th SMW, *M. rileyi* recorded highest parasitism (23.57 %) followed by *C.*

chloridae (20.95 %) to which it was on par. *T. remus* and *Trichogramma* spp. were next to follow which recorded parasitism of 15.00 and 5.00 per cent, respectively.

In the 40th SMW, *M. rileyi* recorded the highest parasitism (26.82 %) followed by *C. chloridae* and *T. remus*, ranging from 16.75 to 16.67 per cent. *C. chloridae* recorded the highest parasitism (5.00 %) followed by *M. rileyi* (4.00 %) during 41th SMW.

The week wise mean of per cent parasitism revealed that 36th SMW recorded the highest parasitism of natural enemies (29.44 %), on par with the 37th SMW (25.33 %). The next to follow were 35th, 38th and 39th SMW, being at par which recorded parasitism which ranged from 20.65 to 16.13 per cent, which was followed by 40th, 34th and 41th SMW weeks with a parasitism in the range of 15.06 to 2.25 per cent.

The mean of parasitism of all the natural enemies revealed that *T. remus* had the highest parasitism (27.50 %), followed by *M. rileyi*, *C. chloridae* and *Trichogramma* spp. which recorded 14.33, 10.61 and 7.73 per cent parasitism, respectively.

The data on interaction between week and parasitism by natural enemies indicated that the egg parasitoid, *T. remus* was significantly superior, recording the highest parasitism (65.33 %) in the 36th SMW.

4.1.1.2 Predators observed during *kharif* 2021

The data pertaining to predators (spiders, coccinellids and earwigs) observation during *kharif* 2021 are presented in Table 12.

The 35th SMW recorded the highest population of predators (0.55 adults/plant). It was, however, at par with 36th and 37th SMW which recorded 0.49 and 0.47 adults per plant, respectively. The next to follow were 38th, 34th and 39th SMW, being at par which recorded predators ranged from 0.43 to 0.32 adults per plant. The 40th recorded 0.26 adults per plant. This was followed by 41th and 33th SMW which recorded predators of 0.13 to 0.05 adults per plant, respectively.

The mean of all predators revealed that earwigs had the highest population (0.38 adults/plant) followed by spiders (0.36 adults /plant) to which it was on par. The next to follow was coccinellids which recorded 0.27 adults per plant.

Table 10. Natural enemies on FAW during field survey

SN	Name of the parasitoid/predators/pathogen	Order and family	Type
1	<i>Telonomus remus</i>	Hymenoptera: Platygasteridae	Egg parasitoid
2	<i>Trichogramma</i> spp.	Hymenoptera: Trichogrammatidae	Egg parasitoid
3	<i>Chelonus formosanus</i>	Hymenoptera: Braconidae	Egg-larval parasitoid
4	<i>Campoletis chlorideae</i>	Hymenoptera :Ichneumonidae	Larval parasitoid
5	<i>Metarhizium rileyi</i>	Clavicipitaceae	Entomopathogenic fungus
6	Earwig	Dermaptera	Predator
7	Spiders	Araneae	Predator
8	Coccinellids	Coleoptera	Predator

Table 11. Per cent parasitism by parasitoids and entomopathogens during *kharif* 2021

S N	Natural Enemies	Standard Meteorological Week									
		33	34	35	36	37	38	39	40	41	Average
1	<i>Telenomus remus</i>	0.00 (0.00)	26.67 (25.04)	46.44 (42.88)	65.33 (54.08)	48.36 (44.10)	29.00 (32.40)	15.00 (14.99)	16.67 (16.05)	0.00 (0.00)	27.50 (25.51)
2	<i>Trichogramma</i> spp.	0.00 (0.00)	6.67 (7.05)	18.45 (25.39)	20.67 (26.94)	15.91 (21.03)	2.86 (4.44)	5.00 (6.00)	0.00 (0.00)	0.00 (0.00)	7.73 (10.09)
3	<i>Metarhizium rileyi</i>	0.00 (0.00)	0.00 (0.00)	11.39 (15.49)	19.24 (25.61)	20.90 (27.11)	23.03 (28.54)	23.57 (28.89)	26.82 (28.13)	4.00 (5.31)	14.33 (17.68)
4	<i>Campoletis chlorideae</i>	0.00 (0.00)	0.00 (0.00)	6.32 (11.33)	12.53 (18.48)	16.15 (23.40)	17.79 (24.31)	20.95 (26.27)	16.75 (21.38)	5.00 (6.00)	10.61 (14.57)
	Mean	0.00 (0.00)	8.33 (8.02)	20.65 (23.77)	29.44 (31.28)	25.33 (28.91)	18.17 (22.42)	16.13 (19.04)	15.06 (16.39)	2.25 (2.83)	
		S.Em. +					CD at 5 %				
	NEs	1.52					4.26				
	Week	2.28					6.39				
	NEs x Week	4.57					12.78				

Figures in the parentheses are arc sin transformed values, DAS =Days after sowing

The data on the interaction between week and predators indicated that the earwigs recorded the highest population (0.64 adults/ plant) in the 35th SMW. It was, however, at par with coccinellids (0.62 adults/plant -34th SMW and 0.54 adults/plant-35th SMW) and spiders (0.62 adults/plant – 38th SMW and 0.50 adults/plant – 36th and 37th SMW).

Correlation coefficient study (Table 13) revealed that the predators i.e. spiders, coccinellids and earwigs indicated positive correlation, as larval population and per cent infestation of fall armyworm increases the population of predator also increases.

4.1.2 Natural enemies (*rabi* 2021)

4.1.2.1 Per cent parasitism by parasitoids

The data (Table 14) on the per cent parasitism observation on weekly basis during *rabi* 2021 are presented below.

In the 44th SMW, no parasitism was recorded. During the 45th SMW *T. remus* recorded the highest parasitism (21.67 %) followed by *C. chloridae* (11.67 %). In the 46th SMW, *T. remus* recorded the highest parasitism (29.00 %), followed by *C. chloridae* (28.45 %) to which it was on par. *Trichogramma* spp. was next to follow which recorded 4 per cent parasitism. In the 47th SMW, *T. remus* recorded the highest parasitism (31.67 %) followed by *C. chloridae* (21.64 %) and *Trichogramma* spp. (12.33 %).

In the 48th SMW, highest parasitism recorded by *T. remus* (38.32 %) but was at par with *C. chloridae* (35.15 %). The next to follow was *Trichogramma* spp. which recorded 11.94 per cent parasitism. In the 49th SMW, *C. chloridae* recorded highest parasitism i.e. 35.71 per cent followed by *T. remus* (21.33 %) and *Trichogramma* spp. (3.33 %). *C. chloridae* recorded highest parasitism 37.35 per cent even at 50th SMW. The next to follow was *T. remus* which recorded 9.00 per cent parasitism. In the 51st and 52nd SMW, *C. chloridae* recorded highest parasitism which recorded 18.00 and 4.00 per cent respectively.

Among the weeks, the highest parasitism of parasitoids (28.47 %) recorded during 48th SMW. It was, however, at par with 47th SMW which recorded 21.88 per cent parasitism. The next to follow were 46th, 49th and 50th SMW, being at par, recorded parasitism in the range of 20.48 to 15.45 per cent. The next in decreasing parasitism rate of parasitoids were recorded in 45th, 51st and 52st SMW which ranged from 11.11 to 1.33 per cent.

Table 12. Predators observed during *kharif* 2021

Sr. No.	Natural Enemies	Standard Meteorological Week									Mean of NEs /plant
		33	34	35	36	37	38	39	40	41	
1.	Spiders /plant	0.04 (1.02)	0.32 (1.15)	0.46 (1.21)	0.50 (1.22)	0.50 (1.22)	0.62 (1.27)	0.34 (1.16)	0.28 (1.13)	0.16 (1.08)	0.36 (1.16)
2.	Coccinellids /plant	0.12 (1.06)	0.62 (1.27)	0.54 (1.24)	0.40 (1.18)	0.30 (1.14)	0.16 (1.08)	0.14 (1.07)	0.12 (1.06)	0.06 (1.03)	0.27 (1.13)
3.	Earwigs /plant	0.00 (1.00)	0.08 (1.04)	0.64 (1.28)	0.58 (1.26)	0.60 (1.27)	0.52 (1.23)	0.48 (1.22)	0.38 (1.17)	0.16 (1.08)	0.38 (1.17)
	Mean	0.05 (1.03)	0.34 (1.15)	0.55 (1.24)	0.49 (1.22)	0.47 (1.21)	0.43 (1.19)	0.32 (1.15)	0.26 (1.12)	0.13 (1.06)	
		SE (m)					CD at 5 %				
	NEs	0.01					0.02				
	Week	0.01					0.04				
	NEs x Week	0.02					0.06				

Figures in parenthesis are $\sqrt{x + 0.05}$ transformed values, DAS =Days after sowing

Table 13. Correlation between the incidence of fall armyworm and its predators in maize (*kharif* 2021)

S N	Particulars of fall armyworm	Predators		
		Spiders/plant	Coccinellids/plant	Earwigs /plant
1	Larval population/ plant	0.756**	0.546*	0.722**
2	% infestation FAW	0.784**	0.554*	0.712**

No. of observations N=9, *Significant at 5 per cent level, ** Significant at 1 per cent level, SMW: Standard Meteorological Week

Table 14. Parasitism by parasitoids (%) during *rabi* 2021

Sr. No.	Natural Enemies	Standard Meterological Week									Mean of NEs
		44	45	46	47	48	49	50	51	52	
1.	<i>Telenomus remus</i>	0.00 (0.00)	21.67 (22.04)	29.00 (32.17)	31.67 (34.04)	38.32 (38.12)	21.33 (24.72)	9.00 (11.31)	0.00 (0.00)	0.00 (0.00)	16.78 (18.05)
2.	<i>Trichogramma</i> spp.	0.00 (0.00)	0.00 (0.00)	4.00 (5.31)	12.33 (16.13)	11.94 (18.08)	3.33 (4.82)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	3.51 (4.93)
3.	<i>Camponotus chlorideae</i>	0.00 (0.00)	11.67 (13.05)	28.45 (31.44)	21.64 (24.76)	35.15 (36.28)	35.71 (36.54)	37.35 (37.38)	18.00 (19.84)	4.00 (5.31)	21.33 (22.73)
	Mean	0.00 (0.00)	11.11 (11.70)	20.48 (22.98)	21.88 (24.98)	28.47 (30.83)	20.13 (22.03)	15.45 (16.23)	6.00 (6.61)	1.33 (1.77)	
		SE (m)					CD at 5 %				
	NEs	1.52					4.28				
	Week	2.64					7.41				
	NEs x Week	4.57					12.83				

Figures in the parentheses are arc sin transformed values, DAS =Days after sowing

The mean of all parasitoids revealed *C. chloridae* as the dominant species (21.33 % parasitism). It was followed by *T. remus* and *Trichogramma* spp. which recorded the parasitism of 16.78 and 3.51 per cent, respectively. The data on the interaction between week and parasitism by natural enemies indicated that *T. remus* recorded the highest parasitism (38.32 %) during the 48th SMW. It was, however, at par with *C. chloridae* which recorded parasitism of 37.35, 35.71 and 35.15 per cent in 50th, 49th and 48th SMW, respectively.

It could be also seen that among the mean of all natural enemies the highest parasitism recorded by *T. remus* and *C. chloridae* during *kharif* 2021 and *rabi* 2021 respectively in maize field (Fig.1 to 2).

4.1.2.2 Predators observed during *rabi* 2021

The data pertaining to predators (spiders, coccinellids and earwigs) observation during *rabi* 2021 are presented in Table 15.

The data on the week wise mean of predators revealed that 46th SMW recorded the highest population of predators (0.50 adults/plant). It was, however, at par with 47th SMW which recorded 0.43 adults per plant. The next to follow were 48th and 49th SMW, being at par which recorded predators of 0.37 and 0.34 adults per plant, respectively. The 50th SMW recorded 0.28 adults per plant but was at par with 51st and 45th SMW which recorded 0.22 and 0.21 adults per plant, respectively. This was followed by 52nd and 44th SMW which recorded predators of 0.12 and 0.03 adults per plant, respectively.

The mean of all predators revealed that earwigs had the highest population (0.33 adults/plant) followed by spiders (0.28 adults /plant) to which it was on par. The next to follow was coccinellids which recorded 0.22 adults per plant. The data on interaction between week and predators indicated that the earwigs recorded the highest population (0.54 adults/plant) in the 48th SMW. It was, however, at par with coccinellids (0.52 adults/plant – 46th SMW) and spiders (0.52 adults/plant- 46th SMW and 0.46 adults/plant-47th SMW).

Correlation coefficient study (Table 16) revealed that the predators i.e. spiders, coccinellids and earwigs indicated positive correlation, as larval population and per cent infestation of fall armyworm increases the population of predator also increases.

Table 15. Predators observed during *rabi* 2021

Sr. No.	Natural Enemies	Standard Meteorological Week									Mean of NEs/ plant
		44	45	46	47	48	49	50	51	52	
1.	Spiders / plant	0.00 (1.00)	0.08 (1.04)	0.52 (1.23)	0.46 (1.21)	0.34 (1.16)	0.36 (1.17)	0.34 (1.16)	0.26 (1.12)	0.12 (1.06)	0.28 (1.13)
2.	Coccinellids / plant	0.08 (1.04)	0.38 (1.18)	0.52 (1.23)	0.36 (1.17)	0.24 (1.11)	0.16 (1.08)	0.16 (1.08)	0.06 (1.03)	0.06 (1.03)	0.22 (1.10)
3.	Earwigs / plant	0.00 (1.00)	0.16 (1.08)	0.46 (1.21)	0.46 (1.21)	0.54 (1.24)	0.50 (1.22)	0.34 (1.16)	0.34 (1.16)	0.18 (1.09)	0.33 (1.15)
	Mean	0.03 (1.01)	0.21 (1.10)	0.50 (1.22)	0.43 (1.19)	0.37 (1.17)	0.34 (1.16)	0.28 (1.13)	0.22 (1.10)	0.12 (1.06)	
		SE (m)					CD at 5 %				
	NEs	0.01					0.02				
	Week	0.01					0.03				
	NEs x Week	0.02					0.05				

Figures in parenthesis are $\sqrt{x + 0.05}$ transformed values, DAS =Days after sowing

Table 16. Correlation between the incidence of fall armyworm and its predators in maize (*rabi* 2021)

SN	Particulars of fall armyworm	Predators		
		Spiders/plant	Coccinellids/plant	Earwigs/plant
1	Larval population/ plant	0.904**	0.893**	0.800**
2	% infestation FAW	0.912**	0.915**	0.817**

No. of observations N=9, *Significant at 5 per cent level, ** Significant at 1 per cent level, SMW: Standard Meteorological Week

4.1.3 Survey of Natural enemies

A comprehensive survey was conducted in Rahuri Tahsil to document natural enemies. Five distinct species targeting fall armyworm (FAW) were recorded in the surveyed locations, comprising egg, egg/larval, larval and fungal pathogens (Table 17 to 19). These included two species of *Telenomus remus* Nixon and *Trichogramma* spp. as egg parasitoids, *Chelonus formosanus* as an egg/larval parasitoid, *C. chloridae* as a larval parasitoid and the fungal pathogen *M. rileyi*. In all, 145 egg masses were collected, with 34 being parasitized by the egg parasitoids, resulting in a 23.75 per cent parasitism rate in the maize ecosystem.

The per cent parasitism by egg parasitoids ranged from 12.50 to 66.67 per cent in Rahuri Tehsil. *Chelonus formosanus* exhibited a 33.33 per cent parasitism rate with only two egg masses. The larval parasitism of fall armyworm by *C. chloridae* ranged from 7.69 to 31.58 per cent, contributing to a total larval parasitism of 16.65 per cent in maize. Additionally, *M. rileyi*-infected cadavers were recorded at various locations, with numbers ranging from 1 to 3. In the experimental farm, predators such as earwigs, spiders and coccinellids were observed. The presence of natural enemies plays a pivotal role in designing biological control strategies for fall armyworm, whether through the conservation of local natural enemies, introduction from external sources, or augmentative releases. In the present investigation, eight different natural enemies species affecting various life stages of fall armyworm were identified, including three predators, four parasitoids and one pathogen.

Predators:

Among natural enemies, earwigs, spiders and coccinellids were observed, mostly during the vegetative stage of the crop. These predators were frequently found in the whorls of the plants. The findings of the present study are in line with Sueldo *et al.*(2010) who reported that the earwig, *Doru lineare* Eschscholtz (Dermaptera: Forficulidae) was fed on fall armyworm egg masses in maize fields in Argentina. However, earlier research reports described *Cosmolestes sp.*, spiders and *Oxyopes birmanicus*) as predators of fall armyworm larvae as reported by Firake and Behere, (2020a).

Parasitoids

The studies identified two egg parasitoids, *T. remus* and *Trichogramma* spp., one egg/larval parasitoid, *Chelonus formosanus* and one larval parasitoid, *C. chloridae*. *T. remus* exhibited a higher rate of parasitism (16.67 % to 66.67 %) compared to *Trichogramma* spp. The current findings are also consistent with those of Sissay *et al.* (2019a), who reported that *T. remus* was the major egg parasitoid and recorded 69.30 per cent egg mortality. Laminou *et al.* (2020) and Liao *et al.* (2019) found that *T. remus* parasitized eggs at the rate of about 64 per cent and 50 per cent, respectively under field conditions. All these reports lend support to the present findings.

Navik *et al.* (2021) reported that, *T. remus* and *T. chilonis* parasitized eggs of *S. frugiperda* to the extent of 5.44 to 8.78 per cent and 15.81 to 23.87 per cent, respectively. A range of 14.5 to 25.9 per cent egg parasitism by *T. remus* was reported by Agboyi *et al.* (2020). In the present investigation, it was revealed that *T. remus* was found to dominate in egg parasitism over *T. chilonis*. *Telenomus sp.* was able to get through the protective layer of scales on FAW egg masses and they parasitized equally. Because of its larger, more robust size compared to *T. chilonis*. *Telenomus sp.* was described as an aggressive parasitoid because it allowed it to penetrate all layers of the FAW egg mass and parasitize more eggs by putting its ovipositor vertically downward. Similar findings were reported by Cave and Acosta (1999), Cave (2000), Pomari *et al.* (2012) and Laminou *et al.* (2020). All these earlier reports are in support of present findings.

Among larval parasitoids, *C. chloridae* cocoon sightings were frequent in the field, suggesting potential target of early instar larvae. These findings are in accordance with Bajpai *et al.* (2006), who reported that *C. chloridae* mostly attack the first or second instars of *S. litura*. According to Sharanabasappa *et al.* (2019) and Navik *et al.* (2021) larval parasitism by *C. chloridae* was 2 - 3, 1.86 - 6.63 per cent, respectively. Further, Mallapur *et al.* (2022) also reported that larvae of *S. frugiperda* was parasitized by the *C. chloridae* (2-11 pupae/20 pls). All these earlier reports lend support to the present finding.

The present findings on the egg larval parasitoid *Chelonus formosanus* are in agreement with Firake and Behere (2020b) who recorded 74 per cent larval mortality, mainly due to the egg-larval parasitoid *C. formosanus* Sonan (5 %). Also, Dorji *et al.* (2022)

identified 48 natural enemy species associated with the fall armyworm infested maize fields in Bhutan and one of them was *C. formosanus* which was found to parasitize on eggs of FAW. Parasitism of *S. frugiperda* by *C. formosanus* (0-2 adults/ 20 pls) noticed in the natural ecosystem was also endorsed by Mallapur *et al.* (2022).

Table 17. Fall armyworm parasitoids and their parasitism in maize

Location	Age of crop (Weeks)	Total egg mass (No)	Parasitized egg mass (No)	parasitism (%)	Species
Rahuri	4	6	3	50.00	<i>T. remus</i> and <i>Trichogramma</i> spp.
	4	3	1	33.33	<i>Chelonus formosanus</i>
	4	7	2	28.57	<i>T. remus</i>
	5	5	1	20.00	<i>T. remus</i>
	5	11	2	18.18	<i>T. remus</i>
	5	8	1	12.50	<i>Trichogramma</i> spp.
Digras	3	4	0	0.00	--
	4	3	1	33.33	<i>T. remus</i>
	4	4	1	25.00	<i>T. remus</i>
	5	6	1	16.67	<i>T. remus</i>
	5	8	2	25.00	<i>T. remus</i>
Taklimiya	4	6	1	16.67	<i>Trichogramma</i> spp.
	4	4	1	25.00	<i>T. remus</i>
	5	5	1	20.00	<i>T. remus</i>
	6	4	0	0.00	--
	6	5	0	0.00	--
Vambori	4	4	1	25.00	<i>T. remus</i>
	4	6	2	33.33	<i>T. remus</i>
	5	8	1	12.50	<i>Trichogramma</i> spp.
	6	5	1	20.00	<i>T. remus</i>
	6	7	0	0.00	--
Experimental farm	4	4	1	25.00	<i>T. remus</i>
	4	6	4	66.67	<i>T. remus</i>
	5	3	1	33.33	<i>Trichogramma</i> spp.
	5	5	2	40.00	<i>T. remus</i> and <i>Trichogramma</i> spp.
	6	8	3	37.50	<i>T. remus</i>
Average parasitism				23.75	

Activity of predators *viz.*, earwigs, spiders and coccinellids, as observed in the present investigation are in conformity with Mallapur *et al.* (2022). It was reported

that *S. frugiperda* was severely attacked by earwigs (1-8 / 20 pls), spiders (1-7 / 20 pls), coccinellids (1-5 grubs/ 20 pls). All these reports lend support to the present finding.

Fungal Pathogen

The survey identified *Metarhizium rileyi* as an entomopathogenic fungus in the maize field, contributing to the natural control of fall armyworm. Present findings are in conformity with Mallapur *et al.* (2022) who observed *M. rileyi* infection to the extent of 8- 43 per cent. Further, Firake and Behere (2020a) reported more than 50 per cent of natural mortality of FAW larvae by the entomopathogenic fungus, *M. rileyi* and the baculovirus, *SpfvNPV* were observed throughout the season. Studies by Ruiz *et al.* (2013) revealed that the natural occurrence of *M. rileyi* fungus in the area of origin in Mexico with about 3 per cent of FAW larval mortality of 3rd- 6th instar in whorl-stage maize. All these reports lend support to the present findings.

Table 18. Parasitism by *Campoletis chloridae* on FAW in Maize

Location	Age of crop (Week)	Larvae (No)	Parasitized larvae (No)	Larval Parasitism (%)
Rahuri	4	8	1	12.50
	5	12	3	25.00
	5	10	2	20.00
	6	19	6	31.58
	7	13	3	23.08
Digras	5	6	0	0.00
	6	14	2	14.29
	6	18	4	22.22
	7	9	1	11.11
	7	10	2	20.00
Taklimiya	5	13	2	15.38
	5	15	1	6.67
	6	17	3	17.65
	6	11	3	27.27
	7	16	4	25.00
Vambori	4	12	0	0.00
	5	15	2	13.33
	5	17	3	17.65
	5	13	1	7.69
	6	11	0	0.00
Experimental farm	4	7	1	14.29
	5	9	2	22.22
	6	16	5	31.25
	6	14	3	21.43
	7	12	2	16.67
Average parasitism				16.65

Table 19. Infection by fungal pathogen on FAW in Maize

Location	Age of crop (Week)	No of cadavers	Species recorded
Rahuri	7	3	<i>M. rileyi</i>
	8	2	<i>M. rileyi</i>
Digras	7	2	<i>M. rileyi</i>
	7	1	<i>M. rileyi</i>
Taklimiya	8	3	<i>M. rileyi</i>
	8	2	<i>M. rileyi</i>
Vambori	7	3	<i>M. rileyi</i>
	8	1	<i>M. rileyi</i>
Experimental farm	8	3	<i>M. rileyi</i>
	8	2	<i>M. rileyi</i>

4.2 Evaluation of the efficacy of biopesticides against *Spodoptera frugiperda*

In the present investigation, different biopesticides were evaluated for their efficacy against *S. frugiperda* infesting maize under laboratory and field conditions. The study was conducted for the efficacy of these biopesticides and the results are presented.

4.2.1 Efficacy of different biopesticides against *S. frugiperda* under laboratory conditions

The data on per cent mortality of larvae of *S. frugiperda* under laboratory conditions are presented in Table 20. There were significant variations among treatments at all intervals of observation.

At 2 DAT, it reveals that botanicals viz. azadirachtin @ 5 ml/l and karanj oil @ 3 ml/l recorded 10, 6.67 per cent larval mortality, respectively whereas the treatment *B. thuringiensis* @ 2 g/l recorded 6.67 per cent mortality. However, these treatments were non-significant to each other and there was no larval mortality observed in the treatments with mycoinsecticides.

At 4 DAT, *B. thuringiensis* 2 g/l (56.67 %) was the most effective treatment. It was, however, at par with azadirachtin @ 5 ml/l (43.33 %). The next effective treatments were *M. rileyi* @ 5 g/l, karanj oil @ 3 ml/l, *M. anisopliae* @ 5 g/l and *B. bassiana* @ 5 g/l, being at par, recorded, the larval mortality of 40.00, 36.67, 36.67 and 30.00 per cent, respectively.

At 6 DAT, *B. thuringiensis* @ 2 g/l (75.93 %) was found to be the most effective and was at par with *M. rileyi* @ 5 g/l (65.19 %). The next promising treatment

was *M. anisopliae* @ 5 g/l (54.81 %) followed by azadirachtin @ 5 ml/l (44.44 %) to which it was on par. The next to follow were karanj oil @ 3 ml/l (40.74 %) and *B. bassiana* @ 5 g/l (37.78 %) but were at par with each other.

At 8 DAT, *B. thuringiensis* @ 2 g/l (82.96 %) was found to be the best treatment. It was however at par with *M. rileyi* @ 5 g/l (75.56 %). This was followed by *M. anisopliae* @ 5 g/l (68.52 %). Azadirachtin @ 5 ml/l (47.78 %), *B. bassiana* @ 5 g/l (44.81 %) and karanj oil @ 3 ml/l (44.44 %) were next to follow but were at par with each other. Almost a similar trend in effectiveness was observed at 10 DAT.

The treatment with *B. thuringiensis* @ 2 g/l maintained its superiority by recording highest larval mortality (85.56 %) even at 12 DAT. It was, however, at par with *M. rileyi* 5 g/l (82.56 %). This was followed by *M. anisopliae* 5 g/l (75.19 %). The next promising treatments were, *B. bassiana* @ 5 g/l, azadirachtin @ 5 ml/l and karanj oil 3 ml/l, being at par recorded 53.33, 50.37, 42.96 per cent larval mortality, respectively.

The results of laboratory evaluation of biopesticides revealed that the treatment *B. thuringiensis* @ 2 g/l was the most effective against *S. frugiperda* in which more than 75 per cent mortality of larvae was obtained at 6 DAT and more than 82 per cent mortality at 8 DAT. The next best treatment, *M. rileyi* 5 g/l recorded > 75 per cent mortality at 8 DAT and > 82 per cent mortality at 12 DAT whereas the treatment of *M. anisopliae* 5 g/l recorded > 75 per cent mortality of larvae at 12 DAT. The rest of the treatments viz., *B. bassiana* 5 g/l, azadirachtin @ 5 ml/l and karanj oil 3 ml/l caused < 55 per cent mortality of larvae.

The present finding is in agreement with Patel *et al.* (2020b) who reported *Bt* as a superior biopesticide with the highest (64.65 and 59.01 %) mortality of second and third instar larvae of *S. frugiperda* in the laboratory conditions. Similarly, Aarthi *et al.* (2021) reported that *B. thuringiensis* was effective with larval mortality of 85.92 per cent in the laboratory. According to Dos *et al.* (2009), 70 per cent of larval mortality of *S. frugiperda* was observed on the fifth day.

Further, among the mycoinsecticides, *M. rileyi* caused the highest larval mortality from 4th day after treatment and was highest (82.22 %) at 12 DAT. These results are in conformity with Bosa *et al.* (2004) who reported that *M. rileyi* isolates caused 73 - 100 per cent mortality in 2nd instar of *S. frugiperda*.

Tigano *et al.* (1995) and Barros *et al.* (2020) also reported that *M. rileyi* isolates were highly virulent to *S. frugiperda* larvae with mortality rates of 53.3 - 82.2 per cent and 74 - 84 per cent, respectively. Similarly, Ginting *et al.* (2021) reported that the culture filtrate of *N. rileyi* caused more than 50 per cent larval mortality of *S. frugiperda*.

The present finding in respect of the effectiveness of *M. anisopliae* are in corroboration with Shahzad *et al.* (2021) who reported 59 per cent mortality of second instar larvae of *S. frugiperda* under controlled conditions. Likewise, *M. anisopliae* caused 68.7 per cent mortality in *S. frugiperda* adults as reported by Gutierrez *et al.* (2019).

The present finding in respect of the efficacy of *B. bassiana* is in line with Akutse *et al.* (2019) who recorded 30 per cent mortality of second instar larvae of *S. frugiperda* in the laboratory study. Likewise, Ullah *et al.* (2019) studied effects of *B. bassiana* on the biology of *S. litura* and reported reduced larval survival after the 10th day of exposure.

Among the botanicals, the results of azadirachtin are in accordance with Sharma *et al.* (2022) who reported 68 per cent mortality within sixty hours whereas Tavares *et al.* (2010) showed 80 per cent larval mortality.

However, in contrast to present finding Bosa *et al.* (2004) reported that 100 per cent mortality was observed in the second instar of *S. frugiperda* by *M. rileyi* while 82 per cent mortality was observed in the current investigation. Also, Namasivayam and Bharani (2014) reported that the *N. rileyi* metabolite with a concentration of 1 mg/ml caused 100 per cent mortality of second instar larvae of *S. litura* within 1.61 days and 65 per cent mortality in the third instar within 2.17 days.

Kumar *et al.* (2021) reported that *M. anisopliae* @ 7 ml/l caused 100 per cent mortality followed by the treatment *B. bassiana* @ 7 g/l (95 % mortality) at 96 hr after treatment application as against 75 and 53 per cent mortality in *M. anisopliae* @ 5 gm/l and *B. bassiana* @ 5 g/l, respectively at 12 DAT in the present investigation. Likewise, Cruz *et al.* (2019) showed that three strains of *M. anisopliae*, Ma 22, Ma 41 and Mr 8 caused 100 per cent mortality in both eggs and neonate larvae of *S. frugiperda*.

Sagar *et al.* (2020) reported that seed powder of *Azadirachta indica* caused 70 per cent larval mortality of *S. frugiperda* in laboratory as against 50 per cent mortality observed in the present findings.

Table 20. Bio efficacy of biopesticides against second instar larva of *S. frugiperda* in laboratory conditions

Tr. No.	Treatments	Formulation	Dose g or ml/l	Per cent Mortality of <i>S. frugiperda</i>					
				2 DAT	4 DAT	6 DAT	8 DAT	10 DAT	12 DAT
T ₁	<i>M. anisopliae</i>	1.15 % WP	5 g	0.00 (0.00)	36.67 (37.22)	54.81 (47.78)	68.52 (56.14)	71.85 (58.17)	75.19 (60.18)
T ₂	<i>B. bassiana</i>	1.15 % WP	5 g	0.00 (0.00)	30.00 (33.21)	37.78 (37.91)	44.81 (42.01)	50.00 (45.00)	53.33 (46.92)
T ₃	<i>M. rileyi</i>	1.15 % WP	5 g	0.00 (0.00)	40.00 (39.23)	65.19 (53.92)	75.56 (60.54)	78.89 (63.06)	82.22 (65.28)
T ₄	<i>B. thuringiensis</i>	0.5 % WP	2 g	6.67 (12.29)	56.67 (48.93)	75.93 (60.70)	82.96 (65.80)	85.56 (67.99)	85.56 (67.99)
T ₅	Azadiracthin	1500 ppm	5 ml	10.00 (15.00)	43.33 (41.07)	44.44 (41.75)	47.78 (43.68)	50.37 (45.20)	50.37 (45.20)
T ₆	Karanj oil 3 %	Crude oil	3 ml	6.67 (12.29)	36.67 (37.22)	40.74 (39.38)	41.11 (39.83)	42.96 (40.90)	42.96 (40.90)
T ₇	Untreated control	18.5 % SC	0.4 ml	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	S.E.m. ±			4.34	2.56	2.52	2.59	2.90	2.72
	C.D. at 5 %			NS	7.89	7.76	7.98	8.94	7.79
	CV			NS	8.28	11.33	12.05	10.45	10.84

Figures in the parentheses are arc sin transformed values, NS : Non-significant, DAT = Days after treatment

4.2.2 Field efficacy of different biopesticides against *S. frugiperda* in maize

Biopesticides evaluated under laboratory conditions were tested for their efficacy in the field condition against *S. frugiperda* infesting maize during *kharif and rabi* 2021. The observations were recorded on per cent plant damage, larval population and leaf damage score and the results are presented and discussed below.

4.2.2.1 Plant damage (*kharif* 2021)

The data pertaining to effect of different treatments on per cent plant damage due to *S. frugiperda* are presented in Table 21. It reveals that per cent plant damage before the application of insecticide and biopesticides (pre-count) ranged between 58.33 to 63.02 per cent and were statistically non-significant. The plant damage in untreated plots ranged between 59.50 to 61.63 per cent at 5 DAS and 14 DAS.

First application

At 5 DAS, chlorantraniliprole @ 0.4 ml/l proved to be significantly superior over the rest of the treatments by recording least plant damage (42.19 %). This was followed by *M. rileyi* @ 5 g/l recorded 53.13 per cent plant damage. It was, however, at par with karanj oil @ 3 ml/l, *B. thuringiensis* @ 2 g/l, untreated control, *B. bassiana* @ 5 g/l and azadirachtin @ 5 ml/l which recorded 55.73, 58.33 and 59.50, 59.90, 61.98 per cent plant damage, respectively. Highest plant damage was recorded in the treatment of *M. anisopliae* @ 5 g/l (64.06 %).

At 10 DAS, least plant damage (15.63 %) was recorded by chlorantraniliprole @ 0.4 ml/l. This was followed by *M. rileyi* @ 5 g/l which recorded 22.92 per cent plant damage. It was, however, at par with *B. thuringiensis* @ 2 g/l (28.13 %). *M. anisopliae* @ 5 g/l, *B. bassiana* @ 5 g/l, azadirachtin @ 5 ml/l and karanj oil @ 3 ml/l, being at par, were next to follow in the order of effectiveness by recording plant damage in the range of 34.90 to 42.71 per cent. Untreated plots recorded the highest (60.88 %) plant damage.

Chlorantraniliprole @ 0.4 ml/l continued to be superior by recording least (18.75 %) plant damage even at 14 DAS. *M. rileyi* @ 5 g/l was the next best treatment by recording 25.52 per cent plant damage. This was followed by *B. thuringiensis* @ 2 g/l, *M. anisopliae* @ 5 g/l and *B. bassiana* @ 5 g/l, being at par, recorded plant damage in the

range of 32.29 to 43.23 per cent. Maximum (61.63 %) plant damage was recorded by the untreated plots.

Second application

It reveals that the plant damage in the untreated plots was 63.13 per cent and gradually increased to 65.46 per cent at 14 DAS.

At 5 DAS, chlorantraniliprole @ 0.4 ml/l recorded the least plant damage (17.71 %) and proved to be significantly superior to the rest of the treatments. *M. rileyi* @ 5 g/l was the next best treatment with 29.69 per cent plant damage but it was on par with *B. thuringiensis* @ 2 g/l (31.25 %). *M. anisopliae* @ 5 g/l, *B. bassiana* @ 5 g/l, azadirachtin and karanj oil @ 3 ml/l, being at par, were next to follow with plant damage in the range of 42.19 to 49.48 per cent. Untreated plots recorded the highest (63.13 %) plant damage.

At 10 DAS, chlorantraniliprole @ 0.4 ml/l recorded the least (10.42 %) plant damage. The next effective treatment was *M. rileyi* @ 5 g/l recorded 19.27 per cent of plant damage followed by *B. thuringiensis* @ 2 g/l (21.88 %) to which it was on par. *M. anisopliae* @ 5 g/l, azadirachtin @ 5 ml/l, *B. bassiana* @ 5 g/l and karanj oil @ 3 ml/l, being at par, were next to follow with the plant damage in the range of 28.65 to 36.46 per cent. Highest (64.27 %) plant damage was recorded by untreated plots.

Chlorantraniliprole @ 0.4 ml/l maintained its superiority even at 14 DAS by recording significantly lowest (13.02 %) plant damage. It was followed by *M. rileyi* @ 5 g/l which recorded 20.83 per cent plant damage but was on par with *B. thuringiensis* @ 2 g/l (23.96 %). *M. anisopliae* @ 5 g/l and azadirachtin @ 5 ml/l being at par, were next to follow with 30.21 and 35.94 per cent plant damage, respectively. Untreated plots recorded 65.46 per cent plant damage.

4.2.2.2 Plant damage (rabi 2021)

The data pertaining to effect of different treatments on the per cent plant damage due to *S. frugiperda* infesting maize after first and second application are presented in a Table 22. It reveals that per cent of plant damage before the application of insecticide and biopesticides ranged between 51.33 to 55.46 per cent and were statistically non-significant, indicating uniform plant damage in maize. The plant damage in the untreated plots ranged between 52.54 to 60.77 per cent.

Table 21. Evaluation of bio-pesticides against *S. frugiperda* in maize during *kharif* 2021

Tr. No.	Treatments	Formulation	Dose g or ml/l	Per cent plant damage						
				Precount	First Spray			Second Spray		
					5 DAS	10 DAS	14 DAS	5 DAS	10 DAS	14 DAS
T ₁	<i>M. anisopliae</i>	1.15 % WP	5 g	63.02 (52.56)	64.06 (53.19)	34.90 (36.19)	38.54 (38.36)	42.19 (40.46)	28.65 (32.33)	30.21 (33.33)
T ₂	<i>B. bassiana</i>	1.15 % WP	5 g	58.33 (49.82)	59.90 (50.77)	37.50 (37.74)	43.23 (41.11)	44.79 (41.97)	35.94 (36.78)	39.58 (38.97)
T ₃	<i>M. rileyi</i>	1.15 % WP	5 g	58.85 (50.12)	53.13 (46.79)	22.92 (28.52)	25.52 (30.31)	29.69 (32.95)	19.27 (25.97)	20.83 (27.13)
T ₄	<i>B. thuringiensis</i>	0.5 % WP	2 g	59.38 (50.42)	58.33 (49.81)	28.13 (31.96)	32.29 (34.54)	31.25 (33.83)	21.88 (27.86)	23.96 (29.29)
T ₅	Azadiracthin	1500 ppm	5 ml	63.02 (52.58)	61.98 (51.95)	41.67 (40.19)	45.83 (42.61)	48.96 (44.43)	34.90 (36.21)	35.94 (36.83)
T ₆	Karanj oil 3 %	Crude oil	3 ml	61.98 (51.97)	55.73 (48.30)	42.71 (40.78)	46.35 (42.91)	49.48 (44.70)	36.46 (37.12)	39.06 (38.66)
T ₇	Chlorantraniliprole	18.5 % SC	0.4 ml	60.42 (51.05)	42.19 (40.49)	15.63 (23.27)	18.75 (25.65)	17.71 (24.85)	10.42 (18.75)	13.02 (21.05)
T ₈	Untreated control	-	-	58.90 (50.13)	59.50 (50.48)	60.88 (51.28)	61.63 (51.73)	63.13 (52.61)	64.27 (53.29)	65.46 (54.01)
	S.E.m. ±			1.84	1.74	1.57	1.24	2.28	1.70	1.43
	CD @ 5 %			NS	5.27	4.77	3.75	6.92	5.16	4.35
	CV			6.22	6.11	7.35	5.45	9.79	8.63	8.04

Figures in the parentheses are arc sin transformed values, NS : Non-significant, DAS = Days after spraying

First application

At 5 DAS, chlorantraniliprole @ 0.4 ml/l proved to be significantly superior over the rest of the treatments by recording the least plant damage (34.38 %). This was followed by *B. thuringiensis* @ 2 g/l which recorded 42.19 per cent plant damage. It was, however, at par with karanj oil @ 3 ml/l, azadirachtin @ 5 ml/l and *M. rileyi* @ 5 g/l with 44.79, 45.33 and 47.40 per cent plant damage, respectively. *B. bassiana* @ 5 g/l, untreated control and *M. anisopliae* @ 5 g/l, being at par, were next to follow in the range of 50.00 to 56.77 per cent plant damage.

At 10 DAS, chlorantraniliprole @ 0.4 ml/l recorded the least (15.10 %) plant damage. *B. thuringiensis* @ 2 g/l was the next best treatment in minimizing plant damage (23.44 %) followed by *M. rileyi* @ 5 g/l (31.77 %) to which it was on par. The next treatments in order of effectiveness were *M. anisopliae* @ 5 g/l, azadirachtin @ 5 ml/l, *B. bassiana* @ 5 g/l and karanj oil @ 3 ml/l which recorded plant damage in the range of 36.98 to 42.71 per cent. The untreated plots recorded the highest (56.63 %) plant damage.

Chlorantraniliprole @ 0.4 ml/l recorded the lowest (17.10 %) plant damage even at 14 DAS. This was followed by *B. thuringiensis* @ 2 g/l in minimizing plant damage (27.08 %). The next to follow were *M. rileyi* @ 5 g/l and *M. anisopliae* @ 5 g/l, being at par, recorded plant damage of 34.90 and 41.15 per cent, respectively. The next treatments in order of effectiveness were *B. bassiana* @ 5 g/l, azadirachtin @ 5 ml/l and karanj oil @ 3 ml/l which recorded plant damage in the range of 43.23 to 45.31 per cent. The untreated plots recorded the highest (57.90 %) plant damage.

Second application

At 5 DAS, chlorantraniliprole remained the most effective treatment by recording the least (14.67 %) plant damage. This was followed by *B. thuringiensis* @ 2 g/l, azadirachtin @ 5 ml/l and karanj oil, being at par, recorded plant damage of 26.58, 31.63, 32.54 per cent, respectively. *M. rileyi* @ 5 g/l, *M. anisopliae* @ 5 g/l and *B. bassiana* @ 5 g/l, were next to follow with plant damage in the range of 44.00 to 46.35 per cent. Maximum (60.77 %) plant damage was recorded by the untreated plots.

At 10 DAS, chlorantraniliprole @ 0.4 ml/l continued to be superior by recording least (7.81 %) plant damage. *B. thuringiensis* @ 2 g/l was the next best treatment with 13.54 per cent of plant damage. This was followed by *M. rileyi* @ 5 g/l,

azadirachtin @ 5 ml/l, *M. anisopliae* @ 5 g/l and karanj oil @ 3 ml/l, being at par, recorded plant damage in the range of 22.40 to 26.56 per cent. *B. bassiana* @ 5 g/l was the least effective treatment by recording 33.33 per cent of plant damage. The untreated plots recorded the highest (58.71 %) plant damage.

At 14 DAS, chlorantraniliprole @ 0.4 ml/l was proved to be significantly superior over rest of the treatments by recording least (10.42 %) plant damage. This was followed by *B. thuringiensis* @ 2 g/l which recorded minimum plant damage of 16.67 per cent. The next treatment in the order of effectiveness were *M. rileyi* @ 5 g/l, azadirachtin @ 5 ml/l, *M. anisopliae* @ 5 g/l, karanj oil @ 3 ml/l and *B. bassiana* @ 5 g/l which recorded plant damage in the range of 29.50 to 34.90 per cent. The untreated plots recorded the highest (57.98 %) plant damage.

4.2.2.3 Pooled data of two seasons (*kharif* and *rabi* 2021)

The results on the efficacy of different treatments on the per cent plant damage due to *S. frugiperda* infesting maize during *kharif* and *rabi* 2021 were pooled and are presented in Table 23. It could be seen that all treatments were significantly superior over untreated control.

Chlorantraniliprole @ 0.4 ml/l maintained its superiority over the two seasons by recording the least plant damage (18.15 %). Among the biopesticides, *B. thuringiensis* @ 2 g/l was consistently proved to be the most promising by recording the lowest (28.78 %) plant damage. It was, however, at par with *M. rileyi* @ 5 g/l which recorded 31.36 per cent damage to the plant. *M. anisopliae* @ 5 g/l, azadirachtin @ 5 ml/l, karanj oil @ 3 ml/l and *B. bassiana* @ 5 g/l, being at par, were next to follow in the order of effectiveness which recorded plant damage of 39.54, 40.31, 40.99, 42.49 per cent, respectively. The highest (60.02 %) plant damage was recorded by the untreated plots.

Table 22. Evaluation of bio-pesticides against *S. frugiperda* in maize during rabi 2021

Tr. No.	Treatments	Formulation	Dose g or ml/l	Per cent plant damage						
				Precount	First Spray			Second Spray		
					5 DAS	10 DAS	14 DAS	5 DAS	10 DAS	14 DAS
T ₁	<i>M. anisopliae</i>	1.15 % WP	5 g	55.46 (48.14)	56.77 (48.90)	36.98 (37.33)	41.15 (39.87)	45.83 (42.61)	26.04 (30.60)	29.17 (32.58)
T ₂	<i>B. bassiana</i>	1.15 % WP	5 g	51.33 (45.77)	50.00 (45.00)	41.15 (39.88)	43.23 (41.07)	46.35 (42.91)	33.33 (35.24)	34.90 (36.20)
T ₃	<i>M. rileyi</i>	1.15 % WP	5 g	52.25 (46.29)	47.40 (43.50)	31.77 (34.27)	34.90 (36.16)	44.00 (41.52)	22.40 (28.10)	24.48 (29.50)
T ₄	<i>B. thuringiensis</i>	0.5 % WP	2 g	51.79 (46.03)	42.19 (40.50)	23.44 (28.90)	27.08 (31.30)	26.58 (31.01)	13.54 (21.54)	16.67 (24.06)
T ₅	Azadiracthin	1500 ppm	5 ml	55.46 (48.14)	45.33 (42.32)	40.63 (39.59)	44.27 (41.70)	31.63 (34.21)	25.00 (29.99)	27.60 (31.68)
T ₆	Karanj oil 3 %	Crude oil	3 ml	54.54 (47.61)	44.79 (42.01)	42.71 (40.80)	45.31 (42.29)	32.54 (34.74)	26.56 (31.00)	30.21 (33.26)
T ₇	Chlorantraniliprole	18.5 % SC	0.4 ml	53.17 (46.82)	34.38 (35.87)	15.10 (22.83)	17.71 (24.80)	14.67 (22.46)	7.81 (16.18)	10.42 (18.75)
T ₈	Untreated control	-	-	52.54 (46.46)	53.33 (46.91)	56.63 (48.81)	57.90 (49.55)	60.77 (51.22)	58.71 (50.02)	57.98 (49.59)
	S.E.m. ±			1.59	1.33	1.81	1.54	1.72	1.60	1.65
	CD @ 5 %			NS	4.04	5.50	4.68	5.22	4.85	5.01
	CV			5.85	6.29	8.47	8.01	7.69	9.03	8.86

Figures in the parentheses are arc sin transformed values, NS: Non-significant, DAS= Days after spraying

Table 23. Evaluation of biopesticides against *S. frugiperda* in maize (kharif and rabi 2021- Pooled)

Tr. No.	Treatments	Formulation	Dose g or ml/l	Per cent plant damage						Pooled mean	
				Precount	First Spray			Second Spray			
					5 DAS	10 DAS	14 DAS	5 DAS	10 DAS		14 DAS
T ₁	<i>M. anisopliae</i>	1.15 % WP	5 g	59.24 (50.35)	60.42 (51.05)	35.94 (36.76)	39.85 (39.12)	44.01 (41.53)	27.35 (31.47)	29.69 (32.96)	39.54 (38.88)
T ₂	<i>B. bassiana</i>	1.15 %WP	5 g	54.84 (47.80)	54.95 (47.88)	39.32 (38.81)	43.23 (41.09)	45.58 (42.44)	34.64 (36.01)	37.24 (37.59)	42.49 (40.66)
T ₃	<i>M. rileyi</i>	1.15 %WP	5 g	55.56 (48.21)	50.26 (45.15)	27.35 (31.40)	30.21 (33.24)	36.85 (37.24)	20.84 (27.03)	22.66 (28.32)	31.36 (33.88)
T ₄	<i>B. thuringiensis</i>	0.5 % WP	2 g	55.59 (48.22)	50.26 (45.16)	25.78 (30.43)	29.69 (32.92)	28.92 (32.42)	17.71 (24.70)	20.31 (26.67)	28.78 (32.26)
T ₅	Azadiracthin	1500 ppm	5 ml	59.24 (50.36)	53.66 (47.14)	41.15 (39.89)	45.05 (42.15)	40.30 (39.32)	29.95 (33.10)	31.77 (34.26)	40.31 (39.39)
T ₆	Karanj oil 3 %	Crude oil	3 ml	58.26 (49.79)	50.26 (45.16)	42.71 (40.79)	45.84 (42.60)	41.01 (39.72)	31.51 (34.06)	34.64 (35.96)	40.99 (39.80)
T ₇	Chlorantraniliprole	18.5 % SC	0.4 ml	56.79 (48.94)	38.28 (38.18)	15.37 (23.05)	18.23 (25.22)	16.19 (23.66)	9.12 (17.46)	11.72 (19.90)	18.15 (24.90)
T ₈	Untreated control	-	----	55.72 (48.28)	56.42 (48.69)	58.76 (50.04)	59.77 (50.63)	61.95 (51.91)	61.49 (51.64)	61.72 (51.78)	60.02 (50.78)
	S.E.m. ±			1.72	1.55	1.70	1.40	1.95	1.65	1.55	1.45
	CD @ 5 %			NS	4.49	4.92	4.05	5.65	4.78	4.48	4.41
	CV			6.07	6.88	8.54	6.62	9.23	9.82	8.69	7.60

Figures in the parentheses are arc sin transformed values, NS: Non-significant, DAS= Days after spraying

4.2.2.4 Larval population (*kharif* 2021)

The data on the efficacy of different treatments against the larval population of *S. frugiperda* infesting maize after the first and second application are presented in Table 24.

First application

It reveals that the larval population recorded a day before the application of insecticide and biopesticides ranged between 2.13 to 2.60 larvae per plant and was statistically non-significant, indicating a homogeneous population. The larval population recorded by the untreated plots ranged between 2.60 to 2.83 larvae per plant.

At 5 DAS, chlorantraniliprole @ 0.4 ml/l recorded the least larval population (0.93 larvae/plant) and proved to be significantly superior to the rest of the treatments. *M. rileyi* @ 5 g/l was the next effective treatment which recorded 1.43 larvae per plant. Azadirachtin @ 5 ml/l, karanj oil @ 3 ml/l, *B. thuringiensis* @ 2 g/l, *M. anisopliae* @ 5 g/l and *B. bassiana* @ 5 g/l, being at par, were next to follow in the order of effectiveness which recorded larval population in the range of 1.87 to 2.33 larvae per plant. The untreated plots recorded the 2.73 larvae per plant.

Chlorantraniliprole @ 0.4 ml/l recorded the least (0.77 larvae/plant) larval population and was significantly superior over rest of the treatments at 10 DAS. *M. rileyi* @ 5 g/l was the next effective treatment by recording 1.07 larvae per plant. It was, however, at par with *B. thuringiensis* @ 2 g/l (1.17 larvae/plant). *M. anisopliae* @ 5 g/l, *B. bassiana* @ 5 g/l, azadirachtin @ 5 ml/l and karanj oil @ 3 ml/l were next to follow in the order of effectiveness and recorded larval populations in the range of 1.47 to 1.60 larvae per plant. They were, however, at par with each other. The untreated plots recorded 2.80 larvae per plant.

At 14 DAS, chlorantraniliprole @ 0.4 ml/l recorded significantly least (0.97 larvae/plant) population and maintained superiority over the rest of the treatments. *M. rileyi* @ 5 g/l and *B. thuringiensis* @ 2 g/l, being at par, were next to follow in the order of effectiveness with 1.23 and 1.40 larvae per plant, respectively. *M. anisopliae* @ 5 g/l, azadirachtin @ 5 ml/l, karanj oil @ 3 ml/l and *B. bassiana* @ 5 g/l recorded larval population in the range of 1.67 to 1.73 larvae per plant. They were, however, at par with each other. Untreated plots recorded maximum i.e. 2.83 larvae per plant.

Table 24. Field evaluation of biopesticides against the larval population of *S. frugiperda* in maize during *kharif* 2021

Tr. No.	Treatments	Formulation	Dose g or ml/l	Number of larvae/plant						
				Precount	First Spray			Second Spray		
					5 DAS	10 DAS	14 DAS	5 DAS	10 DAS	14 DAS
T ₁	<i>M. anisopliae</i>	1.15 % WP	5 g	2.40 (1.72)	2.30 (1.67)	1.47 (1.40)	1.67 (1.47)	1.37 (1.36)	0.97 (1.21)	1.17 (1.29)
T ₂	<i>B. bassiana</i>	1.15 % WP	5 g	2.53 (1.56)	2.33 (1.68)	1.50 (1.41)	1.73 (1.49)	1.50 (1.41)	1.13 (1.28)	1.23 (1.32)
T ₃	<i>M.rileyi</i>	1.15 % WP	5 g	2.50 (1.73)	1.43 (1.39)	1.07 (1.25)	1.23 (1.32)	0.90 (1.18)	0.70 (1.09)	0.93 (1.20)
T ₄	<i>B. thuringiensis</i>	0.5 % WP	2 g	2.37 (1.69)	2.03 (1.59)	1.17 (1.29)	1.40 (1.38)	1.10 (1.26)	0.80 (1.14)	1.03 (1.24)
T ₅	Azadiracthin	1500 ppm	5 ml	2.23 (1.65)	1.87 (1.54)	1.50 (1.41)	1.67 (1.47)	1.03 (1.24)	1.03 (1.24)	1.27 (1.33)
T ₆	Karanj oil 3 %	Crude oil	3 ml	2.20 (1.64)	1.90 (1.55)	1.60 (1.45)	1.70 (1.48)	1.07 (1.25)	1.07 (1.25)	1.33 (1.35)
T ₇	Chlorantraniliprole	18.5 % SC	0.4 ml	2.13 (1.62)	0.93 (1.20)	0.77 (1.12)	0.97 (1.21)	0.63 (1.06)	0.43 (0.96)	0.60 (1.05)
T ₈	Untreated control	-	-	2.60 (1.76)	2.73 (1.80)	2.80 (1.82)	2.83 (1.83)	2.67 (1.78)	2.60 (1.76)	2.63 (1.77)
	S.Em. ±			0.08	0.05	0.03	0.04	0.03	0.03	0.04
	CD @ 5 %			NS	0.14	0.09	0.11	0.10	0.10	0.12
	CV			8.23	7.68	6.67	7.19	7.32	7.28	6.19

Figures in parenthesis are $\sqrt{x + 0.05}$ transformed values, NS: Non- significant, DAS: Days after spraying

Second application

The data reveals that chlorantraniliprole @ 0.4 ml/l was significantly superior against *S. frugiperda* by recording the least larval population (0.63 larvae/plant) at 5 DAS. This was followed by *M. rileyi* @ 5 g/l which recorded 0.90 larvae per plant. It was, however, at par with azadirachtin @ 5 ml/l, karanj oil @ 3 ml/l and *B. thuringiensis* @ 2 g/l, which recorded larval population in the range of 1.03 to 1.10 larvae per plant. *M. anisopliae* @ 5 g/l (1.37 larvae/plant) and *B. bassiana* @ 5 g/l (1.50 larvae/plant) were next to follow but were at par with each other. The untreated plots recorded 2.67 larvae per plant.

At 10 DAS, chlorantraniliprole @ 0.4 ml/l was most effective by recording the least (0.43 larvae /plant) larval population of *S. frugiperda*. *M. rileyi* @ 5 g/l was next to follow with 0.70 larvae per plant. It was, however, at par with *B. thuringiensis* @ 2 g/l which recorded 0.80 larvae per plant. *M. anisopliae* @ 5 g/l, azadirachtin @ 5 ml/l, karanj oil @ 3 ml/l and *B. bassiana* @ 5 g/l, being at par, were next to follow with 0.97 to 1.13 larvae per plant. The maximum (2.60 larvae/plant) larval population was recorded by the untreated plots.

Chlorantraniliprole @ 0.4 ml/l was significantly superior and maintained its superiority by recording the least (0.60 larvae/plant) larval population even at 14 DAS. *M. rileyi* @ 5 g/l was the next effective treatment with 0.93 larvae per plant. It was, however, at par with *B. thuringiensis* @ 2 g/l, *M. anisopliae* @ 5 g/l and *B. bassiana* @ 5 g/l which recorded 1.03, 1.17, 1.23 larvae per plant, respectively. The maximum (2.63 larvae/plant) larval population was recorded in the untreated plots.

4.2.2.5 Larval population (rabi 2021)

The data on the efficacy of different treatments against the larval population of *S. frugiperda* infesting maize after the first and second applications are presented in Table 25.

It reveals that the larval population recorded a day before the application of insecticide and biopesticides ranged between 1.27 to 1.47 larvae per plant across and was statistically non-significant, indicating a uniform population. The untreated plots recorded the larval population in the range of 1.40 to 2.03 larvae per plant.

First application

At 5 DAS, chlorantraniliprole @ 0.4 ml/l recorded least (0.70 larvae/plant) larval population and was significantly superior over the rest of the treatments. *B. thuringiensis* @ 2 g/l was next effective treatment and recorded 0.97 larvae per plant. It was, however, at par with azadirachtin @ 5 ml/l, karanj oil @ 3 ml/l and *M. anisopliae* @ 5 g/l recorded the larvae per plant in the range of 1.07 to 1.20. *M. rileyi* @ 5 g/l and *B. bassiana* @ 5 g/l, being at par, were next to follow in the order of effectiveness with 1.23 and 1.30 larvae per plant, respectively. The highest (1.63 larvae/plant) larval population was recorded by the untreated plots.

At 10 DAS, chlorantraniliprole @ 0.4 ml/l recorded least larval population (0.53 larvae/plant) and proved to be significantly superior to the rest of treatments. This was followed by *B. thuringiensis* @ 2 g/l recorded 0.77 larvae per plant. *M. rileyi* @ 5 g/l, *M. anisopliae* @ 5 g/l, azadirachtin @ 5 ml/l, karanj oil @ 3 ml/l and *B. bassiana* @ 5 g/l, being at par, were next to follow in the order of effectiveness recorded the larvae per plant in the range of 0.97 to 1.03. Untreated plots recorded the highest i.e. 1.87 larvae per plant.

Chlorantraniliprole @ 0.4 ml/l was significantly superior by recording the least (0.63 larvae/plant) larval population even at 14 DAS. *B. thuringiensis* was the next effective treatment with 0.87 larvae per plant. *M. rileyi* @ 5 g/l, *M. anisopliae* @ 5 g/l, *B. bassiana* @ 5 g/l, azadirachtin @ 5 ml/l and karanj oil @ 3 ml/l, being at par, were next to follow in the order of effectiveness which recorded 1.13 to 1.23 larvae per plant. Highest larval population (1.90 larvae/plant) was recorded in the untreated plots.

Second application

At 5 DAS, chlorantraniliprole @ 0.4 ml/l was significantly superior against *S. frugiperda* by recording the least larval population (0.47 larvae/plant). *B. thuringiensis* @ 2 g/l was next to follow with 0.83 larvae per plant. It was, however, at par with azadirachtin @ 5 ml/l and karanj oil @ 3 ml/l which recorded 0.93 and 0.97 larvae per plant, respectively. *M. rileyi* @ 5 g/l, *M. anisopliae* @ 5 g/l and *B. bassiana* @ 5 g/l, being at par, were next to follow in the order of effectiveness which recorded 1.40 to 1.50 larvae per plant.

Table 25. Field evaluation of biopesticides against the larval population of *S. frugiperda* in maize during rabi 2021

Tr. No.	Treatments	Formulation	Dose g or ml/l	Number of larvae/plant						
				Precount	First Spray			Second Spray		
					5 DAS	10 DAS	14 DAS	5 DAS	10 DAS	14 DAS
T ₁	<i>M. anisopliae</i>	1.15 % WP	5 g	1.40 (1.38)	1.20 (1.30)	1.00 (1.22)	1.17 (1.29)	1.43 (1.39)	1.00 (1.22)	1.17 (1.29)
T ₂	<i>B. bassiana</i>	1.15 %WP	5 g	1.47 (1.40)	1.30 (1.34)	1.03 (1.24)	1.20 (1.30)	1.50 (1.41)	1.03 (1.24)	1.27 (1.33)
T ₃	<i>M.rileyi</i>	1.15 %WP	5 g	1.37 (1.37)	1.23 (1.32)	0.97 (1.21)	1.13 (1.28)	1.40 (1.38)	0.73 (1.11)	1.07 (1.25)
T ₄	<i>B. thuringiensis</i>	0.5 % WP	2 g	1.43 (1.39)	0.97 (1.21)	0.77 (1.12)	0.87 (1.17)	0.83 (1.15)	0.67 (1.08)	0.73 (1.11)
T ₅	Azadiracthin	1500 ppm	5 ml	1.30 (1.34)	1.07 (1.25)	1.00 (1.22)	1.20 (1.30)	0.93 (1.20)	1.00 (1.22)	1.10 (1.26)
T ₆	Karanj oil	Crude oil	3 ml	1.33 (1.35)	1.10 (1.26)	1.03 (1.24)	1.23 (1.32)	0.97 (1.21)	1.03 (1.24)	1.13 (1.28)
T ₇	Chlorantraniliprole	18.5 % SC	0.4 ml	1.27 (1.33)	0.70 (1.09)	0.53 (1.02)	0.63 (1.06)	0.47 (0.98)	0.40 (0.95)	0.47 (0.98)
T ₈	Untreated control	-	-	1.40 (1.38)	1.63 (1.46)	1.87 (1.54)	1.90 (1.55)	2.03 (1.59)	1.63 (1.46)	1.66 (1.47)
	S.Em. ±			0.03	0.03	0.03	0.03	0.04	0.03	0.04
	CD @ 5 %			NS	0.10	0.08	0.10	0.13	0.09	0.12
	CV			5.59	7.37	8.62	7.46	8.77	7.40	7.29

Figures in parenthesis are $\sqrt{x + 0.05}$ transformed values, NS: Non- significant, DAS: Days after spraying

At 10 DAS, chlorantraniliprole @ 0.4 ml/l was the most effective by recording the least (0.40 larvae/plant) larval population. This was followed by *B. thuringiensis* @ 2 g/l which recorded 0.67 larvae per plant. It was, however, at par with *M. rileyi* @ 5 g/l (0.73 larvae/plant). The next to follow were *M. anisopliae* @ 5 g/l, azadirachtin @ 5 ml/l, *B. bassiana* @ 5 g/l and karanj oil @ 3 ml/l which were at par with each other and recorded 1.0 to 1.03 larvae per plant. Maximum (1.63 larvae/plant) larval population was recorded by the untreated plots.

Chlorantraniliprole @ 0.4 ml/l was significantly superior by recording the least (0.47 larvae/plant) larval population even at 14 DAS. *B. thuringiensis* was the next effective treatment with 0.73 larvae per plant. *M. rileyi* @ 5 g/l, azadirachtin @ 5 ml/l, karanj oil @ 3 ml/l, *M. anisopliae* @ 5 g/l and *B. bassiana* @ 5 g/l, being at par, were next to follow in the order of effectiveness which recorded 1.07 to 1.27 larvae per plant. Highest larval population (1.66 larvae/plant) was recorded in the untreated plots.

4.2.2.6 Pooled data of two seasons (kharif and rabi 2021)

The data on the field efficacy of different treatments on the larval population during *kharif* and *rabi* were pooled. The data are presented in Table 26.

Chlorantraniliprole @ 0.4 ml/l (0.86 larvae/plant) remained effective at all intervals of observations. Among the biopesticides, the *B. thuringiensis* @ 2 g/l was found most effective treatment which recorded 1.03 larvae per plant. It was, however, at par with *M. rileyi* @ 5 g/l and *M. anisopliae* @ 5 g/l recorded 1.07, 1.22 larvae per plant, respectively. Azadirachtin @ 5 ml/l, karanj oil @ 3 ml/l and *B. bassiana* @ 5 g/l, being at par, were next to follow in the order of effectiveness which recorded 1.26 to 1.40 larvae per plant. Whereas untreated control recorded 2.25 larvae per plant.

4.2.2.7 Leaf damage score (kharif 2021)

The data pertaining to effect of different treatments on leaf damage score are presented in Table 23. The leaf damage score in the pre-treatment count ranged from 4.77 to 6.20 and was statistically non-significant indicating uniform leaf damage by *S. frugiperda*.

First application

At 5 DAS, least leaf damage score (3.90) was recorded by chlorantraniliprole @ 0.4 ml/l. It was, however, at par with *M. rileyi* @ 5 g/l (4.00). The next effective

Table 26. Field evaluation of biopesticides against the larval population of *S. frugiperda* in maize (kharif and rabi 2021-Pooled)

Tr. No.	Treatments	Formulation	Dose g or ml/l	Larval population per plant						Pooled mean	
				Precount	First Spray			Second Spray			
					5 DAS	10 DAS	14 DAS	5 DAS	10 DAS		14 DAS
T ₁	<i>M. anisopliae</i>	1.15 % WP	5 g	1.77 (1.50)	1.47 (1.39)	1.25 (1.32)	1.43 (1.39)	0.98 (1.22)	1.02 (1.23)	1.18 (1.30)	1.22 (1.31)
T ₂	<i>B. bassiana</i>	1.15 %WP	5 g	1.70 (1.48)	1.82 (1.51)	1.27 (1.33)	1.47 (1.40)	1.50 (1.41)	1.08 (1.26)	1.25 (1.32)	1.40 (1.38)
T ₃	<i>M. rileyi</i>	1.15 %WP	5 g	1.93 (1.55)	1.33 (1.35)	1.02 (1.23)	1.18 (1.30)	1.15 (1.28)	0.72 (1.10)	1.00 (1.22)	1.07 (1.25)
T ₄	<i>B. thuringiensis</i>	0.5 % WP	2 g	1.90 (1.54)	1.50 (1.40)	0.97 (1.21)	1.13 (1.27)	0.97 (1.21)	0.73 (1.11)	0.88 (1.17)	1.03 (1.24)
T ₅	Azadiracthin	1500 ppm	5 ml	1.77 (1.50)	1.50 (1.41)	1.32 (1.34)	1.47 (1.40)	1.02 (1.23)	1.05 (1.24)	1.23 (1.32)	1.26 (1.33)
T ₆	Karanj oil	Crude oil	3 ml	1.97 (1.55)	1.75 (1.49)	1.23 (1.31)	1.42 (1.38)	1.40 (1.38)	0.98 (1.22)	1.17 (1.29)	1.33 (1.35)
T ₇	Chlorantraniliprole	18.5 % SC	0.4 ml	1.70 (1.48)	0.82 (1.14)	0.65 (1.07)	0.80 (1.14)	0.55 (1.02)	0.42 (0.96)	0.53 (1.01)	0.86 (1.17)
T ₈	Untreated control	-	----	2.00 (1.57)	2.18 (1.63)	2.33 (1.68)	2.37 (1.69)	2.35 (1.69)	2.12 (1.61)	2.15 (1.62)	2.25 (1.66)
	S.Em. ±			0.06	0.04	0.03	0.03	0.04	0.03	0.04	0.02
	CD @ 5 %			NS	0.12	0.08	0.10	0.11	0.09	0.11	0.07
	CV			6.79	7.00	6.81	8.46	8.28	8.39	7.45	7.06

Figures in parenthesis are $\sqrt{x + 0.05}$ transformed values, NS: Non- significant, DAS: Days after spraying

Table 27. Evaluation of bio-pesticides against leaf damage score by *S. frugiperda* in maize (kharif 2021)

Tr. No.	Treatments	Formulation	Dose g or ml/l	Leaf damage score						
				Precount	First Spray			Second Spray		
					5 DAS	10 DAS	14 DAS	5 DAS	10 DAS	14 DAS
T ₁	<i>M. anisopliae</i>	1.15 % WP	5 g	4.77	5.00	4.43	5.00	5.20	4.20	4.30
T ₂	<i>B. bassiana</i>	1.15 %WP	5 g	5.17	5.30	4.67	5.20	5.33	4.50	4.67
T ₃	<i>M.rileyi</i>	1.15 %WP	5 g	4.93	4.00	3.07	3.20	4.80	2.70	2.77
T ₄	<i>B. thuringiensis</i>	0.5 % WP	2 g	6.20	6.10	4.13	4.57	4.70	3.50	3.63
T ₅	Azadiracthin	1500 ppm	5 ml	5.20	5.10	4.70	5.60	5.80	4.90	5.10
T ₆	Karanj oil	Crude oil	3 ml	5.27	4.60	4.20	5.50	5.70	4.80	5.20
T ₇	Chlorantraniliprole	18.5 % SC	0.4 ml	6.00	3.90	2.63	2.77	3.93	2.20	2.23
T ₈	Untreated control	-	----	5.80	6.10	6.60	6.70	6.83	6.87	7.07
	S.E.m. ±			0.36	0.31	0.25	0.18	0.27	0.21	0.26
	CD at 5 %			1.09	0.93	0.76	0.54	0.81	0.65	0.78
	CV (%)			11.52	10.57	10.14	6.45	8.70	8.78	10.21

NS: Non- significant, DAS: Days after spraying

treatments were karanj oil @ 3 ml/l, *M. anisopliae*, azadirachtin @ 5 ml/l and *B. bassiana* @ 5 g/l, being at par, recorded the leaf damage score in the range of 4.60 to 5.30. The maximum leaf damage score (6.10) was recorded by *B. thuringiensis* @ 2 g/l and untreated control.

At 10 DAS, chlorantraniliprole @ 0.4 ml/l recorded the lowest leaf damage score (2.63) followed by *M. rileyi* @ 5 g/l (3.07) to which it was on par. The next to follow were *B. thuringiensis* @ 2 g/l, karanj oil @ 3 ml/l, *M. anisopliae* @ 5 g/l, *B. bassiana* @ 5 g/l and azadirachtin @ 5 ml/l, being at par, which recorded the leaf damage score in the range of 4.13 to 4.70. Untreated plots recorded highest (6.60) leaf damage score.

Chlorantraniliprole @ 0.4 ml/l maintained its superiority even at 14 DAS by recording leaf damage score (2.77). It was, however, at par with *M. rileyi* @ 5 g/l (3.20). *B. thuringiensis* @ 2 g/l and *M. anisopliae* @ 5 g/l, being at par, were next to follow in the order of effectiveness which recorded the leaf damage score of 4.57, 5.00, respectively. The next to follow were *B. bassiana* @ 5 g/l (5.20), karanj oil @ 3 ml/l (5.50) and azadirachtin @ 5 ml/l (5.60) but were at par with each other. Highest (6.70) leaf damage score was recorded by untreated plots.

Second application

At 5 DAS, chlorantraniliprole @ 0.4 ml/l recorded least leaf damage score (3.93) and proved to be significantly superior to the rest of the treatments. *B. thuringiensis* @ 2 g/l, *M. rileyi* @ 5 g/l, *M. anisopliae* @ 5 g/l and *B. bassiana* @ 5 g/l, being at par, were next to follow in the order of effectiveness which recorded leaf damage score in the range of 4.80 to 5.33. Karanj oil @ 3 ml/l (5.70) and azadirachtin @ 5 ml/l (5.80) were next to follow but were at par with each other. The highest (6.83) leaf damage score was recorded by untreated plots.

At 10 DAS, chlorantraniliprole @ 0.4 ml/l recorded least (2.20) leaf damage score and was significantly superior over rest of the treatments. The next to follow in the order of effectiveness were *M. rileyi* @ 5 g/l, *B. thuringiensis* @ 2 g/l, *M. anisopliae* @ 5 g/l, *B. bassiana* @ 5 g/l, karanj oil @ 3 ml/l and azadirachtin @ 5 ml/l which recorded leaf damage score in the range of 2.70 to 4.90. The untreated plots recorded leaf damage score of 6.87.

At 14 DAS, chlorantraniliprole @ 0.4 ml/l recorded least (2.23) leaf damage score but was at par with *M. rileyi* @ 5 g/l (2.77). The next effective treatment was *B. thuringiensis* @ 2 g/l (3.63) followed by *M. anisopliae* @ 5 g/l (4.30) to which it was on par. The next to follow in order of effectiveness were *B. bassiana* @ 5 g/l, azadirachtin @ 5 ml/l and karanj oil @ 3 ml/l, being at par, recorded leaf damage score in the range of 4.67 to 5.20. The untreated control showed the highest leaf damage score i.e.7.07.

4.2.2.8 Leaf damage score (*rabi* 2021)

The data (Table 28) on the effect of different treatments on leaf damage score of maize during *rabi* 2021 are presented and discussed below.

First application

It reveals that chlorantraniliprole @ 0.4 ml/l was significantly superior by recording least leaf damage score (3.10) at 5 DAS. *B. thuringiensis* @ 2 g/l, *M. anisopliae* @ 5 g/l and azadirachtin @ 5 ml/l, being at par, were next to follow in the order of effectiveness which recorded leaf damage score in the range of 3.67 to 4.23. The next effective treatment was karanj oil @ 3 ml/l(4.30) followed by *B. bassiana* @ 5 g/l (4.50) to which it was on par. *M. rileyi* @ 5 g/l and untreated plots were at par with each other by recording leaf damage score of 5.50 and 5.53, respectively.

At 10 DAS, chlorantraniliprole @ 0.4 ml/l recorded lowest leaf damage score i.e.2.20. It was, however, at par with *B. thuringiensis* @ 2 g/l (2.70). *M. rileyi* @ 5 g/l, *M. anisopliae* @ 5 g/l, *B. bassiana* @ 5 g/l, azadirachtin @ 5 ml/l and karanj oil @ 3 ml/l, being at par, were next to follow in the order of effectiveness which recorded leaf damage score in the range of 3.00 to 3.70. The highest leaf damage score was observed in the untreated control (5.80).

At 14 DAS, chlorantraniliprole @ 0.4 ml/l recorded the least (2.40) leaf damage score and was at par with *B. thuringiensis* @ 2 g/l (3.00). The next to follow in the order of effectiveness were *M. rileyi* @ 5 g/l, *M. anisopliae* @ 5 g/l, *B. bassiana* @ 5 g/l and azadirachtin @ 5 ml/l, being at par, recorded leaf damage score in the range of 3.30 to 4.10. Karanj oil @ 3 ml/l was next moderately effective treatment by recording leaf damage score of 4.33. The untreated plots recorded leaf damage score of 6.13.

Second application

At 5 DAS, chlorantraniliprole @ 0.4 ml/l recorded the lowest (2.20) leaf damage score and was significantly superior over rest of the treatments. The next effective treatment was *B. thuringiensis* @ 2 g/l (2.90) followed by *M. rileyi* @ 5 g/l (3.50) to which it was on par. The next to follow were *M. anisopliae* @ 5 g/l, azadirachtin @ 5 ml/l, karanj oil @ 3 ml/l and *B. bassiana* @ 5 g/l, being at par, recorded leaf damage score in the range of 3.70 to 4.03. Highest (6.53) leaf damage score was recorded by the untreated plots.

At 10 DAS, chlorantraniliprole @ 0.4 ml/l recorded lowest leaf damage score (1.63). It was, however, at par with *B. thuringiensis* @ 2 g/l (2.03). *M. rileyi* @ 5 g/l (2.30) was next effective treatment but was at par with *M. anisopliae* @ 5 g/l (2.60). *B. bassiana* @ 5 g/l, azadirachtin @ 5 ml/l and karanj oil @ 3 ml/l, being at par, were next to follow with leaf damage scores in the range of 2.80 to 3.20. Untreated plots recorded the highest leaf damage score (6.33).

At 14 DAS, chlorantraniliprole @ 0.4 ml/l recorded lowest leaf damage score i.e.2.00. It was, however, at par with *B. thuringiensis* @ 2 g/l (2.33). *M. rileyi* @ 5 g/l and *M. anisopliae* @ 5 g/l were at par with each other by recording leaf damage score of 2.67 and 2.90, respectively. *B. bassiana* @ 5 g/l, azadirachtin @ 5 ml/l and karanj oil @ 3 ml/l, being at par, recorded leaf damage score in the range of 3.33 to 3.73. The highest leaf damage score was observed in the untreated control (6.20).

4.2.2.9 Pooled leaf damage score (*kharif* and *rabi* 2021)

The data on pooled leaf damage scores of *kharif* and *rabi* 2021 are presented in Table 29. Chlorantraniliprole @ 0.4 ml/l recorded the least (2.60) leaf damage score and also maintained its superiority to the rest of the treatments over the two seasons. Among the biopesticides, the lowest mean leaf damage score (3.31) was recorded by *B. thuringiensis* @ 2 g/l and was at par with *M. rileyi* @ 5 g/l (3.39). *M. anisopliae* @ 5 g/l, *B. bassiana* @ 5 g/l, karanj oil @ 3 ml/l and azadirachtin @ 5 ml/l, being at par, were next to follow in order of effectiveness recorded the leaf damage score in the range of 4.03 to 4.46. Untreated plots recorded the highest (6.39) leaf damage score.

Table 28. Evaluation of bio-pesticides against leaf damage score by *S. frugiperda* in maize (rabi 2021)

Tr. No.	Treatments	Formulation	Dose g or ml/l	Leaf damage score						
				Precount	First Spray			Second Spray		
					5 DAS	10 DAS	14 DAS	5 DAS	10 DAS	14 DAS
T ₁	<i>M. anisopliae</i>	1.15 % WP	5 g	4.33	4.10	3.33	3.60	3.70	2.60	2.90
T ₂	<i>B. bassiana</i>	1.15 % WP	5 g	4.63	4.50	3.50	3.93	4.03	2.80	3.33
T ₃	<i>M. rileyi</i>	1.15 % WP	5 g	5.60	5.50	3.00	3.30	3.50	2.30	2.67
T ₄	<i>B. thuringiensis</i>	0.5 % WP	2 g	4.20	3.67	2.70	3.00	2.90	2.03	2.33
T ₅	Azadiracthin	1500 ppm	5 ml	4.73	4.23	3.60	4.10	3.70	3.10	3.60
T ₆	Karanj oil	Crude oil	3 ml	4.90	4.30	3.70	4.33	3.80	3.20	3.73
T ₇	Chlorantraniliprole	18.5 % SC	0.4 ml	5.20	3.10	2.20	2.40	2.20	1.63	2.00
T ₈	Untreated control	-	-	5.30	5.53	5.80	6.13	6.53	6.33	6.20
	S.E.m. ±			0.33	0.20	0.19	0.26	0.20	0.15	0.21
	CD at 5 %			NS	0.62	0.59	0.80	0.60	0.46	0.63
	CV (%)			11.64	8.13	9.66	11.80	9.05	8.72	10.83

NS: Non- significant, DAS: Days after spraying

Table 29. Evaluation of bio-pesticides against leaf damage score by *S. frugiperda* in maize (*kharif* and *rabi* 2021 - Pooled)

Tr. No.	Treatments	Formulation	Dose g or ml/l	Leaf damage score						Mean	
				Precount	First Spray			Second Spray			
					5 DAS	10 DAS	14 DAS	5 DAS	10 DAS		14 DAS
T ₁	<i>M. anisopliae</i>	1.15 % WP	5 g	4.55	4.55	3.88	4.30	4.45	3.40	3.60	4.03
T ₂	<i>B. bassiana</i>	1.15 %WP	5 g	4.90	4.90	4.08	4.57	4.68	3.65	4.00	4.31
T ₃	<i>M. rileyi</i>	1.15 %WP	5 g	5.27	4.75	3.03	3.25	4.15	2.50	2.68	3.39
T ₄	<i>B. thuringiensis</i>	0.5 % WP	2 g	5.20	4.88	3.32	3.58	3.80	2.77	2.98	3.31
T ₅	Azadiracthin	1500 ppm	5 ml	4.97	4.67	4.15	4.85	4.75	4.00	4.35	4.46
T ₆	Karanj oil	Crude oil	3 ml	5.08	4.45	3.95	4.92	4.75	4.00	4.47	4.42
T ₇	Chlorantraniliprole	18.5 % SC	0.4 ml	5.60	3.50	2.42	2.58	3.07	1.92	2.12	2.60
T ₈	Untreated control	-	----	5.55	5.82	6.20	6.42	6.68	6.60	6.63	6.39
	S.Em. ±			0.34	0.26	0.22	0.22	0.23	0.18	0.23	0.19
	CD @ 5 %			NS	0.75	0.65	0.65	0.68	0.54	0.68	0.59
	CV			11.73	9.96	10.94	9.64	9.58	10.08	11.75	8.12

NS: Non- significant, DAS: Days after spraying

4.2.2.10 Yield of maize (Pooled *kharif* and *rabi* 2021)

The data on the average yield of maize in two seasons are presented in Table 30. It reveals that all the treatments registered significantly higher yield over the untreated control (46.83 q/ha). The highest yield was recorded by chlorantraniliprole 0.4 ml/l (65.42 q/ha). This was followed by the plot treated with *B. thuringiensis* @ 2 g/l which recorded 59.29 q/ha. It was followed by *M. rileyi* @ 5 g/l (58.79 q/ha), *M. anisopliae* @ 5 g/l (54.72 q/ha) and azadirachtin 5 ml/l (54.67 q/ha). Karanj oil 3 ml/l recorded a yield of 52.73 q/ha followed by *B. bassiana* 5 g/lit (52.18 q/ha).

The data also indicated that the highest (39.70 %) per cent increase in yield over control was registered by chlorantraniliprole @ 0.4 ml/l. Among the biopesticides, maximum increase in yield over control was registered by *B. thuringiensis* @ 2 g/l (26.60 %). It was followed by *M. rileyi* @ 5 g/l (25.54 %), *M. anisopliae* @ 5 g/l (16.85 %), azadirachtin 5 ml/l (16.73 %), Karanj oil @ 3 ml/l (12.60 %) and *B. bassiana* @ 5 g/l (11.42 %).

Table 30. Effect of biopesticides tested against *S. frugiperda* on grain yield of maize

Tr. No.	Treatments	Formulation	Dose g or ml/l	Yield (q/ha)			Increase in yield over control (%)
				<i>kharif</i> (2021)	<i>rabi</i> (2021)	Average of two seasons	
T ₁	<i>M. anisopliae</i>	1.15 % WP	5 g	52.59	56.85	54.72	16.85
T ₂	<i>B. bassiana</i>	1.15 %WP	5 g	49.56	54.79	52.18	11.42
T ₃	<i>M. rileyi</i>	1.15 %WP	5 g	58.28	59.31	58.79	25.54
T ₄	<i>B. thuringiensis</i>	0.5 % WP	2 g	54.61	63.96	59.29	26.60
T ₅	Azadirachtin	1500 ppm	5 ml	51.59	57.74	54.67	16.73
T ₆	Karanj oil	Crude oil	3 ml	49.92	55.54	52.73	12.60
T ₇	Chlorantraniliprole	18.5 % SC	0.4 ml	62.51	68.34	65.42	39.70
T ₈	Untreated control	-	-	44.20	49.46	46.83	--
	S.Em. ±			0.41	0.39	0.34	--
	CD @ 5 %			1.23	1.19	1.03	--
	CV			12.80	11.75	10.42	--

4.2.2.10.1 Cost economics of different treatments during *kharif* and *rabi* 2021

The pooled data on cost economics of different bio-intensive treatments (Table 31) used in this experiment is presented below.

The highest ICBR (1:4.45) was recorded in the treatment of *B. thuringiensis* @ 2 g/l. It was followed by *M. rileyi* @ 5 g/l (1:3.31), chlorantraniliprole @ 0.4 ml/l (1:3.02), *M. anisopliae* @ 5 g/l (1:1.84), azadirachtin @ 5 ml/l (1:1.38), karanj oil @ 3 ml/l (1:1.12) and *B. bassiana* @ 5 g/l (1:0.92).

The data over two seasons consistently proved that chlorantraniliprole 18.5 % SC was the most promising treatment in reducing per cent of plant damage, larval population and leaf damage score. This was followed by *B. thuringiensis* @ 2 g/l. This effect was reflected in an increase of grain yield of maize (Fig. 3).

The data over two seasons indicated that among all the treatments chlorantraniliprole 18.5 % SC exhibited the highest yield as compared to other treatments. This could be attributed to minimum plant damage, least larval population and least leaf damage score recorded in the plots treated with chlorantraniliprole. However, it was followed by *B. thuringiensis* @ 2 g/l and *M. rileyi* @ 5 g/l.

In the present investigation, chlorantraniliprole @ 0.4 ml/l was the most effective and excelled over all other treatments in checking *S. frugiperda* population. Next in the order of effectiveness were *B. thuringiensis* @ 2 g/l and *M. rileyi* @ 5 g/l. This was followed by *M. anisopliae* @ 5 g/l, azadirachtin @ 5 ml/l, karanj oil @ 3 ml/l and *B. bassiana* @ 5 g/l.

The results of the present finding that chlorantraniliprole @ 0.4 ml/l was the most effective treatment against *S. frugiperda* are in corroboration with several earlier workers. Ramesh and Tayde (2022) reported that chlorantraniliprole 18.5 % SC (6.24 %) was an effective treatment in reducing the per cent incidence of maize fall armyworm. Bajracharya *et al.* (2020) reported that Chlorantraniliprole 18.5 % SC @ 0.4 ml/l was

Table 31. Economics of different biopesticides in the management of fall armyworm on maize (*kharif* and *rabi* 2021- Pooled)

Tr. No.	Treatments	Formulation	Dose g or ml/l	Grain yield (q/ha)	Additional yield over control (q/ha)	Total cost (Rs/ha)	Value of additional yield over untreated control (Rs/ha)	Net Profit (Rs/ha)	ICBR
T ₁	<i>M. anisopliae</i>	1.15 % WP	5 g	54.72	7.89	5196	14750.95	9554.95	1:1.84
T ₂	<i>B. bassiana</i>	1.15 %WP	5 g	52.18	5.35	5196	10001.28	4805.28	1:0.92
T ₃	<i>M. rileyi</i>	1.15 %WP	5 g	58.79	11.96	5196	22371.43	17175.43	1:3.31
T ₄	<i>B. thuringiensis</i>	0.5 % WP	2 g	59.29	12.46	4276	23293.85	19017.85	1:4.45
T ₅	Azadiracthin	1500 ppm	5 ml	54.67	7.84	5796	14657.23	8861.23	1:1.53
T ₆	Karanj oil	Crude oil	3 ml	52.73	5.90	5196	11030.60	5834.60	1:1.12
T ₇	Chlorantraniliprole	18.5 % SC	0.4 ml	65.42	18.59	8652	34770.36	26118.36	1:3.02
T ₈	Untreated control	-	----	46.83	-	-	-	-	-

Total cost: Cost of biopesticides and labour charges.

Cost of cultivation of maize - Rs.39500/ha.

Maize grain selling rate - Rs. 1870/qtl

Labour - Rs.299/labour

Karanj oil - Rs.667/500 ml

Azadiracthin - Rs.460/500 ml

Chlorantraniliprole 18.5 % SC -Rs. 2796/150 ml

B. thuringiensis var. *kurstaki* - Rs.385/250 gm

M. anisopliae - Rs.200/250 gm

B. bassiana - Rs.200/250 gm

M.rileyi - Rs.200/250 gm

superior treatment compared to all other treatments and recorded average foliage damage score. Likewise, Chlorantraniliprole 200 SC was effective in reducing foliar damage of maize in green house experiment (Sisay *et al.*, 2019b). Chlorantraniliprole 18.5 SC 0.006 % was effective treatment against *S. litura* and *A. janata* in castor and recorded the lowest number of 0.42 and 0.22 larvae per plant, respectively (Bhut *et al.* 2022). All these reports lend supports to the present finding.

Efficacy of *B. thuringiensis* @ 2 g/l as observed in the present investigation is in line with Wayal *et al.* (2021) who reported that *Bt* 85 % @ 20g /10l was the most effective biopesticide in reducing the plant damage of 67.78 per cent. The minimum plant damage (17.70 %) was recorded by *B. thuringiensis* var. *kurstaki* 1 % WG @ 20 g/10 l during *kharif* 2019 (Dhobi *et al.*, 2020). Further, Capalbo *et al.* (2001) reported that mortality of neonate larvae was 100 per cent within two days of spraying of *B. thuringiensis* @ 2×10^6 spores/ml and all larvae were found dead on leaves.

Similarly, Liu *et al.* (2019) and Prasanna *et al.* (2018) found that *B. thuringiensis* was very effective biopesticide for larval mortality of *S. frugiperda* infesting maize. Yubak *et al.* (2020) confirmed that *Bt* was the most effective biopesticide. Molina *et al.* (2003) concluded that *B. thuringiensis* @ 2 g/l caused significant mortality in *S. frugiperda* population and reduced leaf defoliation in crops. Similarly, *B. thuringiensis* @ 1.0 g/l was most effective treatment in reducing larval population and leaf damage by 94.38 and 24.74 per cent, respectively, (Chandrayudu *et al.*, 2015). These outcomes of earlier research work are in conformity with present findings.

M. rileyi @ 5 g/l was next best treatment against *S. frugiperda* in maize as observed in the present investigation is in conformity with many earlier reports. Mallapur *et al.* (2018), found that *M. rileyi* @ 2 g/l application reduced pest infestation by 58.91 to 62.87 per cent and concluded that *M. rileyi* @ 2 g/l was an effective biopesticide for controlling invasive pest *S. frugiperda* during *kharif* 2018. Also, Lingappa *et al.* (2002) endorsed that the larval population was reduced by 28 and 62 per cent in 10 days by *N. rileyi* @ 3g/l after the first and second applications, respectively. Harika *et al.* (2020) revealed that *M. rileyi* @ 2 g/l recorded the lowest leaf damage compared to the control in maize.

Further, *M. rileyi* @ 5 g/l recorded lowest larval population (1.81 larvae /10 plants) with minimum plant damage (15.34 %) during *kharif* 2019 (Dhobi *et al.*, 2020). Wayal *et al.* (2021) reported that *N. rileyi* @ 30 g/ 10 l, was effective treatment in reducing 60.37 per cent plant damage. Gomez *et al.* (2022) reported that higher larval mortality was observed by combined use of NPV: *M. rileyi* (50:50 %). Chandrayudu *et al.* (2015) demonstrated that *N. rileyi* @ 1.5×10^8 spores/l caused reduction of larval population of *S. litura* by 91.90 per cent and minimum leaf damage by 26.60 per cent.

All these earlier reports lend support to the present findings.

The results in respect of the efficacy of *M. anisopliae* as observed in the present investigation are in line with the Joseph *et al.* (2022) who reported that *M. anisopliae* @ 5 g/l was effective and could be used sustainably to manage the invasive FAW in maize cropping systems. Moreover, Cab *et al.* (2022) reported that *M. anisopliae* @ 2 l/ha was effective in suppressing leaf damage by *S. frugiperda*.

M. anisopliae @ 3 g/l was effective in reducing the per cent larval mortality of *S. frugiperda* and also minimized leaf defoliation in crops (Molina *et al.*, 2003). Likewise, Wayal *et al.* (2021) also revealed that *M. anisopliae* @ 50 g/ 10 l was the most effective biopesticide in reducing the plant damage (57.04 %) due to *S. frugiperda*. Similarly, Ramos *et al.* (2020) reported that *M. anisopliae* @ 1×10^8 CFU/ml killed (75 %) of the fourth larval instars, respectively. Jahan (2022) reported the highest (52.02 %) per cent reduction of leaf infestation in the treatment of *M. anisopliae* @ 8 g/l. Ramanujam *et al.* (2020) concluded that *M. anisopliae* ICAR-NBAIR Ma 35 strain exhibited 70 per cent reduction in *S. frugiperda* infestation.

Efficacy of azadirachtin against *S. frugiperda* in present investigation is in accordance with Kubo and Klocke (1981) who reported 95 per cent antifeedant activity of azadirachtin and helped in controlling the fall armyworm. Furthermore, Lima *et al.* (2010) reported that minimum damage rating (1.3) observed in neem leaf extract @ 5 % treated plot compared to the control plot in the maize. Azadirachtin 1500 ppm @ 50 ml/ 10 l significantly reduced the plant damage (53.33 %) as reported by Wayal *et al.* (2021). Yubak *et al.* (2020) also reported that neem-based pesticides were the most effective in reducing the plant damage by *S. frugiperda*.

The results in respect of the efficacy of *B. bassiana* as observed in the present investigation are in corroboration with the Cab *et al.* (2022) who revealed that *B. bassiana* @ 2 l/ha was effective in suppressing the leaf damage by *S. frugiperda*. Similarly, *B. bassiana* caused significant mortality in FAW populations and also reduced leaf defoliation in crops (Molina *et al.*, 2003). Likewise, Rodriguez *et al.* (2016) also reported that entomopathogenic fungi *B. bassiana* @5 g/l against the *S. frugiperda* caused larval mortality of 4.10, 26.60, 48.30 and 75 per cent at 4, 7, 10 and 14 DAT, respectively.

According to Chandrayudu *et al.* (2015), minimum per cent of leaf damage (28.19) and reduction of the larval population of *S. litura* (68.64 %) was observed in plots treated with *B. bassiana* @ 1.5×10^8 spores/ml.

All these reports lend support to the present findings.

The infestation of *M. rileyi* on *S. frugiperda* during the present study varied across *kharif* and *rabi* seasons which may be attributed to several climatic factors such as rainfall, temperature and relative humidity. These results supported by the previous research (Singh and Kumar, 2003 and Manjula *et al.*, 2003) which found that temperature, rainfall and relative humidity exhibited a favorable association with the occurrence of disease. Similarly, Choudhary *et al.* (2012) stated that the incidence, distribution, prevalence and effectiveness of entomopathogenic fungi are significantly influenced by weather factors like temperature, humidity and rainfall. Likewise, Rachappa and Lingappa (2007) reported that the disease development in *S. litura* is significantly influenced by moisture levels and rainfall.

In the present investigation chlorantraniliprole registered the highest yield (65.42 q/ha). These findings are in agreement with Ramesh and Tayde (2022) who reported that the chlorantraniliprole 18.5 % SC registered grain yield of 35.91 q/ha. Likewise, Bhamare *et al.* (2020) reported that the maximum grain yield by chlorantraniliprole 0.004 per cent (34.87 q/ha) in soybean crop against the *S. litura*.

B. thuringiensis @ 2 g/lit (59.29 q/ha) registered the second highest yield in maize and these results are in conformity with Walther *et al.* (2022) who reported that grain yield of maize treated with *B. thuringiensis* var. *kurtaki* was 58.53 q/ha. Similarly,

Khairnar *et al.* (2023) and Dhobi *et al.* (2020) recorded higher grain yield in the treatment of *B. thuringiensis* @ 2 ml/l by 55.93 and 29.32 q/ha, respectively.

According to Sowmya *et al.* (2021) maximum yield (92.57 q/ha) was recorded by *M. rileyi* @ 1×10^8 spores/ml. Dhobi *et al.* (2020) recorded the higher grain yield with *N. rileyi* 1 % WP (29.57 q/ha). Effective control of *S. frugiperda* by *M. rileyi* @3g/l with higher yield 58.62 q/ha was reported by Khairnar *et al.* (2023).

Grain yield obtained in respect of *M. anisopliae* @ 1×10^8 spores/ml is in conformity with Sowmya *et al.* (2021) who confirmed that maximum yield recorded by *M. anisopliae* (89.87q/ha). Similarly, Cab *et al.* (2022) also demonstrated that grain yield of plots treated *M. anisopliae* @ 2 l/ha was 61.52 q/ha.

Azadirachtin @ 5 ml/l was also an effective treatment in increasing the yield which is in accordance with Khairnar *et al.* (2023) who reported that plot treated with azadirachtin @ 5 ml/l registered the grain yield of 53.53 q/ha in *kharif* 2020.

According to Cab *et al.* (2022), grain yield of plots treated *B. bassiana* @ 2 l/ha registered yield between 59 to 75 q/ha which lend support to the present finding.

The results of present study in respect of ICBR of grain yield are in corroboration with many early workers. Shinde *et al.* (2021) reported that *N. rileyi* @ 2.5 kg/ha, *M. anisopliae* @ 2.5 kg/ha and *B. bassiana* @ 2.5 kg/ha recorded the ICBR of 1:7.2, 1:5.9 and 1:2.9, respectively. Khairnar *et al.* (2023) reported the ICBR of *M. rileyi* @ 5 g/ l, *B. thuringiensis* @ 2 ml / l and azadirachtin @ 5 ml/ l were 1:6.44, 1:3.72 and 1:0.47, respectively. Patel *et al.* (2020a) reported that *B. thuringiensis* 0.2 % and Neem oil 1 % recorded the ICBR of 1:3.07 and 1:1.93, respectively in moringa fodder crop. These earlier reports lend support to the present findings.

4.3 Field evaluation of whorl application of poison baits against *S. frugiperda* in maize

Poison baits were tested for their efficacy in the field against *S. frugiperda* in maize during *kharif and rabi* 2021. Two applications of baits were carried out at an interval of 15 days. The findings on the plant damage, larval population and leaf damage score are presented and discussed.

4.3.1 Plant damage (*kharif* 2021)

The data pertaining on per cent plant damage are presented in Table 32. One day prior to the application of poison baits, the plant damage varied from 60.94 to 65.63 per cent and was statistically non-significant which confirmed the uniform plant damage of maize caused by *S. frugiperda*.

First application

At 5 DAA, GF - 4867@ 0.1 per cent (Ready to use bait-test product containing spinetoram) recorded least (44.79 %) plant damage. It was, however at par with chlorantraniliprole 18.5 % SC @1.88 ml/kg, thiodicarb 75 WP @ 12.50 g/kg and emamectin benzoate 5 % SG @ 2.50 g/kg which recorded plant damage in the range of 45.83 to 52.60 per cent. The next to follow were *B. thuringiensis* @ 25 g/kg, *B. thuringiensis* @ 12.5 g/kg and untreated plots, being at par, recorded plant damage in the range of 50.52 to 61.45 per cent.

At 10 DAA, the least (22.40 %) plant damage was recorded by GF-4867@ 0.1 per cent followed by chlorantraniliprole 18.5 % SC @1.88 ml/kg (45.83 %) to which it was on par. Thiodicarb 75 WP @ 12.50 g/kg (31.77 %) and emamectin benzoate 5 % SG @ 2.50 g/kg (34.29 %) were next to follow but were at par with each other. This was followed by *B. thuringiensis* @ 25 g/kg and *B. thuringiensis* @ 12.5 g/kg, being at par, recorded 40.10 and 45.31 per cent plant damage, respectively.

GF-4867@ 0.1 % (20.83 %) maintained their superiority in minimizing plant damage even at 14 DAA. This was, however, at par with chlorantraniliprole 18.5 % SC @1.88 ml/kg (21.88 %). The next to follow were thiodicarb 75 WP @ 12.50 g/kg and emamectin benzoate 5 % SG @ 2.50 g/kg, being at par, recorded plant damage of 29.69, 31.25 per cent, respectively. *B. thuringiensis* @ 25 g/kg and @ 12.50 g/kg, recorded plant damage of 39.06 and 43.23 per cent, respectively. They were, however, at par with each other. The untreated plots recorded the highest (63.30 %) plant damage in maize.

Second application

GF-4867@ 0.1 per cent (14.58 %) has remained the most effective treatment recording the lowest plant damage at 5 DAA. It was, however, at par with chlorantraniliprole 18.5 % SC @1.88 ml/kg (15.63 %). The next effective treatment was thiodicarb 75 WP @ 12.50 g/kg (23.96 %) but was at par with emamectin benzoate 5 %

Table 32. Effect of whorl application of poison baits on the plant damage by *S. frugiperda* in maize during *kharif* 2021

Tr. No.	Treatments	Dose g or ml/l	Per cent plant damage						
			Precount	First Spray			Second Spray		
				5 DAA	10 DAA	14 DAA	5 DAA	10 DAA	14 DAA
T ₁	<i>Bt</i> var. <i>kurstaki</i> 0.5 %WP	12.50 g/kg	65.63 (54.12)	60.42 (51.02)	45.31 (42.31)	43.23 (41.10)	38.02 (38.05)	28.65 (32.33)	27.60 (31.63)
T ₂	<i>Bt</i> var. <i>kurstaki</i> 0.5 %WP	25.00 g/kg	60.94 (51.34)	54.69 (47.70)	40.10 (39.29)	39.06 (38.68)	33.33 (35.24)	24.48 (29.64)	23.96 (29.29)
T ₃	Thiodicarb 75 WP	12.50 g/kg	61.98 (51.94)	50.52 (45.29)	31.77 (34.30)	29.69 (33.00)	23.96 (29.27)	16.15 (23.62)	15.10 (22.83)
T ₄	Emamectin benzoate 5 % SG	2.50 g/kg	61.46 (51.65)	52.60 (46.50)	32.29 (34.62)	31.25 (33.98)	25.52 (30.33)	18.23 (25.24)	17.19 (24.48)
T ₅	Chlorantraniliprole 18. 5 % SC	1.88 ml/kg	63.02 (52.58)	45.83 (42.61)	23.44 (28.81)	21.88 (27.80)	15.63 (23.17)	10.94 (19.19)	9.90 (18.26)
T ₆	GF-4867@0.1 %	1.00 g/whorl	65.63 (54.15)	44.79 (42.00)	22.40 (28.16)	20.83 (27.06)	14.58 (22.41)	9.90 (18.26)	8.85 (17.14)
T ₇	Untreated control	-----	60.10 (50.83)	61.45 (51.62)	62.80 (52.42)	63.30 (52.71)	65.30 (53.91)	66.85 (54.85)	67.20 (55.06)
	S.Em. ±		1.62	2.00	1.45	1.47	1.47	1.27	1.16
	CD @ 5 %		NS	6.16	4.47	4.52	4.53	3.92	3.59
	CV		6.33	8.26	7.69	8.12	8.16	7.40	8.90

Figures in the parantheses are arc sin transformed values, NS: Non-significant, DAA= Days after application

SG @ 2.50 g/kg (25.52 %). *B. thuringiensis* @ 25 g/kg and @ 12.50 g/kg, being at par, recorded plant damage of 33.33 and 38.02 per cent, respectively.

Almost a similar trend was noticed at 10 DAA.

At 14 DAA, the GF-4867 @0.1 per cent (8.85 %) maintained their superiority in minimizing plant damage. It was, however, at par with chlorantraniliprole 18.5 % SC @1.88 ml/kg (9.90 %). The next to follow were thiodicarb 75 WP @ 12.50 g/kg and emamectin benzoate 5 % SG @ 2.50 g/kg, being at par, recorded plant damage of 15.10, 17.19 per cent, respectively. Baits of *B. thuringiensis* @ 25 g/kg and @ 12.50 g/kg recorded plant damage of 23.96 and 27.60 per cent, respectively. They were, however, at par with each other. The untreated plots recorded the highest (67.20 %) plant damage in maize.

4.3.2 Plant damage (*rabi* 2021)

The data (Table 33) on the per cent plant damage are presented and discussed below. The plant damage (one day) before the application of baits were non-significant indicating uniform plant damage of maize.

First application

The plant damage recorded in untreated control a day before application was 53.13 and increased gradually to 59.38 per cent at 14 DAA.

At 5 DAA, GF-4867@ 0.1 per cent was proved to be superior by recording the least (39.58 %) the plant damage. It was, however, at par with chlorantraniliprole 18.5 % SC @1.88 ml/kg, thiodicarb 75 WP @ 12.50 g/kg and emamectin benzoate 5 % SG @ 2.50 g/kg which recorded plant damage in the range of 41.15 to 46.35 per cent, respectively. *B. thuringiensis* @25 g/kg, *B. thuringiensis* @ 12.50 g/kg and untreated plots, being at par, were next to follow and recorded the plant damage in the range of 45.83 to 54.69 per cent.

At 10 DAA, GF-4867 @0.1 per cent was the most effective treatment by recording the least(16.67 %) plant damage and was at par with chlorantraniliprole 18.5 % SC @1.88 ml/kg (18.75 %). The next to follow in order of effectiveness were thiodicarb 75 WP @ 12.50 g/kg and emamectin benzoate 5 % SG @ 2.50 g/kg, being at par, recorded plant damage of 25.52 and 26.04 per cent, respectively. *B. thuringiensis* @25 g/kg (33.33 %) and *B. thuringiensis* @ 12.50 g/kg (34.90 %) were next to follow but were at par with each other. However, the highest (58.33 %) plant damage was recorded in the untreated plots.

Table 33. Effect of whorl application of poison baits on the plant damage by *S. frugiperda* in maize during rabi 2021

Tr. No.	Treatments	Dose g or ml/l	Per cent plant damage						
			Precount	First Spray			Second Spray		
				5 DAA	10 DAA	14 DAA	5 DAA	10 DAA	14 DAA
T ₁	<i>Bt</i> var. <i>kurstaki</i> 0.5 %WP	12.50 g/kg	54.17 (47.39)	50.00 (45.00)	34.90 (36.07)	34.38 (35.89)	29.69 (32.98)	22.40 (28.14)	21.88 (27.85)
T ₂	<i>Bt</i> var. <i>kurstaki</i> 0.5 %WP	25.00 g/kg	55.21 (48.00)	48.44 (44.09)	33.33 (35.22)	32.81 (34.93)	27.60 (31.68)	20.31 (26.71)	18.75 (25.55)
T ₃	Thiodicarb 75 WP	12.50 g/kg	53.13 (46.80)	45.83 (42.60)	25.52 (30.00)	23.44 (28.89)	19.79 (26.34)	13.02 (21.10)	12.50 (20.68)
T ₄	Emamectin benzoate 5 % SG	2.50 g/kg	51.04 (45.60)	46.35 (42.89)	26.04 (30.55)	25.52 (30.30)	21.35 (27.31)	14.58 (22.41)	13.54 (21.54)
T ₅	Chlorantraniliprole 18.5 % SC	1.88 ml/kg	56.25 (48.61)	41.15 (39.87)	18.75 (25.44)	18.23 (25.27)	13.54 (21.56)	8.85 (17.30)	8.33 (16.71)
T ₆	GF-4867@0.1 %	1.00 g/whorl	54.17 (47.41)	39.58 (38.95)	16.67 (23.96)	16.15 (23.54)	12.50 (20.68)	7.81 (16.18)	6.77 (15.06)
T ₇	Untreated control	-----	53.13 (46.80)	54.69 (47.70)	58.33 (49.85)	59.38 (50.44)	62.50 (52.30)	60.94 (51.37)	59.90 (50.73)
	S.Em. ±		1.62	1.53	1.34	1.25	1.54	1.03	1.00
	CD @ 5 %		NS	4.73	4.15	3.85	4.74	3.19	3.08
	CV		6.93	7.18	8.36	8.04	8.76	7.84	7.37

Figures in the parantheses are arc sin transformed values, NS: Non-significant, DAA= Days after application

At 14 DAA, the least (16.15 %) plant damage was observed in the plot treated with GF-4867 @ 0.1 per cent. It was, however, at par with the chlorantraniliprole 18.5 % SC @1.88 ml/kg (18.23 %). The next treatment was thiodicarb 75 WP @ 12.50 g/kg (23.44 %) followed by emamectin benzoate 5 % SG @ 2.50 g/kg (25.52 %) to which it was on par. The treatments *B. thuringienesis* @ 25 g/kg (32.81 %) and @ 12.50 g/kg (34.38 %) were at par with each other in their efficacy against the pest. However, the highest (59.38 %) plant damage was recorded in the untreated control.

Second application

At 5 DAA, the GF-4867@ 0.1 per cent recorded the lowest of (12.50 %) plant damage. It was, however, at par with the treatment of chlorantraniliprole 18.5 % SC @1.88 ml/kg (13.54 %). This was followed by thiodicarb 75 WP @ 12.50 g/kg and emamectin benzoate 5 % SG @ 2.50 g/kg, being at par, recorded plant damage of 17.79 and 21.35 per cent, respectively. The next moderately effective treatments were *B. thuringiensis* @25 g/kg and *B. thuringiensis* @ 12.50 g/kg, being at par, recorded plant damage in the range of 27.60 to 29.69 per cent. Whereas, the highest (62.50 %) per cent plant damage was recorded in the untreated plots.

Almost a similar trend of the effectiveness was observed at 10 DAA.

At 14 DAA, the least (6.77 %) plant damage was observed in the plot treated with GF-4867@0.1 per cent. It was, however, at par with the chlorantraniliprole 18.5 % SC @1.88 ml/kg (8.33 %). The next treatment was thiodicarb 75 WP @ 12.50 g/kg (12.50 %) followed by emamectin benzoate 5 % SG @ 2.50 g/kg (13.54 %) to which it was on par. The treatments *B.thuringienesis* @ 25 g/kg (18.75 %) and @ 12.50 g/kg (21.88 %) were at par with each other in their efficacy against *S. frugiperda*. However, the highest (59.29 %) plant damage was noted in the untreated control.

4.3.3 Pooled data of two seasons (kharif and rabi 2021)

The cumulative effect of various baits application on plant damage caused by *S. frugiperda* infesting maize during *kharif* and *rabi* 2021 (Table 34) was compared and the results are discussed below. The data was significant at all the intervals of observation except untreated control.

Table 34. Effect of whorl application of poison baits on the plant damage of *S. frugiperda* in maize (*kharif* and *rabi* 2021 - Pooled)

Tr. No.	Treatments	Dose g or ml/l	Per cent plant damage						Pooled mean	
			Precount	First Spray			Second Spray			
				5 DAA	10 DAA	14 DAA	5 DAA	10 DAA		14 DAA
T ₁	<i>Bt</i> var. <i>kurstaki</i> 0.5 % WP	12.50 g/kg	59.90 (50.76)	55.21 (48.01)	40.11 (39.19)	38.80 (38.50)	33.86 (35.52)	25.52 (30.24)	24.74 (29.74)	36.37 (37.04)
T ₂	<i>Bt</i> var. <i>kurstaki</i> 0.5 % WP	25.00 g/kg	58.08 (49.67)	51.56 (45.90)	36.72 (37.26)	35.94 (36.81)	30.47 (33.46)	22.40 (28.17)	21.36 (27.42)	33.07 (35.04)
T ₃	Thiodicarb 75 WP	12.50 g/kg	57.55 (49.37)	48.18 (43.94)	28.65 (32.15)	26.56 (30.94)	21.88 (27.81)	14.59 (22.36)	13.80 (21.75)	25.61 (30.23)
T ₄	Emamectin benzoate 5 % SG	2.50 g/kg	56.25 (48.63)	49.48 (44.69)	29.17 (32.58)	28.39 (32.14)	23.44 (28.82)	16.41 (23.83)	15.37 (23.01)	27.04 (31.18)
T ₅	Chlorantraniliprole 18.5 % SC	1.88 ml/kg	59.64 (50.60)	43.49 (41.24)	21.09 (27.13)	20.05 (26.54)	14.58 (22.37)	9.90 (18.24)	9.12 (17.48)	19.71 (26.08)
T ₆	GF-4867@0.1 %	1.00 g/whorl	59.90 (50.78)	42.19 (40.48)	19.53 (26.06)	18.49 (25.30)	13.54 (21.54)	8.86 (17.22)	7.81 (16.10)	17.40 (24.65)
T ₇	Untreated control	-	56.62 (48.80)	58.07 (49.64)	60.57 (51.10)	61.34 (51.55)	63.90 (53.07)	63.90 (53.07)	63.55 (52.86)	61.89 (51.88)
	S.Em. ±	-	1.62	1.78	1.40	1.36	1.50	1.16	1.08	1.37
	CD @ 5 %	-	NS	5.20	4.08	3.97	4.39	3.38	3.16	4.21
	CV	-	6.62	8.85	7.87	7.78	8.15	7.18	7.87	8.95

Figures in the parantheses are arc sin transformed values, NS: Non-significant, DAA= Days after application

The pooled data of two seasons revealed that the treatment with the GF-4867 @ 0.1 % showed overall superiority in recording the lowest (17.40 %) plant damage in maize followed by chlorantraniliprole 18.5 % SC @1.88 ml/kg (19.71 %) to which it was on par. The next to follow in the order of effectiveness were thiodicarb 75 WP @ 12.50 g/kg and emamectin benzoate 5 % SG @ 2.50 g/kg, being at par, recorded the plant damage of 25.61, 27.04 per cent, respectively. The next effective treatments were *B. thuringiensis* @ 25 g/kg (33.07 %) and *B. thuringiensis* @ 12.50 g/kg (36.37 %) but were at par with each other. Highest (61.89 %) plant damage due to *S. frugiperda* was observed in the untreated plots.

4.3.4 Larval population (*kharif* 2021)

The data (Table 35) on the field evaluation of baits on larval populations during *kharif* 2021 are presented below.

In the experimental plot, one day before the application of baits the larval population was uniform, ranging from 1.87 to 2.47 larvae per plant across the plots and statistically non-significant. A range of 1.93 to 2.60 larvae per plant was recorded in the untreated control.

First application

At 5 DAA, GF-4867@ 0.1 per cent was effective by recording least (0.37 larvae /plant) the larval population. It was, however, at par with chlorantraniliprole 18.5 % SC @ 1.88 ml/kg (0.43 larvae /plant). The next to follow were thiodicarb 75 WP @ 12.50 g/kg and emamectin benzoate 5 % SG @ 2.50 g/kg, being at par, recorded larvae per plant of 0.87 and 1.00, respectively. The next effective treatment was *B. thuringiensis* @ 25 g/kg (1.23 larvae/plant) followed by *B. thuringiensis* @ 12.50 g/kg (1.40 larvae/plant). Untreated plots recorded the highest i.e.2.23 larvae per plant.

Almost a similar trend in effectiveness was observed even at 10 DAA

At 14 DAA, GF-4867@ 0.1 per cent (0.33 larvae/plant) was most effective and was at par with the chlorantraniliprole 18.5 % SC @1.88 ml/kg (0.37 larvae/plant) by recording larval population. Thiodicarb 75 WP @ 12.50 g/kg and emamectin benzoate 5 % SG @ 2.50 g/kg were next to follow by recording 0.80 and 0.93 larvae per plant, respectively. They were on par with each other. This was followed by *B. thuringiensis* @ 25 g/kg and *B. thuringiensis* @ 12.50 g/kg, being at par, recorded larvae per plant of 1.20 and 1.37, respectively.

Table 35. Effect of whorl application of poison baits on the larval population of *S. frugiperda* in maize during *kharif* 2021

Tr. No.	Treatments	Dose in g or ml /kg	Number of larvae/plant						
			Precount	First Spray			Second Spray		
				5 DAA	10 DAA	14 DAA	5 DAA	10 DAA	14 DAA
T ₁	<i>Bt</i> var. <i>kurstaki</i> 0.5 %WP	12.50 g/kg	2.47 (1.72)	1.40 (1.38)	1.37 (1.37)	1.37 (1.37)	1.13 (1.28)	1.07 (1.25)	1.07 (1.25)
T ₂	<i>Bt</i> var. <i>kurstaki</i> 0.5 %WP	25.00 g/kg	2.23 (1.65)	1.23 (1.32)	1.20 (1.30)	1.20 (1.30)	0.93 (1.20)	0.87 (1.17)	0.83 (1.15)
T ₃	Thiodicarb 75 WP	12.50 g/kg	2.07 (1.60)	0.87 (1.17)	0.83 (1.15)	0.80 (1.14)	0.57 (1.03)	0.50 (1.00)	0.47 (0.98)
T ₄	Emamectin benzoate 5 % SG	2.50 g/kg	1.87 (1.54)	1.00 (1.22)	0.93 (1.20)	0.93 (1.20)	0.60 (1.05)	0.57 (1.03)	0.57 (1.03)
T ₅	Chlorantraniliprole 18.5 % SC	1.88 ml/kg	2.27 (1.66)	0.43 (0.97)	0.40 (0.95)	0.37 (0.93)	0.20 (0.84)	0.17 (0.82)	0.17 (0.82)
T ₆	GF-4867@0.1 %	1.00 g /whorl	2.37 (1.69)	0.37 (0.93)	0.33 (0.91)	0.33 (0.91)	0.17 (0.82)	0.13 (0.80)	0.13 (0.80)
T ₇	Untreated control	-	1.93 (1.56)	2.23 (1.65)	2.37 (1.69)	2.60 (1.76)	2.50 (1.73)	2.53 (1.74)	2.57 (1.75)
	S.Em. ±	-	0.04	0.03	0.03	0.04	0.03	0.03	0.04
	CD @ 5 %	-	NS	0.11	0.10	0.13	0.10	0.09	0.12
	CV	-	6.26	8.81	7.47	9.72	7.74	7.40	8.12

Figures in parenthesis are $\sqrt{x + 0.05}$ transformed values, NS: Non- significant, DAS: Days after application

Second application

At 5 DAA, the least larval population was recorded in plots treated the GF-4867 @ 0.1 per cent (0.17 larvae/plant). It was at par with chlorantraniliprole 18.5 % SC @ 1.88 ml/kg (0.20 larvae/plant). Thiodicarb 75 WP @ 12.50 g/kg (0.57 larvae/plant) was the next effective treatment but was at par with emamectin benzoate 5 % SG @ 2.50 g/kg (0.60 larvae/plant). This was followed by *B. thuringiensis* @ 25 g/kg and @ 12.50 g/kg with 0.93 and 1.13 larvae per plant, respectively. The untreated plots recorded the highest (2.50) larvae per plant.

Almost a similar trend of effectiveness of treatments was observed at 10 DAA.

At 14 DAA, the plots treated with GF-4867 @ 0.1 per cent recorded the lowest (0.13 larvae/plant) larvae among all the baits. This was followed by chlorantraniliprole 18.5 % SC @ 1.88 ml/kg (0.17 larvae /plant) to which it was on par. The next to follow were thiodicarb 75 WP @ 12.50 g/kg and emamectin benzoate 5 % SG @ 2.50 g/kg, being at par, recorded the larvae per plant of 0.47 and 0.57, respectively. The next in order of effectiveness were *B. thuringiensis* @ 25 g/kg and @ 12.50 g/kg which recorded 0.83 and 1.07 larvae per plant, respectively.

4.3.5 Larval population (*rabi* 2021)

The data on the field evaluation of baits on larval populations during *rabi* 2021 are presented in Table 36.

One day prior to the application of the baits, the larval population in the experimental plot was uniform and ranged between 1.03 to 1.13 larvae per plant across the plots and it was statistically non-significant. Larvae per plant increased gradually from 1.10 to 1.67 in the untreated plot.

First application

At 5 DAA, GF-4867@ 0.1 per cent was found most effective by recording lowest (0.23 larvae/plant) larval population. It was, however, at par with chlorantraniliprole 18.5 % SC @ 1.88 ml/kg (0.30 larvae/plant). Thiodicarb 75 WP @ 12.50 g/kg and emamectin benzoate 5 % SG @ 2.50 g/kg, being at par, were next to follow by recording 0.43 and 0.50 larvae per plant, respectively. *B. thuringiensis* @ 25 g/kg (0.77 larvae/plant) and *B. thuringiensis* @ 12.50 g/kg (0.90 larvae/plant) were next

Table 36. Effect of whorl application of poison baits on the larval population of *S. frugiperda* in maize (rabi 2021)

Tr. No.	Treatments	Dose in g or ml /kg	Number of larvae/plant						
			Precount	First Spray			Second Spray		
				5 DAA	10 DAA	14 DAA	5 DAA	10 DAA	14 DAA
T ₁	<i>Bt</i> var. <i>kurstaki</i> 0.5 %WP	12.50 g/kg	1.13 (1.28)	0.90 (1.18)	0.87 (1.17)	0.83 (1.15)	0.57 (1.03)	0.57 (1.03)	0.53 (1.02)
T ₂	<i>Bt</i> var. <i>kurstaki</i> 0.5 %WP	25.00 g/kg	1.07 (1.25)	0.77 (1.13)	0.73 (1.11)	0.73 (1.11)	0.47 (0.98)	0.47 (0.98)	0.50 (1.00)
T ₃	Thiodicarb 75 WP	12.50 g/kg	1.13 (1.28)	0.43 (0.96)	0.40 (0.95)	0.37 (0.93)	0.33 (0.91)	0.30 (0.89)	0.30 (0.89)
T ₄	Emamectin benzoate 5 % SG	2.50 g/kg	1.03 (1.24)	0.50 (1.00)	0.47 (0.98)	0.47 (0.98)	0.40 (0.95)	0.37 (0.93)	0.37 (0.93)
T ₅	Chlorantraniliprole 18.5 % SC	1.88 ml/kg	1.07 (1.25)	0.30 (0.89)	0.27 (0.88)	0.23 (0.85)	0.17 (0.82)	0.13 (0.80)	0.13 (0.80)
T ₆	GF-4867@0.1 %	1.00 g /whorl	1.10 (1.26)	0.23 (0.86)	0.17 (0.82)	0.20 (0.84)	0.10 (0.77)	0.10 (0.77)	0.10 (0.77)
T ₇	Untreated control	-	1.10 (1.26)	1.40 (1.38)	1.67 (1.47)	1.63 (1.46)	1.47 (1.40)	1.50 (1.41)	1.40 (1.38)
	S.Em. ±	-	0.02	0.03	0.02	0.03	0.02	0.02	0.02
	CD @ 5 %	-	NS	0.08	0.07	0.10	0.05	0.06	0.06
	CV	-	7.14	8.44	8.60	9.20	7.92	8.19	8.67

Figures in parenthesis are $\sqrt{x + 0.05}$ transformed values, NS: Non- significant, DAS : Days after application

to follow but were at par with each other. Whereas, the highest number of larvae were recorded in the untreated plots (1.40 larvae/plant).

Almost a similar trend in effectiveness was observed at 10 DAA.

GF-4867@ 0.1 per cent was effective by recording the lowest (0.20 larvae /plant) larval population even at 14 DAA. It was, however, at par with chlorantraniliprole 18.5 % SC @ 1.88 ml/kg (0.23 larvae /plant). The next to follow were thiodicarb 75 WP @ 12.50 g/kg and emamectin benzoate 5 % SG @ 2.50 g/kg, being at par, recorded 0.37 and 0.47 larvae per plant, respectively. *B. thuringiensis* @ 25 g/kg (0.73 larvae/plant) and *B. thuringiensis* @ 12.50 g/kg (0.83 larvae/plant) were next to follow but were at par with each other.

Second application

At 5 DAA, the least (0.10 larvae/plant) population of larvae was recorded by GF-4867@ 0.1 per cent followed by chlorantraniliprole 18.5 % SC @1.88 ml/kg (0.17 larvae/plant) to which it was on par. This was followed by thiodicarb 75 WP @ 12.50 g/kg and emamectin benzoate 5 % SG @ 2.50 g/kg, being at par, recorded 0.33 and 0.40 larvae per plant, respectively. *B. thuringiensis* @ 25 g/kg and @ 12.50 g/kg recorded 0.47 and 0.57 larvae per plant, respectively. The untreated plots recorded 1.47 larvae per plant.

Almost a similar trend of effectiveness was noticed at 10 DAA.

GF-4867@ 0.1 per cent (0.10 larvae/plant) maintained its superiority even at 14 DAA. It was, however, at par with chlorantraniliprole 18.5 % SC @1.88 ml/kg (0.13 larvae/plant). The next in the order of effectiveness were thiodicarb 75 WP @ 12.50 g/kg, emamectin benzoate 5 % SG @ 2.50 g/kg, *B. thuringiensis* @25 g/kg and *B. thuringiensis* @ 12.50 g/kg and recorded larvae in the range of 0.30 to 0.53. Whereas, the untreated plots recorded 1.40 larvae per plant.

4.3.6 Pooled data (kharif and rabi 2021)

According to pooled data (Table 37), the average fall armyworm larvae were found to be significantly reduced by all the treatments as compared to the untreated plot. The plots treated with GF-4867@ 0.1 per cent recorded the lowest larvae (0.83 larvae/plant). It was, however, at par with chlorantraniliprole 18.5 % SC @1.88 ml/kg (0.86 larvae/plant). Thiodicarb 75 WP @ 12.50 g/kg and emamectin benzoate 5 % SG @ 2.50 g/kg, being at par, were next to follow recorded 1.00 and 1.04 larvae per plant. This was followed by *B. thuringiensis* @ 25 g/kg (1.15 larvae/plant).The maximum (1.57 larvae/plant) larval population was found in the untreated plots.

Table 37. Effect of whorl application of poison baits on the larval population of *S. frugiperda* in maize (*kharif* and *rabi* 2021 – Pooled)

Tr. No.	Treatments	Dose g or ml/l	Larval population							Pooled mean
			Precount	First Spray			Second Spray			
				5 DAA	10 DAA	14 DAA	5 DAA	10 DAA	14 DAA	
T ₁	<i>Bt</i> var. <i>kurstaki</i> 0.5 %WP	12.50 g/kg	1.50 (1.41)	1.28 (1.33)	1.27 (1.33)	1.26 (1.33)	1.15 (1.28)	1.14 (1.28)	1.13 (1.28)	1.20 (1.31)
T ₂	<i>Bt</i> var. <i>kurstaki</i> 0.5 %WP	25.00 g/kg	1.45 (1.39)	1.22 (1.31)	1.21 (1.31)	1.21 (1.31)	1.09 (1.26)	1.08 (1.25)	1.08 (1.26)	1.15 (1.28)
T ₃	Thiodicarb 75 WP	12.50 g/kg	1.44 (1.39)	1.07 (1.25)	1.05 (1.24)	1.03 (1.24)	0.97 (1.21)	0.95 (1.20)	0.94 (1.20)	1.00 (1.23)
T ₄	Emamectin benzoate 5 % SG	2.50 g/kg	1.39 (1.37)	1.11 (1.27)	1.09 (1.26)	1.09 (1.26)	1.00 (1.22)	0.98 (1.22)	0.98 (1.22)	1.04 (1.24)
T ₅	Chlorantraniliprole 18.5 % SC	1.88 ml/kg	1.45 (1.40)	0.93 (1.20)	0.91 (1.19)	0.89 (1.18)	0.83 (1.15)	0.81 (1.14)	0.81 (1.14)	0.86 (1.17)
T ₆	GF-4867@0.1 %	1.00 g/whorl	1.48 (1.40)	0.89 (1.18)	0.87 (1.17)	0.87 (1.17)	0.79 (1.14)	0.78 (1.13)	0.78 (1.13)	0.83 (1.15)
T ₇	Untreated control	-	1.41 (1.38)	1.51 (1.42)	1.58 (1.44)	1.61 (1.45)	1.57 (1.44)	1.58 (1.44)	1.56 (1.43)	1.57 (1.44)
	S.Em. ±	-	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	CD @ 5 %	-	NS	0.04	0.03	0.04	0.03	0.03	0.03	0.03
	CV	-	5.42	8.63	7.46	7.70	7.39	7.32	8.28	8.37

Figures in parenthesis are $\sqrt{x + 0.05}$ transformed values, NS : Non- significant, DAS : Days after application

4.3.7 Leaf damage score (*kharif 2021*)

The visual observations on leaf damage were categorized according to the scale given by Davis and Williams (1992). The results on the leaf damage score are presented below.

The mean leaf damage score in the pre-treatment count was ranged between 4.70 to 6.30 and it was statistically non-significant (Table 38) whereas there were significant differences among the treatments at all intervals of observation after the treatment.

First application

At 5 DAA, the least leaf damage score was recorded in GF-4867@ 0.1 per cent (4.13). It was, however, at par with chlorantraniliprole 18.5 % SC @ 1.88 ml/kg, *B. thuringiensis* @ 25 g/kg, thiodicarb 75 WP @ 12.50 g/kg, emamectin benzoate 5 % SG @ 2.50 g/kg which recorded leaf damage in the range of 4.20 to 4.93. *B. thuringiensis* @ 12.50 g/kg was the least (5.13) effective whereas the untreated plots recorded the leaf damage score of 6.20.

At 10 DAA, GF-4867@ 0.1 per cent was most effective with a leaf damage score (2.73). It was, however, at par with chlorantraniliprole 18.5 % SC @ 1.88 ml/kg (2.90) thiodicarb 75 WP @ 12.50 g/kg (3.03). This was followed by emamectin benzoate 5 % SG @ 2.50 g/kg (3.33). The next to follow were *B. thuringiensis* @ 25 g/kg and @ 12.50 g/kg (4.33), being at par, recorded leaf damage score of 3.90 and 4.33, respectively as against the untreated control (6.70).

GF-4867 @ 0.1 per cent (2.50) recorded the least leaf damage score at 14 DAA. It was, however, at par with chlorantraniliprole 18.5 % SC @ 1.88 ml/kg (2.80) and thiodicarb 75 WP @ 12.50 g/kg (2.90). Emamectin benzoate 5 % SG @ 2.50 g/kg (3.40) and *B. thuringiensis* @ 25 g/kg (3.80) were next to follow but were at par with each other. This was followed by *B. thuringiensis* @ 12.50 g/kg (4.40). The leaf damage score was increased in the untreated plots (6.90).

Second application

At 5 DAA, GF-4867 @ 0.1 per cent was the most effective treatment with leaf damage score (2.00). It was, however, at par with the chlorantraniliprole 18.5 % SC @ 1.88 ml/kg (2.30) and thiodicarb 75 WP @ 12.50 g/kg (2.50). The next in order of

Table 38. Effect of poison baits on the leaf damage score by *S. frugiperda* in maize (kharif 2021)

Tr. No.	Treatments	Dose in g or ml /kg	Leaf damage score						
			Precount	First Spray			Second Spray		
				5 DAA	10 DAA	14 DAA	5 DAA	10 DAA	14 DAA
T ₁	<i>Bt</i> var. <i>kurstaki</i> 0.5 %WP	12.50 g/kg	5.40	5.13	4.33	4.40	4.03	3.00	3.10
T ₂	<i>Bt</i> var. <i>kurstaki</i> 0.5 %WP	25.00 g/kg	4.70	4.33	3.90	3.80	3.53	2.80	2.70
T ₃	Thiodicarb 75 WP	12.50 g/kg	5.20	4.73	3.03	2.90	2.50	2.03	1.90
T ₄	Emamectin benzoate 5 % SG	2.50 g/kg	4.83	4.93	3.33	3.40	3.00	2.43	2.00
T ₅	Chlorantraniliprole 18.5 % SC	1.88 ml/kg	5.90	4.20	2.90	2.80	2.30	1.30	1.30
T ₆	GF-4867@0.1 %	1.00 g /whorl	6.30	4.13	2.73	2.50	2.00	1.10	1.00
T ₇	Untreated control	-	5.43	6.20	6.70	6.90	7.10	7.13	7.20
	S.Em. ±	-	0.43	0.28	0.18	0.21	0.18	0.18	0.20
	CD @ 5 %	-	NS	0.85	0.55	0.66	0.54	0.55	0.62
	CV	-	13.85	9.97	8.02	9.68	8.69	10.91	12.67

NS: Non- significant, DAS: Days after application

effectiveness were emamectin benzoate 5 % SG @ 2.50 g/kg and *B. thuringiensis* @25 g/kg, being at par, recorded leaf damage score of 3.00 and 3.53, respectively. A maximum (4.03) leaf damage score was recorded in treatment *B. thuringiensis* @ 12.50 g/kg. The highest (7.10) leaf damage score was recorded in the untreated plots.

At 10 DAA, the most effective treatment in reducing leaf damage was GF-4867@ 0.1 per cent (1.10) followed by chlorantraniliprole 18.5 % SC @1.88 ml/kg (1.30) to which it was on par. This was followed by thiodicarb 75 WP @ 12.50 g/kg (2.03) and was at par with emamectin benzoate 5 % SG @ 2.50 g/kg (2.43).The next to follow were *B. thuringiensis* @ 25 g/kg (2.80) and *B. thuringiensis* @ 12.50 g/kg (3.10) but were at par with each other.

GF-4867 @ 0.1 per cent was effective by recording the leaf damage score of 1.00 even at 14 DAS. This was followed by chlorantraniliprole 18.5 % SC @1.88 ml/kg (1.30) to which it was on par. The next to follow were thiodicarb 75 WP @ 12.50 g/kg and emamectin benzoate 5 % SG @ 2.50 g/kg, being at par, recorded leaf damage score of 1.90 and 2.00, respectively. The next moderately effective treatments were *B. thuringiensis* @ 25 g/kg (3.90) and the *B. thuringiensis* @ 12.50 g/kg (4.10) but were at par with each other. The untreated plots recorded highest leaf damage score i.e.7.20.

4.3.8 Leaf damage score (*rabi* 2021)

The data on the effect of whorl applications of different baits on leaf damage score of maize during *rabi* 2021 are presented in Table 39. The leaf damage score before treatment varied from 4.63 and 5.23 and were statistically non-significant showing uniform leaf damage score in the experimental plot. The mean leaf damage score was the maximum in untreated plot which ranged between 5.50 to 6.83.

First application

It was noticed that the least (4.20) leaf damage score was recorded by GF-4867 @ 0.1 per cent at 5 DAA. It was, however, at par with chlorantraniliprole 18.5 % SC @ 1.88 ml/kg, thiodicarb 75 WP @ 12.50 g/kg, emamectin benzoate 5 % SG @ 2.50 g/kg, *B. thuringiensis* @ 25 g/kg and *B. thuringiensis* @ 12.50 g/kg which recorded leaf damage score in the range of 4.30 to 4.83.Untreated plots recorded the highest leaf damage score of 5.67.

Almost a similar trend of effectiveness was observed at 10 DAA.

Table 39. Effect of poison baits on the leaf damage score by *S. frugiperda* in maize (rabi 2021)

Tr. No.	Treatments	Dose in g or ml /kg	Leaf damage score						
			Precount	First Application			Second Application		
				5 DAA	10 DAA	14 DAA	5 DAA	10 DAA	14 DAA
T ₁	<i>Bt</i> var. <i>kurstaki</i> 0.5 %WP	12.50 g/kg	5.07	4.83	4.10	4.20	4.03	3.20	3.40
T ₂	<i>Bt</i> var. <i>kurstaki</i> 0.5 %WP	25.00 g/kg	5.10	4.90	3.90	4.13	3.80	2.70	2.80
T ₃	Thiodicarb 75 WP	12.50 g/kg	4.63	4.50	3.50	3.60	3.40	2.10	2.00
T ₄	Emamectin benzoate 5 % SG	2.50 g/kg	4.93	4.60	3.63	3.80	3.70	2.30	2.30
T ₅	Chlorantraniliprole 18.5 % SC	1.88 ml/kg	4.97	4.30	3.20	3.40	2.50	1.50	1.43
T ₆	GF-4867@0.1 %	1.00 g /whorl	5.23	4.20	3.00	3.10	2.80	1.30	1.20
T ₇	Untreated control	-	5.50	5.67	5.87	6.20	6.83	6.60	6.50
	S.Em. ±	-	0.30	0.25	0.23	0.23	0.23	0.15	0.16
	CD @ 5 %	-	NS	0.77	0.70	0.71	0.70	0.45	0.51
	CV	-	10.16	9.20	10.18	9.86	10.20	8.99	10.17

NS : Non- significant, DAS: Days after application

GF-4867 @ 0.1 per cent, chlorantraniliprole 18.5 % SC @ 1.88 ml/kg, thiodicarb 75 WP @ 12.50 g/kg and emamectin benzoate 5 % SG @ 2.50 g/kg, being at par, recorded leaf damage score of in the range of 3.10 to 3.80 at 14 DAS. The next to follow were *B. thuringiensis* @ 25 g/kg (4.13) and the *B. thuringiensis* @ 12.50 g/kg (4.20) but they were at par with each other.

Second application

At 5 DAA, the least (2.50) leaf damage score was recorded by chlorantraniliprole 18.5 % SC @1.88 ml/kg but was at par with GF-4867@ 0.1 per cent (2.80). The next in the order of effectiveness were thiodicarb 75 WP @ 12.50 g/kg, emamectin benzoate 5 % SG @ 2.50 g/kg, *B. thuringiensis* @ 25 g/kg and *B. thuringiensis* @ 12.50 g/kg, being at par, recorded leaf damage score in the range of 3.40 to 4.03. However, untreated plots recorded leaf damage score of 6.83.

At 10 DAA, GF-4867 @ 0.1 per cent recorded lowest (1.30) leaf damage score. It was, however, at par with chlorantraniliprole 18.5 % SC @ 1.88 ml/kg (1.50). The next to follow was thiodicarb 75 WP @ 12.50 g/kg (2.10) and emamectin benzoate 5 % SG @ 2.50 g/kg (2.30). They were, however, at par with each other. *B. thuringiensis* @ 25 g/kg and *B. thuringiensis* @ 12.50 g/kg, recorded leaf damage score of 2.70 and 3.20, respectively.

GF-4867@ 0.1 per cent recorded lowest (1.20) leaf damage score even at 14 DAA. It was, however, at par with chlorantraniliprole 18.5 % SC @1.88 ml/kg (1.43). The next minimum leaf damage score was observed in the treatment of thiodicarb 75 WP @ 12.50 g/kg (2.00) followed by emamectin benzoate 5 % SG @ 2.50 g/kg (2.30) to which it was on par. *B. thuringiensis* @ 25 g/kg and *B. thuringiensis* @ 12.50 g/kg were next effective treatments which recorded leaf damage score of 2.80 and 3.40, respectively.

4.3.9 Pooled leaf damage score (kharif and rabi 2021)

The data on pooled mean leaf damage scores of *kharif* and *rabi* 2021 are presented in Table 40. The pooled mean of leaf damage score after whorl applications of baits ranged between 2.42 to 6.58.

The lowest leaf damage score was recorded by GF @ 4867- 0.1 per cent (2.42). It was, however, at par with chlorantraniliprole 18.5 % SC @ 1.88 ml/kg (2.59).

Table 40. Effect of poison baits on the leaf damage score by *S. frugiperda* in maize (*kharif* and *rabi* 2021 - pooled)

Tr. No.	Treatments	Dose g or ml/l	Leaf damage score						Pooled mean	
			Precount	First Spray			Second Spray			
				5 DAA	10 DAA	14 DAA	5 DAA	10 DAA		14 DAA
T ₁	<i>Bt</i> var. <i>kurstaki</i> 0.5 %WP	12.50 g/kg	5.23	4.98	4.22	4.30	4.03	3.10	3.25	3.98
T ₂	<i>Bt</i> var. <i>kurstaki</i> 0.5 %WP	25.00 g/kg	4.90	4.62	3.90	3.97	3.67	2.75	2.75	3.61
T ₃	Thiodicarb 75 WP	12.50 g/kg	4.92	4.62	3.27	3.25	2.95	2.07	1.95	3.02
T ₄	Emamectin benzoate 5 % SG	2.50 g/kg	4.88	4.77	3.48	3.60	3.35	2.37	2.15	3.29
T ₅	Chlorantraniliprole 18.5 % SC	1.88 ml/kg	5.43	4.25	3.05	3.10	2.40	1.40	1.37	2.59
T ₆	GF-4867@0.1 %	1.00 g/whorl	5.77	4.17	2.87	2.80	2.40	1.20	1.10	2.42
T ₇	Untreated control	-	5.47	5.93	6.28	6.55	6.97	6.87	6.85	6.58
	S.Em. ±	-	0.37	0.26	0.20	0.22	0.20	0.16	0.18	0.17
	CD @ 5 %	-	NS	0.77	0.60	0.65	0.59	0.48	0.54	0.52
	CV	-	12.27	9.60	9.18	9.78	9.56	10.00	11.46	8.07

NS: Non- significant, DAS : Days after application

The next to follow were thiodicarb 75 WP @ 12.50 g/kg (3.02) and emamectin benzoate 5 % SG @ 2.50 g/kg (3.29), being at par, recorded the leaf damage score of 3.02 and 3.29, respectively. The next moderately effective treatments were *B. thuringiensis* @25 g/kg (3.61) and *B. thuringiensis* 75 WP @ 12.50 g/kg (3.98) but they were at par with each other.

It reveals that, lowest leaf damage score was recorded in GF-4867@ 0.1 per cent followed by chlorantraniliprole 18.5 % SC @1.88 ml/kg, thiodicarb 75 WP @ 12.50 g/kg, emamectin benzoate 5 % SG @ 2.50 g/kg and *B. thuringiensis* @ 25 g/kg.

4.3.10 Yield of maize (Pooled *kharif* and *rabi* 2021)

The data on the mean yield of two seasons are presented in Table 41. The data reveals that all the treatments recorded significantly higher yield over the untreated control (46.65 q/ha). Differential efficacy of treatments reflected in the maize yield. The plot treated with GF-4867@ 0.1 % recorded the highest yield (75.56 q/ha). It was followed by chlorantraniliprole 18.5 % SC @1.88 ml/kg (74.06 q/ha), thiodicarb 75 WP @ 12.50 g/kg (67.73 q/ha) and emamectin benzoate 5 % SG @ 2.50 g/kg (64.09 q/ha). The next treatment was *B. thuringiensis* @ 25 g/kg recorded a yield of 60.71 q/ha followed by *B. thuringiensis* @ 12.50 g/kg (56.84 q/ha).

Table 41. Influence of poison baits on the grain yield of maize

Tr. No.	Treatments	Dose in g or ml /kg	Yield (q/ha)			Increase in yield over control (%)
			<i>kharif</i> (2021)	<i>rabi</i> (2021)	Pooled mean	
T ₁	<i>Bt</i> var. <i>kurstaki</i> 0.5 %WP	12.50 g/kg	55.29	58.38	56.84	21.83
T ₂	<i>Bt</i> var. <i>kurstaki</i> 0.5 %WP	25.00 g/kg	58.17	63.25	60.71	30.14
T ₃	Thiodicarb 75 WP	12.50 g/kg	65.32	70.15	67.73	45.19
T ₄	Emamectin benzoate 5 % SG	2.50 g/kg	62.44	65.74	64.09	37.38
T ₅	Chlorantraniliprole 18.5 % SC	1.88 ml/kg	71.50	76.62	74.06	58.76
T ₆	GF-4867@0.1 %	1.00 g / whorl	72.18	78.93	75.56	61.96
T ₇	Untreated control	-	45.33	47.96	46.65	-
	S.E.m. ±	-	0.36	0.41	0.30	-
	CD @ 5 %	-	1.10	1.27	0.93	-
	CV (%)	-	10.04	10.87	8.20	-

The data also indicated that among all baits the highest per cent increase yield over control was observed in plots treated with GF-4867 @ 0.1 per cent (61.96 %). This was followed by chlorantraniliprole 18.5 % SC @ 1.88 ml/kg (58.76 %), thiodicarb 75 WP @ 12.50 g/kg (45.19 %) emamectin benzoate 5 % SG @ 2.50 g/kg (37.38 %).

4.3.10.1 Cost Economics of different poison bait treatments during *kharif* and *rabi* 2021

The cost economics of different bait applications used in this experiment are presented in Table 42. The highest ICBR (1: 2.44) was reaped in the treatment, chlorantraniliprole 18.5 % SC @ 1.88 ml/kg. The next in descending order of ICBR were recorded in the treatments viz., emamectin benzoate 5 % SG @ 2.50 g/kg (1:1.89), thiodicarb 75 WP @ 12.50 g/kg (1:1.41) and GF-4867@ 0.1 % (1:1.25).

It is observed from the results, that the whorl application of bait in maize proved to be most effective in reducing the larval population and damage caused by *S. frugiperda* with increased yield. However, there was an increase in damage in untreated control throughout the period of experimentation in *kharif* and *rabi*.

The data over two season consistently proved that bait of GF - 4867@ 0.1 % was the most promising treatment in reducing per cent of plant damage, larval population and leaf damage score. This was followed by bait of chlorantraniliprole 18.5 % SC. This resulted the increase in grain yield of maize (Fig. 4).

In the present investigation, the bait application of GF-4867@ 0.1 per cent (test product containing spinetoram) was consistently proved to be most effective in reducing plant damage, larval population and leaf damage infesting *S. frugiperda* and also registered highest yield of 75.56 q/ha. This was followed by the chlorantraniliprole 18.5 % SC @1.88 ml/kg, thiodicarb 75 WP @ 12.50 g/kg, emamectin benzoate 5 % SG @ 2.50 g/kg and *B. thuringiensis* @25 g/kg.

There is very little information in the literature on the efficacy of poison baits on *S. frugiperda*. Therefore, related literature in respect of poison baits in other crops are also discussed.

Table 42. Economics of poison baits for the management of fall armyworm on maize (*kharif* and *rabi*- 2021-Pooled)

Tr. No.	Treatments	Dose in g or ml /kg	Grain yield (q/ha)	Additional yield over control (q/ha)	Total cost (Rs/ha)	Value of additional yield over untreated control (Rs/ha)	Net Profit (Rs/ha)	ICBR
T ₁	<i>Bt</i> var. <i>kurstaki</i> 0.5 %WP	12.50 g/kg	56.84	10.19	11584	19056	7472	1:0.64
T ₂	<i>Bt</i> var. <i>kurstaki</i> 0.5 %WP	25.00 g/kg	60.71	14.07	14664	26303	11639	1:0.79
T ₃	Thiodicarb 75 WP	12.50 g/kg	67.73	21.09	16344	39434	23090	1:1.41
T ₄	Emamectin benzoate 5 % SG	2.50 g/kg	64.09	17.44	11304	32619	21315	1:1.89
T ₅	Chlorantraniliprole 18. 5 % SC	1.88 ml/kg	74.06	27.42	14910	51269	36359	1:2.44
T ₆	GF-4867@0.1 %	1.00 g /whorl	75.56	28.91	24068	54062	29994	1:1.25
T ₇	Untreated control	-	46.65	-	-	-	-	-

Cost of cultivation of maize	: Rs. 39500/ha.	Thiodicarb	: Rs. 980/250 g
Maize grain selling rate	: Rs. 1870/qtl	Chlorantraniliprole	: Rs. 213/10 ml
Labour	: Rs. 299/labour	<i>B. thuringensis</i>	: Rs. 385/250 g
Wheat bran	: Rs. 20/kg	Emamectin benzoate	: Rs. 350/50 g
Jaggary	: Rs. 40/ kg	GF-4867	: Rs. 500/ 250 g

Effectiveness of poison bait GF-4867 @ 0.1 per cent as observed in the present investigation is in conformity with Dileep Kumar *et al.* (2020) reported that poison bait of spinetoram 11.7 SC@ 5 ml/kg of bait recorded maximum larval mortality as well as reduced the leaf damage by *S. frugiperda* and also registered highest grain yield of 33.83 q/ha in maize. Similarly, Kumar and Mohan (2020) reported reduction of the larval population by 97.32 per cent in the plots treated with spinetoram 11.7 % SC in *rabi* and *kharif* season of 2021. Whorl application of spinetoram 11.7 SC 5ml/kg of soil was effective in reducing the damage by FAW in maize (Jindal *et al.*, 2022). Further, *S. frugiperda* was effectively controlled by using bait of spinetoram (Radiant 120 SC) as reported by Sisay *et al.* (2019b). Similarly, Yeddula *et al.* (2022) revealed that poison bait with spinetoram 11.7 % SC @ 250 ml/ha registered the grain yield of 68.13 q/ha.

All these reports lend support to the present finding.

Chlorantraniliprole was the next best treatment against *S. frugiperda* as observed in the present investigation. This is in agreement with many earlier reports. Dileep Kumar *et al.* (2020) reported that poison baits using chlorantraniliprole 18.5 % SC @ 3 ml/kg reduced larval population of *S. frugiperda*, leaf damage and also registered highest grain yield (31.33q/ha) in maize. Similarly, Divya *et al.* (2022) revealed that whorl application of sand mixed with chlorantraniliprole 18.5 % SC @ 0.4 ml/kg was found most effective with a significant reduction in leaf damage and registered the highest grain yield (60.34 q/ha) in maize. Further, Kamakshi *et al.* (2023) reported that poison bait containing chlorantraniliprole 18.5 SC was effective in reducing fall armyworm infestation (13.37 %).

Effectiveness of thiodicarb 75 WP against *S. frugiperda* as observed in the present investigation is in agreement with many earlier reports. Lunagariya *et al.* (2020) reported that poison bait of thiodicarb 75 WP 250 g/ha was found superior in managing the population of FAW which reduced plants and cob damage with highest grain yield (26.35 q/ha) in maize. The whorl application of poison bait of thiodicarb 75 WP@10g/kg bait caused maximum reduction of larval population of *S. frugiperda* as well as registered grain yield of 26.27 q/ha in maize (Dileep Kumar *et al.*, 2020). Similarly, Shinde *et al.* (2021) reported that the plots treated with whorl application of poison bait (wheat bran 10

Kg + jaggary 2 kg + 3 lit. water + thiodicarb 100 g) recorded the lowest (25 %) damaged plants.

Poison bait containing thiodicarb 75 SP (9.52 %) was also found effective in reducing fall armyworm infestation (Kamakshi *et al.*, 2023). Similarly, poison bait with thiodicarb (100 g/acre) at 40 days after germination of maize recorded lowest per cent plant damage against *S. frugiperda* as reported by Omprakash *et al.* (2020). Shahanaz (2018) concluded that poison bait of thiodicarb 75 % WP was found superior and showed 100 per cent mortality of *S. litura* infesting tobacco. Also, Yeddula *et al.* (2022) revealed that poison bait with thiodicarb 75 SP (50 kg rice bran + 5 kg jaggery + 500 g thiodicarb 75 SP @ 50 kg/ha) was effective in the management of fall armyworm and registered grain yield of 73.44 q/ha. Likewise, Divya *et al.* (2022) found that whorl application of bait of thiodicarb 75WP (49.46 q/ha) mixed with sand registered the maximum grain yield against *S. frugiperda* infesting maize.

All these earlier reports support to the present finding.

The result in respect of emamectin benzoate as observed in the present investigation is in accordance with Lunagariya *et al.* (2020) who reported that poison bait of emamectin benzoate 5 SG @ 125 g/ha was found effective in reducing the larval population of *S. frugiperda* and also registered maximum grain yield (25.14 q/ha) in maize. Emamectin benzoate 5 SG @ 4 g/kg bait recorded maximum larval mortality and reduced the leaf damage by *S. frugiperda* and registered grain yield of 32.47 q/ha in maize as reported by Dileep Kumar *et al.* (2020).

Divya *et al.* (2022) reported that whorl application of sand mixed with emamectin benzoate 5 % SG @ 0.4 g/ kg was found effective with maximum reduction in leaf damage due to *S. frugiperda* and also registered maximum grain yield (58.60 q/ha) in maize. Further, poison bait containing emamectin benzoate 5 SG (16.21 %) was found more effective against fall armyworm with maximum reduction of infestation of maize (Kamakshi *et al.*, 2023). Shahanaz (2018) also confirmed the effectiveness of poison bait of emamectin benzoate 5 % SG in reducing larval population of *S. litura* in tobacco. Sreedhar and Nageswararao (2016) reported that the rice bran baits prepared with emamectin benzoate 5 SG was found effective for the management of *S. litura* in tobacco. These earlier reports lend support to the present finding.

Regarding the poison bait of *Bt* formulations are in accordance with Sharma *et al.* (2019) reported that the per cent mortality of *Spodoptera litura* (15.64 to 81.06 %) was observed in plot treated with poison bait of *Bt* (1 kg rice or wheat flour + 1.2 kg jaggery +5 g *Bt*/l) in tomato crop.

In the present investigation, the highest ICBR (1:2.63) was reaped by chlorantraniliprole 18.5 % SC followed by emamectin benzoate 5 % SG (1:1.89), thiodicarb 75 WP (1:1.41) and GF-4867-0.1 % (1:1.13). Results of present investigations are in accordance with the earlier finding of Kamakshi *et al.* (2023) who reported that higher yields with greater benefit-cost ratio was reported in chlorantraniliprole 18.5 SC (57.55 q/ha; BC ratio 2.7) followed by thiodicarb 75 SP (49.40 q/ha; BC ratio 2.3) and emamectin benzoate 5 SG (46.77 q/ha; BC ratio 2.6).

Likewise, Shinde *et al.* (2021) reported that the ICBR (1:1.67) of poison bait of thiodicarb (wheat bran 10 kg + jaggery 2 kg + 3 lit. water + 100 g @ 44 kg/ha) in the management of FAW in maize. Further, Divya *et al.* (2022) revealed that whorl application of insecticides mixed with sand in maize against *S. frugiperda* and derived the highest ICBR in the treatment of emamectin benzoate 5 SG (1:2.35) followed by chlorantraniliprole 18.5 SC (1:2.29) and thiodicarb 75WP (1:1.95).

4.4 Field evaluation of farmer's practices against *Spodoptera frugiperda*.

In the present experiment, different farmer's practices were evaluated for their efficacy in the field against *S. frugiperda* in maize during *kharif* and *rabi* 2021. The findings of the observations on the per centage of plant damage, the larvae population and the leaf damage score are presented and discussed .

4.4.1 Plant damage (*kharif* 2021)

First application

The data on per cent plant damage (Table 43) revealed that there was a significant difference among the treatments at all the intervals of observations except pre-treatment count. The plant damage one day before the application (pre-count) of farmer's practices ranged between 58.33 to 64.58 per cent and it was statistically non-significant, indicating uniform plant damage of maize due to *S. frugiperda*. The plant damage in the untreated plots ranged between 60.42 to 63.54 per cent at 5 DAA and 14 DAA.

Table 43. Evaluation of farmer's practices on plant damage of *S. frugiperda* in maize during kharif 2021

Tr. No.	Treatments	Dose /whorl or l	Per cent plant damage						
			Precount	First Application			Second Application		
				5 DAA	10 DAA	14 DAA	5 DAA	10 DAA	14 DAA
T ₁	Wood ash	5 g/whorl	64.58 (53.49)	54.69 (47.70)	44.79 (41.99)	51.56 (45.90)	52.60 (46.50)	34.90 (35.99)	47.92 (43.78)
T ₂	Soil	5 g/whorl	63.02 (52.58)	55.73 (48.30)	45.31 (42.30)	52.60 (46.50)	53.13 (46.82)	35.94 (36.76)	48.96 (44.40)
T ₃	Sand	5 g/whorl	58.33 (49.82)	56.77 (48.90)	47.40 (43.51)	53.13 (46.79)	51.56 (45.90)	38.02 (38.04)	51.04 (45.60)
T ₄	Neem seed powder	2 g/whorl	60.94 (51.34)	49.48 (44.68)	33.85 (35.55)	38.02 (38.06)	33.33 (35.25)	22.40 (28.22)	25.00 (29.95)
T ₅	Lime	5 g/whorl	61.46 (51.65)	52.08 (46.20)	43.23 (41.11)	50.52 (45.30)	51.04 (45.62)	33.85 (35.58)	46.88 (43.21)
T ₆	Chilli extract spray 10 %	10 ml/l	62.50 (52.27)	58.85 (50.13)	49.48 (44.70)	57.29 (49.22)	59.90 (50.72)	40.10 (39.29)	53.65 (47.15)
T ₇	Chlorine water 0.03 %	10 ml/whorl	60.94 (51.33)	57.81 (49.51)	47.92 (43.80)	58.33 (49.85)	59.90 (50.73)	41.15 (39.88)	52.60 (46.52)
T ₈	Chlorantraniliprole 18.5 % SC	0.4 ml/l	60.94 (51.37)	39.58 (38.97)	25.52 (30.33)	27.60 (31.68)	22.92 (28.57)	12.50 (20.68)	13.54 (21.54)
T ₉	Detergent water spray	5 g/l	61.46 (51.63)	59.90 (50.72)	56.25 (48.63)	60.42 (51.09)	63.54 (52.87)	62.50 (52.30)	64.58 (53.52)
T ₁₀	Untreated control	-	59.38 (50.43)	60.42 (51.03)	62.50 (52.26)	63.54 (52.86)	66.15 (54.45)	66.67 (54.77)	67.19 (55.09)
	S.E.m ±		1.85	1.91	1.51	1.85	2.13	2.17	2.41
	CD @ 5 %		NS	5.67	4.50	5.51	6.33	6.46	7.15
	CV		7.20	8.36	8.08	8.02	8.06	9.87	9.68

Figures in the parantheses are arc sin transformed values, NS: Non-significant, DAA= Days after application

At 5 DAA, chlorantraniliprole @ 0.4 ml/l proved to be significantly superior over the rest of the treatments by recording least plant damage (39.58 %). This was followed by neem seed powder @ 2 g/whorl which recorded 49.48 per cent plant damage. The next effective treatments were lime @ 5 g/whorl, wood ash @ 5 g/whorl, soil @ 5 g/whorl, sand @ 5 g/whorl, chlorine water @ 10 ml/whorl, chilli extract @ 10 ml/l and detergent water @ 5 g/l which recorded plant damage in the range of 52.08 to 59.90 per cent.

Almost, a similar trend was noticed at 10 DAA.

Chlorantraniliprole @ 0.4 ml/l continued to be effective by recording the least (27.60 %) plant damage even at 14 DAA. Neem seed powder @ 2 g/whorl (38.02 %) was the next effective treatment by recording the minimum per cent of plant damage. Lime @ 5 g/whorl, wood ash @ 5 g/whorl, soil @ 5 g/whorl, sand @ 5 g/whorl, chilli extract spray @ 10 ml/l and chlorine water @ 10 ml/whorl, being at par, were next to follow with plant damage in the range of 50.52 to 58.33 per cent. Detergent water @ 5 g/l (66.15 %) was less effective in reducing plant damage.

Second application

It reveals that the plant damage in the untreated plots was 66.15 per cent at 5 DAA and gradually increased to 67.19 per cent at 14 DAA.

At 5 DAA, chlorantraniliprole @ 0.4 ml/l was the most effective treatment by recording the lowest (22.92 %) plant damage. Neem seed powder @ 2 g/whorl was the next effective treatment by recording 33.33 per cent plant damage. It was, however, at par with the lime @ 5 g/whorl (51.04 %), wood ash @ 5 g/whorl (52.60 %), soil @ 5 g/whorl (52.60 %) and sand @ 5 g/whorl (51.56 %). Chilli extract spray @ 10 ml/l, chlorine water @ 10 ml/whorl and detergent water @ 5 g/l, being at par, were next to follow with the plant damage in the range of 59.90 to 63.54 per cent..

At 10 DAA, almost a similar trend in the effectiveness of treatments was noticed.

Chlorantraniliprole @ 0.4 ml/l maintained its superiority even at 14 DAA by recording significantly lowest (13.54 %) plant damage. The next effective treatments were neem seed powder @ 2 g/whorl followed by lime @ 5 g/whorl, wood ash @ 5 g/whorl, soil @ 5 g/whorl, sand @ 5 g/whorl, chlorine water @ 10 ml/whorl and chilli

extract spray @ 10 ml/l which recorded the plant damage in the range of 25.00 to 53.65 per cent.

4.4.2 Plant damage (*rabi* 2021)

First application

The data on the efficacy of different treatments of farmers' practices on the per cent plant damage due to *S. frugiperda* infesting maize after first and second application are presented in Table 44. It revealed that per cent plant damage recorded a day before the application of treatments ranged between 51.21 to 55.21 per cent and were statistically non-significant, indicating uniform plant damage of maize. The plant damage in the untreated plots was ranged between 52.60 to 61.46 per cent.

At 5 DAA, chlorantraniliprole @ 0.4 ml/l (40.63 %) was the most effective treatment but it was on par with neem seed powder @ 2 g/whorl (47.92 %). The next effective treatments were lime @ 5 g/whorl, wood ash @ 5 g/whorl, soil @ 5 g/whorl, sand @ 5 g/whorl, chlorine water @ 10 ml/whorl, chilli extract spray @ 10 ml/l and detergent water @ 5 g/l which recorded plant damage in the range of 51.04 to 54.17 per cent.

Almost a similar trend was noticed at 10 DAA.

Chlorantraniliprole @ 0.4 ml/l recorded the lowest (27.60 %) plant damage even at 14 DAA. This was followed by neem seed powder @ 2 g/whorl (36.46 %). The next effective treatment was lime @ 5 g/whorl recorded 45.83 per cent of plant damage. It was, however, at par with wood ash @ 5 g/whorl, soil @ 5 g/whorl, sand @ 5 g/whorl, chilli extract spray @ 10 ml/l and chlorine water @ 10 ml/whorl which recorded plant damage in the range of 47.90 to 53.13 per cent. The detergent water @ 5 g/l (55.21 %) was the least effective treatment in reducing plant damage. The untreated control recorded the highest (58.33 %) plant damage.

Table 44. Evaluation of farmer's practices on plant damage of *S. frugiperda* in maize during rabi 2021

Tr. No.	Treatments	Dose /whorl or l	Per cent plant damage						
			Precount	First Application			Second Application		
				5 DAA	10 DAA	14 DAA	5 DAA	10 DAA	14 DAA
T ₁	Wood ash	5 g/whorl	54.17 (47.41)	51.56 (45.90)	43.23 (41.10)	47.92 (43.80)	50.00 (45.00)	34.90 (36.19)	41.67 (40.19)
T ₂	Soil	5 g/whorl	53.13 (46.80)	52.08 (46.20)	43.75 (41.40)	49.48 (44.70)	52.08 (46.20)	35.94 (36.78)	43.75 (41.38)
T ₃	Sand	5 g/whorl	54.17 (47.39)	52.60 (46.49)	45.83 (42.61)	50.52 (45.30)	53.65 (47.09)	38.02 (38.05)	47.92 (43.80)
T ₄	Neem seed powder	2 g/whorl	55.21 (48.01)	47.92 (43.78)	34.90 (36.08)	36.46 (37.12)	31.77 (34.26)	21.35 (27.46)	22.40 (28.22)
T ₅	Lime	5 g/whorl	51.04 (45.60)	51.04 (45.60)	43.75 (41.40)	45.83 (42.61)	49.48 (44.70)	33.85 (35.55)	40.63 (39.59)
T ₆	Chilli extract spray 10 %	10 ml/l	52.08 (46.20)	53.13 (46.81)	45.31 (42.30)	52.60 (46.51)	55.21 (48.00)	41.15 (39.89)	48.44 (44.10)
T ₇	Chlorine water 0.03 %	10 ml/whorl	51.04 (45.60)	52.60 (46.50)	46.88 (43.21)	53.13 (46.79)	54.69 (47.70)	39.06 (38.66)	47.92 (43.80)
T ₈	Chlorantraniliprole 18.5 % SC	0.4 ml/l	55.21 (48.00)	40.63 (39.58)	26.04 (30.62)	27.60 (31.68)	24.48 (29.62)	14.06 (22.00)	14.06 (21.94)
T ₉	Detergent water spray	5 g/l	54.17 (47.39)	53.13 (46.80)	51.04 (45.60)	55.21 (48.00)	58.85 (50.10)	52.08 (46.20)	55.21 (48.01)
T ₁₀	Untreated control	-	52.60 (46.50)	53.65 (47.09)	57.29 (49.21)	58.33 (49.81)	61.46 (51.63)	59.38 (50.41)	58.33 (49.80)
	S.E.m ±		1.55	1.42	1.59	1.70	1.32	1.37	2.03
	CD @ 5 %		NS	4.21	4.72	5.05	3.92	4.08	6.02
	CV		7.73	8.40	8.65	9.17	8.15	8.41	10.76

Figures in the parantheses are arc sin transformed values, NS: Non-significant, DAA= Days after application

Second application

At 5 DAA, chlorantraniliprole @ 0.4 ml/l was the most effective treatment recording the lowest (24.48 %) plant damage. Neem seed powder @ 2 g/whorl was the next to follow by recording plant damage (31.77 %). Lime @ 5 g/whorl, wood ash @ 5 g/whorl, soil @ 5 g/whorl, sand @ 5 g/whorl, chlorine water @ 10 ml/whorl and chilli extract spray @ 10 ml/l, being at par, were next to follow in the range of 49.48 to 55.21 per cent plant damage. The detergent water @ 5 g/l was recorded as the maximum plant damage (58.85 %) followed by the untreated plots (61.46 %).

Almost a similar trend in the order of effectiveness of treatments was noticed even after 10 DAA.

At 14 DAA, chlorantraniliprole @ 0.4 ml/l (14.06 %) was found to be superior over all the treatments by recording plant damage due to *S. frugiperda*. Neem seed powder @ 2 g/whorl was next remained effective by recording the lowest (22.40 %) plant damage. Lime @ 5 g/whorl, wood ash @ 5 g/whorl, soil @ 5 g/whorl, sand @ 5 g/whorl, chlorine water @ 10 ml/whorl and chilli extract spray @ 10 ml/l, being at par, were next to follow in the range of 40.63 to 48.44 per cent plant damage. The next treatment detergent water @ 5 g/l was recorded 55.21 per cent damage to the plant. The untreated plots was recorded the highest i.e. 58.33 per cent of plant damage.

4.4.3 Pooled data of two seasons (*kharif* and *rabi* 2021)

The data on the per cent plant damage due to *S. frugiperda* infesting maize were pooled and are presented in Table 45. It could be seen that all treatments were significantly superior over the untreated plots.

Chlorantraniliprole @ 0.4 ml/l maintained its superiority over the two seasons by recording the least plant damage (24.05 %). Among the farmer's practices the neem seed powder @ 2 g/whorl (33.07 %) was significantly superior to rest of the treatments at all intervals. The lime @ 5 g/whorl (45.18 %) was found next effective treatment but it was at par with wood ash @ 5 g/whorl, soil @ 5 g/whorl and sand @ 5 g/whorl which recorded plant damage of 46.31, 47.70 and 48.87 per cent, respectively. The next effective treatments were chlorine water @ 10 ml/whorl (51.00 %) and chilli extract spray @ 10 ml/l (51.26 %). The detergent water @ 5 g/l was next effective treatment with 57.73 per cent plant damage. The highest (61.24 %) per cent of plant damage recorded by the untreated control.

Table 45. Evaluation of farmer's practices on plant damage of *S. frugiperda* in maize (*kharif* and *rabi* 2021-Pooled)

Tr. No.	Treatments	Dose g or ml/l	Per cent plant damage						Pooled mean	
			Precount	First Spray			Second Spray			
				5 DAA	10 DAA	14 DAA	5 DAA	10 DAA		14 DAA
T ₁	Wood ash	5 g/whorl	59.38 (50.41)	53.13 (46.80)	44.01 (41.56)	49.74 (44.85)	51.30 (45.75)	34.90 (36.13)	44.79 (41.99)	46.31 (42.87)
T ₂	Soil	5 g/whorl	58.07 (49.65)	53.91 (47.24)	44.53 (41.86)	51.04 (45.60)	52.60 (46.50)	35.94 (36.79)	46.35 (42.90)	47.40 (43.50)
T ₃	Sand	5 g/whorl	56.25 (48.60)	54.69 (47.69)	46.61 (43.06)	51.82 (46.05)	52.60 (46.49)	38.02 (38.06)	49.48 (44.70)	48.87 (44.35)
T ₄	Neem seed powder	2 g/whorl	58.07 (49.67)	48.70 (44.25)	34.38 (35.82)	37.24 (37.59)	32.55 (34.79)	21.88 (27.87)	23.70 (29.13)	33.07 (35.04)
T ₅	Lime	5 g/whorl	56.25 (48.60)	51.56 (45.90)	43.49 (41.25)	48.18 (43.95)	50.26 (45.15)	33.85 (35.58)	43.75 (41.41)	45.18 (42.22)
T ₆	Chilli extract spray 10 %	10 ml/l	57.29 (49.21)	55.99 (48.46)	47.40 (43.51)	54.95 (47.86)	57.55 (49.34)	40.63 (39.59)	51.04 (45.60)	51.26 (45.72)
T ₇	Chlorine water 0.03 %	10 ml/whorl	55.99 (48.45)	55.21 (48.00)	47.40 (43.51)	55.73 (48.29)	57.29 (49.21)	40.10 (39.28)	50.26 (45.16)	51.00 (45.57)
T ₈	Chlorantraniliprole 18.5 % SC	0.4 ml/l	58.07 (49.67)	40.10 (39.29)	25.78 (30.48)	27.60 (31.68)	23.70 (29.12)	13.28 (21.36)	13.80 (21.75)	24.05 (29.23)
T ₉	Detergent water spray	5 g/l	57.81 (49.50)	56.51 (48.75)	53.65 (47.09)	57.81 (49.50)	61.20 (51.48)	57.29 (49.20)	59.90 (50.74)	57.73 (49.45)
T ₁₀	Untreated control	-	55.99 (48.45)	57.03 (49.05)	59.90 (50.72)	60.94 (51.33)	63.80 (53.01)	63.02 (52.56)	62.76 (52.41)	61.24 (51.50)
	S.E.m ±		1.41	1.29	1.14	1.22	1.21	1.43	1.87	1.01
	CD @ 5 %		NS	3.83	3.39	3.63	3.59	4.25	5.55	3.00
	CV		6.97	8.02	8.13	8.92	8.63	9.58	10.78	8.62

Figures in the parantheses are arc sin transformed values, NS: Non-significant, DAA= Days after application

4.4.4 Larval population (*kharif* 2021)

The data on the efficacy of different practices of farmers against the larval population of *S. frugiperda* infesting maize after the first and second applications are presented in Table 46.

First application

It revealed that the larval population recorded a day before the application of different treatments ranged between 1.83 to 2.37 per plant and it was statistically non-significant, indicating a uniform larval population of *S. frugiperda*. The larval population recorded by the untreated plots ranged between 2.17 to 2.67 larvae per plant.

At 5 DAA, chlorantraniliprole @ 0.4 ml/l recorded the least larval population (0.70 larvae /plant) and proved to be significantly superior over rest of the treatments. Neem seed powder @ 2 g/whorl was the next effective treatment which recorded 0.93 larvae per plant. Lime @ 5 g/whorl, soil @ 5 g/whorl, sand @ 5 g/whorl, wood ash @ 5 g/whorl and chlorine water @ 10 ml/whorl, being at par, were next to follow in the order of effectiveness and ranged from 1.23 to 1.43 larvae per plant. Chilli extract spray @ 10 ml/l and detergent water @ 5 g/l recorded 1.70 and 1.93 larvae per plant respectively.

Almost a similar trend in the efficacy of treatments were observed at 10 DAA.

At 14 DAA, chlorantraniliprole @ 0.4 ml/l recorded significantly least (0.70 larvae/plant) population and maintained superiority over the rest of the treatments. Neem seed powder @ 2 g/whorl was next best treatment which recorded 1.00 larvae per plant. The next in the order of effectiveness were lime @ 5 g/whorl, soil @ 5 g/whorl, sand @ 5 g/whorl, wood ash @ 5 g/whorl, chlorine water @ 10 ml/whorl, chilli extract spray @ 10 ml/l and detergent water @ 5 g/l which recorded larval population 1.40 to 2.27 larvae per plant. Untreated plots recorded maximum larval population of 2.67 larvae per plant.

Second application

At 5 DAA, the plots treated with chlorantraniliprole @ 0.4 ml/l recorded the lowest number of larvae (0.53 larvae/plant). Neem seed powder @ 2 g/whorl was found next effective by recording larval population i.e.0.90 larvae per plant. This was

Table 46. Evaluation of farmer's practices on the larval population of *S. frugiperda* in maize during kharif 2021

Tr. No.	Treatments	Dose /whorl or l	Number of larvae/plant						
			Precount	First Application			Second Application		
				5 DAA	10 DAA	14 DAA	5 DAA	10 DAA	14 DAA
T ₁	Wood ash	5 g/whorl	2.20 (1.64)	1.43 (1.39)	1.33 (1.35)	1.53 (1.43)	1.07 (1.25)	1.00 (1.22)	1.47 (1.40)
T ₂	Soil	5 g/whorl	1.90 (1.55)	1.23 (1.32)	1.17 (1.29)	1.43 (1.39)	1.13 (1.28)	1.17 (1.29)	1.50 (1.41)
T ₃	Sand	5 g/whorl	2.30 (1.67)	1.33 (1.35)	1.20 (1.30)	1.47 (1.40)	1.23 (1.32)	1.20 (1.30)	1.50 (1.41)
T ₄	Neem seed powder	2 g/whorl	2.33 (1.68)	0.93 (1.20)	0.90 (1.18)	1.00 (1.22)	0.73 (1.11)	0.70 (1.09)	0.77 (1.12)
T ₅	Lime	5 g/whorl	1.83 (1.53)	1.23 (1.32)	1.13 (1.28)	1.40 (1.38)	1.03 (1.24)	0.90 (1.18)	1.40 (1.38)
T ₆	Chilli extract spray 10 %	10 ml/l	2.30 (1.67)	1.70 (1.48)	1.67 (1.47)	1.87 (1.54)	1.30 (1.34)	1.27 (1.33)	1.63 (1.46)
T ₇	Chlorine water 0.03 %	10 ml/whorl	2.27 (1.66)	1.43 (1.39)	1.33 (1.35)	1.57 (1.44)	1.30 (1.34)	1.23 (1.32)	1.57 (1.44)
T ₈	Chlorantraniliprole 18.5 % SC	0.4 ml/l	2.37 (1.69)	0.70 (1.09)	0.67 (1.08)	0.70 (1.09)	0.53 (1.02)	0.50 (1.00)	0.53 (1.01)
T ₉	Detergent water spray	5 g/l	2.37 (1.69)	1.93 (1.56)	1.97 (1.57)	2.27 (1.66)	1.93 (1.56)	2.03 (1.59)	2.20 (1.64)
T ₁₀	Untreated control	-	2.10 (1.61)	2.17 (1.63)	2.57 (1.75)	2.67 (1.78)	2.43 (1.71)	2.47 (1.72)	2.70 (1.79)
	S.E.m ±		0.04	0.03	0.03	0.03	0.03	0.03	0.03
	CD @ 5 %		NS	0.09	0.08	0.09	0.08	0.08	0.10
	CV		6.26	8.88	8.42	9.74	9.56	8.43	9.10

Figures in parenthesis are $\sqrt{x + 0.05}$ transformed values, NS: Non- significant, DAS: Days after application

followed by lime @ 5 g/whorl which recorded 1.03 larvae /plant. It was, however, at par with wood ash @ 5 g/whorl, soil @ 5 g/whorl and sand @ 5 g/whorl, which recorded larval population in the range of 1.07 to 1.23 larva per plant. The next in the order of effectiveness were chilli extract spray @ 10 ml/l and chlorine water @ 10 ml/whorl, detergent water @ 5 g/l which recorded larval population in the range of 1.30 to 1.93 larvae per plant. The highest (2.43 larvae/plant) larval population was recorded by untreated plots.

Almost a similar trend in the order of effectiveness of treatments was noticed even after 10 DAA.

At 14 DAA, chlorantraniliprole @ 0.4 ml/l recorded least (0.53 larvae/plant) larval population. This was followed by neem seed powder @ 2 g/whorl (0.77 larvae/plant). Lime @ 5 g/whorl was next effective treatment which recorded 1.40 larvae per plant. It was, however, at par with wood ash @ 5 g/whorl, soil @ 5 g/whorl, sand @ 5 g/whorl, chlorine water @ 10 ml/whorl and chilli extract spray @ 10 ml/l recorded larval population in the range of 1.47 to 1.63 larvae per plant. The next treatment was detergent water @ 5 g/l which recorded 2.20 larvae per plant. Highest (2.63 larvae/plant) larval population was found in the untreated plots among all treatments.

4.4.5 Larval population (*rabi* 2021)

It reveals that the larval population recorded a day before the application of treatments was consistent and statistically non-significant by recording 1.17 to 1.40 larvae per plant across the plots. The larval population was recorded in untreated plots ranged from 1.40 to 1.87 larvae per plant. The data on the efficacy of different treatments after first and second applications during *rabi* 2021 are presented in Table 47.

First application

At 5 DAA, chlorantraniliprole @ 0.4 ml/l recorded least (0.53 larvae/plant) larval population. Neem seed powder @ 2 g/whorl was next effective treatment by recording 0.73 larvae per plant. The whorl application of lime @ 5 g/whorl (0.93 larvae/plant) was found next best treatment. It was, however, at par with wood ash @ 5 g/whorl, soil @ 5 g/whorl and sand @ 5 g/whorl, chlorine water @ 10 ml/whorl, chilli extract spray @ 10 ml/l and detergent water @ 5 g/l which recorded larval

Table 47. Evaluation of farmer's practices on the larval population of *S. frugiperda* in maize during rabi 2021

Tr. No.	Treatments	Dose /whorl or l	Number of larvae/plant						
			Precount	First Application			Second Application		
				5 DAA	10 DAA	14 DAA	5 DAA	10 DAA	14 DAA
T ₁	Wood ash	5 g/whorl	1.37 (1.37)	0.97 (1.21)	1.00 (1.22)	1.20 (1.30)	0.83 (1.15)	0.80 (1.14)	1.07 (1.25)
T ₂	Soil	5 g/whorl	1.37 (1.37)	1.00 (1.22)	0.97 (1.21)	1.23 (1.32)	0.87 (1.17)	0.83 (1.15)	1.03 (1.24)
T ₃	Sand	5 g/whorl	1.33 (1.35)	1.03 (1.24)	1.03 (1.24)	1.27 (1.33)	0.90 (1.18)	0.90 (1.18)	1.13 (1.28)
T ₄	Neem seed powder	2 g/whorl	1.30 (1.34)	0.73 (1.11)	0.73 (1.11)	0.77 (1.13)	0.53 (1.02)	0.50 (1.00)	0.53 (1.02)
T ₅	Lime	5 g/whorl	1.40 (1.38)	0.93 (1.20)	0.97 (1.21)	1.13 (1.28)	0.80 (1.14)	0.77 (1.13)	1.00 (1.22)
T ₆	Chilli extract spray 10 %	10 ml/l	1.33 (1.35)	1.10 (1.26)	1.13 (1.28)	1.37 (1.37)	1.03 (1.24)	1.03 (1.24)	1.33 (1.35)
T ₇	Chlorine water 0.03 %	10 ml/whorl	1.30 (1.34)	1.07 (1.25)	1.10 (1.26)	1.37 (1.37)	1.00 (1.22)	0.97 (1.21)	1.17 (1.29)
T ₈	Chlorantraniliprole 18.5 % SC	0.4 ml/l	1.17 (1.29)	0.53 (1.02)	0.50 (1.00)	0.57 (1.03)	0.37 (0.93)	0.33 (0.91)	0.33 (0.91)
T ₉	Detergent water spray	5 g/l	1.37 (1.36)	1.13 (1.28)	1.30 (1.34)	1.47 (1.40)	1.07 (1.25)	1.10 (1.26)	1.40 (1.38)
T ₁₀	Untreated control	-	1.40 (1.38)	1.73 (1.49)	1.83 (1.53)	1.87 (1.54)	1.77 (1.50)	1.60 (1.45)	1.57 (1.44)
	S.E.m ±		0.05	0.03	0.03	0.02	0.03	0.03	0.03
	CD @ 5 %		0.14	0.08	0.08	0.07	0.08	0.08	0.10
	CV		7.89	9.58	9.89	8.01	8.78	9.00	9.67

Figures in parenthesis are $\sqrt{x + 0.05}$ transformed values, NS: Non- significant, DAA: Days after application

population in the range of 0.97 to 1.13 larvae per plant. The highest (1.73 larvae/plant) larval population was recorded in untreated plots.

Almost a similar trend was noticed even after 10 DAA.

Chlorantraniliprole @ 0.4 ml/l continued to be superior to the rest of treatments even at 14 DAA by recording least larval population (0.57 larvae/plant). The next effective treatment was neem seed powder @ 2 g/whorl in reducing the larval population i.e. 0.77 larvae per plant.

The next in the order of effectiveness were lime @ 5 g/whorl, wood ash @ 5 g/whorl, soil @ 5 g/whorl and sand @ 5 g/whorl being at par, which recorded larval population in the range of 1.13 to 1.27 larvae per plant. The next effective treatments were chilli extract spray @ 10 ml/l, chlorine water @ 10 ml/whorl and detergent water @ 5 g/l which recorded larval population 1.37, 1.37 and 1.47 larvae per plant, respectively.

Second application

At 5 DAA, chlorantraniliprole @ 0.4 ml/l recorded the lowest number of larvae (0.37 larvae/plant). Neem seed powder @ 2 g/whorl was found next best treatment by recording 0.53 larvae per plant. Lime @ 5 g/whorl, wood ash @ 5 g/whorl, soil @ 5 g/whorl, sand @ 5 g/whorl, chlorine water @ 10 ml/whorl, being at par, were next to follow which recorded larval population in the range of 0.80 to 1.00 larvae per plant. The next in the order of effectiveness were chilli extract spray @ 10 ml/l and detergent water @ 5 g/l which recorded 1.03 and 1.07 larvae per plant.

Almost a similar trend was noticed in the order of effectiveness of treatments even after 10 DAA.

At 14 DAA, the least larval population (0.33 larvae/plant) was recorded by chlorantraniliprole @ 0.4 ml/l. This was followed by neem seed powder @ 2 g/whorl (0.53 larvae/plant). The whorl application of lime @ 5 g/whorl (1.00 larvae/plant) was the next best treatment but at par with soil @ 5 g/whorl, wood ash @ 5 g/whorl, sand @ 5 g/whorl and chlorine water @ 10 ml/whorl, which recorded larval population in the range of 1.03 to 1.17 larvae per plant. The next in the order of effectiveness were chilli extract spray @ 10 ml/l (1.33 larvae/plant) and detergent water @ 5 g/l (1.40 larvae/plant). In the untreated plots, the highest larval population was recorded i.e. 1.57 larvae per plant.

4.4.6 Pooled data of two seasons (*kharif* and *rabi* 2021)

The results of pooled data are presented in Table 48. The plot treated with chlorantraniliprole @ 0.4 ml/l (0.85 larvae/plant) remained effective at all intervals of observations and was significantly superior over rest of the treatments. Whereas untreated control showed the highest (2.11 larvae/plant) larval population in maize. Among the treatments of farmer's practices, the whorl application of neem seed powder @ 2 g/whorl was found most effective treatment by recording the lowest (0.91 larvae/plant) larval population. This was followed by lime @ 5 g/whorl (1.06 larvae/plant). It was however, at par with soil @ 5 g/whorl and wood ash @ 5 g/whorl which recorded larval population 1.13 and 1.14 larvae per plant, respectively. The next in the order of effectiveness were sand @ 5 g/whorl, chlorine water @ 10 ml/whorl and chilli extract spray @ 10 ml/l which recorded larval population in the range of 1.18 to 1.37 larvae per plant. The Detergent water @ 5 g/l (1.65 larvae/plant) was the effective treatment among all practices.

4.4.7 Leaf damage score (*kharif* 2021)

The observations pertaining to leaf damage score are presented in Table 49. The leaf damage score in the pre-treatment count ranged between 4.90 to 6.20 and it was statistically non-significant indicating uniform leaf damage by *S. frugiperda*.

First application

At 5 DAS, lowest (4.00) leaf damage score was recorded by chlorantraniliprole @ 0.4 ml/l followed by neem seed powder @ 2 g/whorl (4.40) to which it was on par. Sand @ 5 g/whorl, lime @ 5 g/whorl, detergent water @ 5 g/l, wood ash @ 5 g/whorl, soil @ 5 g/whorl and chlorine water @ 10 ml/whorl, being at par, were next to follow by recording leaf damage score in the range of 5.10 to 5.80. The maximum leaf damage score were recorded in untreated plots (6.20) and chilli extract spray @ 10 ml/l (6.30).

Almost a similar trend was observed in effectiveness of treatments even after 10 DAA.

Chlorantraniliprole @ 0.4 ml/l maintained its superiority even at 14 DAS by recording leaf damage score (2.80). Neem seed powder @ 2 g/whorl was next best treatment by recording leaf damage score (3.90) followed by lime @ 5 g/whorl (4.70) to

Table 48. Evaluation of farmer's practices on the larval population of *S. frugiperda* in maize (kharif and rabi 2021-Pooled)

Tr. No.	Treatments	Dose g or ml/l	Number of larvae/plant						Pooled mean	
			Precount	First Spray			Second Spray			
				5 DAA	10 DAA	14 DAA	5 DAA	10 DAA		14 DAA
T ₁	Wood ash	5 g/whorl	1.78 (1.51)	1.20 (1.30)	1.17 (1.29)	1.37 (1.37)	0.95 (1.20)	0.90 (1.18)	1.27 (1.33)	1.14 (1.28)
T ₂	Soil	5 g/whorl	1.63 (1.46)	1.12 (1.27)	1.07 (1.25)	1.33 (1.35)	1.00 (1.22)	1.00 (1.22)	1.27 (1.33)	1.13 (1.28)
T ₃	Sand	5 g/whorl	1.82 (1.52)	1.18 (1.30)	1.12 (1.27)	1.37 (1.37)	1.07 (1.25)	1.05 (1.24)	1.32 (1.35)	1.18 (1.30)
T ₄	Neem seed powder	2 g/whorl	1.82 (1.52)	0.83 (1.15)	0.82 (1.15)	0.88 (1.18)	0.63 (1.06)	0.60 (1.05)	0.65 (1.07)	0.91 (1.19)
T ₅	Lime	5 g/whorl	1.62 (1.45)	1.08 (1.26)	1.05 (1.24)	1.27 (1.33)	0.92 (1.19)	0.83 (1.15)	1.20 (1.30)	1.06 (1.25)
T ₆	Chilli extract spray 10 %	10 ml/l	1.82 (1.52)	1.40 (1.38)	1.40 (1.38)	1.62 (1.45)	1.17 (1.29)	1.15 (1.28)	1.48 (1.41)	1.37 (1.37)
T ₇	Chlorine water 0.03 %	10 ml/whorl	1.78 (1.51)	1.25 (1.32)	1.22 (1.31)	1.47 (1.40)	1.15 (1.28)	1.10 (1.26)	1.37 (1.37)	1.26 (1.33)
T ₈	Chlorantraniliprole 18.5 % SC	0.4 ml/l	1.77 (1.51)	0.62 (1.06)	0.58 (1.04)	0.63 (1.06)	0.45 (0.97)	0.42 (0.96)	0.43 (0.96)	0.85 (1.16)
T ₉	Detergent water spray	5 g/l	1.87 (1.54)	1.53 (1.43)	1.63 (1.46)	1.87 (1.54)	1.50 (1.41)	1.57 (1.44)	1.80 (1.52)	1.65 (1.47)
T ₁₀	Untreated control	-	1.75 (1.50)	1.95 (1.56)	2.20 (1.64)	2.27 (1.66)	2.10 (1.61)	2.03 (1.59)	2.13 (1.62)	2.11 (1.62)
	S.E.m ±		0.04	0.02	0.02	0.02	0.02	0.02	0.03	0.01
	CD @ 5 %		NS	0.06	0.05	0.05	0.06	0.06	0.08	0.04
	CV		6.17	8.65	7.02	7.06	8.57	8.85	9.54	7.78

Figures in parenthesis are $\sqrt{x + 0.05}$ transformed values, NS: Non- significant, DAS: Days after application

Table 49. Evaluation of farmer's practices against leaf damage score by *S. frugiperda* in maize (*kharif* 2021)

Tr. No.	Treatments	Dose /whorl or l	Leaf damage score						
			Precount	First Application			Second Application		
				5 DAA	10 DAA	14 DAA	5 DAA	10 DAA	14 DAA
T ₁	Wood ash	5 g/whorl	5.53	5.40	4.50	4.80	4.60	3.80	5.00
T ₂	Soil	5 g/whorl	6.10	5.80	4.60	5.00	4.90	3.90	5.20
T ₃	Sand	5 g/whorl	5.20	5.10	4.67	5.10	4.97	4.03	5.40
T ₄	Neem seed powder	2 g/whorl	5.40	4.40	3.80	3.90	3.20	2.60	4.20
T ₅	Lime	5 g/whorl	5.30	5.20	4.40	4.70	5.20	3.80	4.90
T ₆	Chilli extract spray 10 %	10 ml/l	6.20	6.30	5.10	5.50	5.40	5.10	5.60
T ₇	Chlorine water 0.03 %	10 ml/whorl	5.80	5.80	4.70	5.20	5.10	4.20	5.50
T ₈	Chlorantraniliprole 18.5 % SC	0.4 ml/l	4.90	4.00	2.77	2.80	2.50	1.80	2.17
T ₉	Detergent water spray	5 g/l	5.60	5.40	5.20	5.70	5.50	5.30	5.70
T ₁₀	Untreated control	-	5.10	6.20	6.70	6.90	7.07	7.13	7.23
	S.E.m ±		0.42	0.35	0.29	0.30	0.30	0.30	0.33
	CD @ 5 %		NS	1.03	0.85	0.88	0.89	0.90	0.98
	CV		13.31	11.16	10.63	10.35	10.75	12.53	11.25

NS: Non-significant, DAA= Days after application

which it was on par. The next to follow were wood ash @ 5 g/whorl, soil @ 5 g/whorl, sand @ 5 g/whorl, chlorine water @ 10 ml/whorl and chilli extract spray @ 10 ml/l, being at par, which recorded the leaf damage score in the range of 4.80 to 5.50. The detergent water @ 5 g/l was effective in decreasing the leaf damage score (5.70). Untreated plots recorded highest (6.90) leaf damage score.

Second application

At 5 DAA, the least (2.50) leaf damage score was recorded by chlorantraniliprole @ 0.4 ml/l. This was followed by neem seed powder @ 2 g/whorl with a leaf damage score (3.20). The whorl application of wood ash @ 5 g/whorl (4.60) was the next promising treatment but it was at par with the treatments of soil @ 5 g/whorl, sand @ 5 g/whorl, chlorine water @ 10 ml/l, lime @ 5 g/whorl and chilli extract spray @ 10 ml/l which recorded leaf damage scores in the range of 4.90 to 5.40. Detergent water @ 5 g/l was next treatment by recording leaf damage score i.e. 5.50.

At 10 DAA, almost a similar trend was noticed in term of effectiveness of treatments.

At 14 DAA, chlorantraniliprole @ 0.4 ml/l was the most effective treatment by recording leaf damage score (2.17). The neem seed powder @ 2 g/whorl (4.20) was the second most effective treatment but it was at par with lime @ 5 g/whorl (4.90) and wood ash @ 5 g/whorl (5.00). The next to follow were soil @ 5 g/whorl, sand @ 5 g/whorl, chlorine water @ 10 ml/whorl, chilli extract spray @ 10 ml/l and detergent water @ 5 g/l, being at par, which recorded leaf damage score in the range of 5.20 to 5.70. The untreated plots recorded the highest mean leaf damage score i.e. 7.23.

4.4.8 Leaf damage score (*rabi* 2021)

The data on the effect of different farmer's practices on mean leaf damage scores of maize during *rabi* 2021 are presented in Table 50.

First application

At 5 DAA, chlorantraniliprole @ 0.4 ml/l recorded lowest leaf damage score i.e. 3.40. Neem seed powder @ 2 g/whorl (3.60) was next best treatment but it was at par with lime @ 5 g/whorl, wood ash @ 5 g/whorl, soil @ 5 g/whorl which recorded leaf damage score of 3.97, 4.13 and 4.30, respectively. The next in the order of effectiveness were detergent water @ 5 g/l, chilli extract spray @ 10 ml/l, sand @ 5

Table 50. Evaluation of farmer's practices against leaf damage score by *S. frugiperda* in maize (rabi 2021)

Tr. No.	Treatments	Dose /whorl or l	Leaf damage score						
			Precount	First Application			Second Application		
				5 DAA	10 DAA	14 DAA	5 DAA	10 DAA	14 DAA
T ₁	Wood ash	5 g/whorl	4.20	4.13	3.80	4.10	4.00	3.47	3.97
T ₂	Soil	5 g/whorl	4.40	4.30	3.87	4.23	4.13	3.60	4.03
T ₃	Sand	5 g/whorl	5.13	5.10	3.90	4.33	4.20	3.67	4.13
T ₄	Neem seed powder	2 g/whorl	4.27	3.60	2.90	3.10	2.83	2.30	2.43
T ₅	Lime	5 g/whorl	4.50	3.97	3.70	4.03	3.93	3.30	3.83
T ₆	Chilli extract spray 10 %	10 ml/l	4.93	4.83	4.30	5.03	4.97	4.40	4.37
T ₇	Chlorine water 0.03 %	10 ml/whorl	5.43	5.50	4.50	5.23	5.07	4.23	4.53
T ₈	Chlorantraniliprole 18.5 % SC	0.4 ml/l	5.23	3.40	2.50	2.60	2.33	1.77	2.17
T ₉	Detergent water spray	5 g/l	4.60	4.67	4.43	4.77	4.73	4.50	5.30
T ₁₀	Untreated control	-	5.17	5.67	5.87	6.27	6.70	6.53	6.40
	S.E.m ±		0.37	0.34	0.29	0.41	0.30	0.36	0.41
	CD @ 5 %		NS	1.01	0.87	1.22	0.90	1.06	1.23
	CV		13.39	13.03	12.71	16.31	12.23	16.42	17.36

NS: Non-significant, DAA= Days after application

g/whorl and chlorine water @ 10 ml/whorl, which recorded leaf damage score in the range of 4.67 to 5.50. The untreated plots recorded highest (5.67) leaf damage score.

Almost a similar trend was noticed at 10 DAA.

At 14 DAA, chlorantraniliprole @ 0.4 ml/l (2.60) was the most effective treatment by recording the leaf damage followed by neem seed powder @ 2 g/whorl (3.10.) to which it was on par. The next to follow were lime @ 5 g/whorl, wood ash @ 5 g/whorl, soil @ 5 g/whorl, sand @ 5 g/whorl, detergent water @ 5 g/l, chilli extract spray @ 10 ml/l and chlorine water @ 10 ml/whorl which recorded mean leaf damage score in the range of 4.03 to 5.23. The untreated plots recorded leaf damage score of 6.27.

Second application

At 5 DAA, chlorantraniliprole @ 0.4 ml/l recorded least (2.33) leaf damage score. This was followed by neem seed powder @ 2g/whorl with leaf damage score (2.83). The next to follow were lime @ 5 g/whorl, wood ash @ 5 g/whorl, soil @ 5 g/whorl, sand @ 5 g/whorl and detergent water @ 5 g/l, being at par, which recorded leaf damage score in the range of 4.03 to 4.73. The next in the order of effectiveness were chilli extract (4.97) and chlorine water @ 10 ml/whorl (5.07). However, they were at par with each other. Untreated plots recorded the highest (6.70) leaf damage score.

Almost a similar trend was noticed in effectiveness of treatments at 10 DAA.

At 14 DAA, chlorantraniliprole @ 0.4 ml/l recorded lowest leaf damage score i.e.2.17.This was followed by neem seed powder @ 2 g/whorl which recorded leaf damage score (2.43). The next to follow were lime @ 5 g/whorl, wood ash @ 5 g/whorl, soil @ 5 g/whorl, sand @ 5 g/whorl, chilli extract spray @ 10 ml/l and chlorine water @ 10 ml/whorl being at par, which recorded leaf damage score in the range of 3.83 to 4.53. The next treatment of detergent water @ 5 g/l (5.30) was the least effective among all treatments. Highest (6.40) leaf damage score was recorded by untreated plots.

4.4.9 Pooled leaf damage score (*kharif* and *rabi* 2021)

The data on pooled mean leaf damage scores of *kharif* and *rabi* 2021 are presented in Table 51.

Chlorantraniliprole @ 0.4 ml/l (2.57) was found superior over rest of treatments in reducing leaf damage due to *S. frugiperda* in maize. The neem seed powder

Table 51. Evaluation of farmer's practices against leaf damage score by *S. frugiperda* in maize (kharif and rabi 2021 - Pooled)

Tr. No.	Treatments	Dose g or ml/l	Leaf damage score						Mean	
			Precount	First Application			Second Application			
				5 DAA	10 DAA	14 DAA	5 DAA	10 DAA		14 DAA
T ₁	Wood ash	5 g/whorl	4.87	4.77	4.15	4.45	4.30	3.63	4.48	4.30
T ₂	Soil	5 g/whorl	5.25	5.05	4.23	4.62	4.52	3.75	4.62	4.46
T ₃	Sand	5 g/whorl	5.17	5.10	4.28	4.72	4.58	3.85	4.77	4.55
T ₄	Neem seed powder	2 g/whorl	4.83	4.00	3.35	3.50	3.02	2.45	3.32	3.27
T ₅	Lime	5 g/whorl	4.90	4.58	4.05	4.37	4.57	3.55	4.37	4.25
T ₆	Chilli extract spray 10 %	10 ml/l	5.57	5.57	4.70	5.27	5.18	4.75	4.98	5.08
T ₇	Chlorine water 0.03 %	10 ml/whorl	5.62	5.65	4.60	5.22	5.08	4.22	5.02	4.96
T ₈	Chlorantraniliprole 18.5 % SC	0.4 ml/l	5.07	3.70	2.63	2.70	2.42	1.78	2.17	2.57
T ₉	Detergent water spray	5 g/l	5.10	5.03	4.82	5.23	5.12	4.90	5.50	5.10
T ₁₀	Untreated control	-	5.13	5.93	6.28	6.58	6.88	6.83	6.82	6.56
	S.E.m ±		0.29	0.26	0.23	0.24	0.22	0.24	0.25	0.11
	CD @ 5 %		NS	0.78	0.67	0.71	0.65	0.72	0.75	0.33
	CV		9.90	9.20	9.13	8.85	8.30	10.52	9.52	6.22

NS: Non-significant, DAA= Days after application

@ 2 g/whorl (3.27) was next best treatment at all intervals of observation in reducing the leaf damage by *S. frugiperda*. The next to follow were lime @ 5 g/whorl, wood ash @ 5 g/whorl, soil @ 5 g/whorl and sand @ 5 g/whorl, being at par, recorded leaf damage score of 4.25, 4.30, 4.46 and 4.55, respectively. Chlorine water @ 10 ml/whorl, chilli extract spray @ 10 ml/l and detergent water @ 5 g/l, being at par, were next to follow and recorded leaf damage score in the range of 4.96 to 5.10. The untreated plots (6.56) recorded the highest (6.56) leaf damage score.

4.4.10 Yield of maize (*kharif* and *rabi* 2021- Pooled)

The data on the average yield of two seasons are summarized in Table 52.

All treatments registered significantly higher yields as compared to the untreated control. It reveals that the effectiveness of treatments against *S. frugiperda* reflected in yield. The highest yield (64.01 q/ha) was registered by chlorantraniliprole @ 0.4ml/ l. Among the farmer's practices, the plot treated with neem seed powder @ 2 g/whorl registered the highest yield, with a production of 56.33 q/ha. Lime @ 5 g/whorl followed with a yield of 47.40 q p/ha. Wood ash @ 5 g/whorl, soil @ 5 g/whorl and sand @ 5 g/whorl recorded yields of 46.08 q/ha, 45.30 q/ha and 45.18 q/ha, respectively. Chlorine water @ 10 ml/whorl, chilli extract spray @ 10 ml/l and detergent water @ 5 g/l were registered grain yield of 44.90 q/ha, 44.85 q/ha and 43.94 q/ha, respectively. Chlorantraniliprole @ 0.4ml/ha and neem seed powder @ 2 g/whorl were the most effective treatments by registering higher yields.

The data also revealed that the treatment with chlorantraniliprole @ 0.4 ml/l resulted in the highest per centage increase in yield (50.84 %) among all treatments. This was followed by neem seed powder @ 2 g/whorl showed a notable increase in yield (32.73 %). The next treatments in descending order of yield increase were lime @ 5 g/whorl (11.69 %), wood ash @ 5 g/whorl (8.57 %), soil @ 5 g/whorl (6.73 %), sand @ 5 g/whorl (6.46 %), chlorine water @ 10 ml/whorl (5.80 %) and chilli extract spray @ 10 ml/l (5.68 %). The treatment with detergent water @ 5 g/l exhibited the lowest per centage increase in yield (3.53 %).

The data over two season consistently proved that chlorantraniliprole @ 0.4 ml/l was the most promising treatment in reducing per cent of plant damage, larval population and leaf damage score. This was followed by neem seed powder @ 2 g/whorl. This was resulted in increase of grain yield of maize (Fig.5).

Table 52. Effect of farmer practices against *S. frugiperda* on grain yield on maize

Tr. No.	Treatments	Dose g or ml/l	Yield (q/ha)			Increase in yield over control (%)
			<i>kharif</i> (2021)	<i>rabi</i> (2021)	Average of two seasons	
T ₁	Wood ash	5 g/whorl	42.60	49.56	46.08	8.57
T ₂	Soil	5 g/whorl	41.98	48.62	45.30	6.73
T ₃	Sand	5 g/whorl	41.86	48.51	45.18	6.46
T ₄	Neem seed powder	2 g/whorl	52.82	59.84	56.33	32.73
T ₅	Lime	5 g/whorl	43.76	51.04	47.40	11.69
T ₆	Chilli extract spray 10 %	10 ml/l	41.40	48.30	44.85	5.68
T ₇	Chlorine water 0.03 %	10 ml/ whorl	41.44	48.36	44.90	5.80
T ₈	Chlorantraniliprole 18.5 % SC	0.4 ml/l	60.51	67.52	64.01	50.84
T ₉	Detergent water spray	5 g/l	40.65	47.22	43.94	3.53
T ₁₀	Untreated control	-	39.05	45.83	42.44	--
	S.E.m ±	-	0.32	0.34	0.22	--
	CD @ 5 %	-	0.95	1.02	0.64	--
	CV	-	12.44	11.56	7.81	--

In the present investigation, chlorantraniliprole @ 0.4 ml/l was the most effective and excelled over all other treatments in suppressing *S. frugiperda* population. Next in the order of effectiveness was neem seed powder @ 2 g/whorl followed by lime @ 5 g/whorl, wood ash @ 5 g/whorl, soil @ 5 g/whorl and sand @ 5 g/whorl.

As observed in the present investigation chlorantraniliprole @ 0.4 ml/l was significantly superior treatment over rest of the treatments against *S. frugiperda* in agreement with several earlier workers Bajracharya *et al.* (2020) reported that chlorantraniliprole 18.5 % SC @ 0.4 ml/l was superior treatment compared to all other treatments and recorded average foliage damage score. Ramesh and Tayde (2022) reported that chlorantraniliprole 18.5 % SC (6.24 %) was effective treatment in reducing the per cent incidence of maize fall armyworm. Similarly, Sisay *et al.* (2019b) concluded

a greenhouse experiment and revealed that chlorantraniliprole 200 SC was effective in reducing leaf damage infesting *S. frugiperda* in maize. Chlorantraniliprole 18.5 SC 0.006 % was effective treatment against *S. litura* and *A. janata* in castor and recorded the lowest number of 0.42 and 0.22 larvae per plant, respectively (Bhut *et al.* 2022).

All these reports lend supports to the present finding.

There is very scanty information in the literature on the efficacy of farmer's practices on *S. frugiperda*. Therefore, related literature in respect of farmer's practices in other crops is also discussed.

Efficacy of neem seed powder @ 2 g/l as observed in the present investigation is in conformity with Silva *et al.*, (2015) who reported that aqueous extracts of neem seed cake was effective for control of fall armyworm on maize in Brazil. Maredia *et al.* (1992) revealed that neem seed powder was effective in killing FAW larvae causing over 70 per cent of mortality. Likewise, Stevenson *et al.* (2017) reported that the botanical pesticides used by farmers against *S. frugiperda* were usually made from neem leaves or seeds in small landholder of agriculture in Africa. Adeye *et al.* (2018) concluded that neem oil at 4.5 l/ha reduced the incidence of pest attacks and the severity of the damage to plants. Botanical like neem can be used without processing or their extracts having a pungent smell used for pest control in insect order like Hemiptera, Lepidoptera, Thysanoptera, Coleoptera and Diptera as reported by Parajuli *et al.* (2022).

Efficacy of lime @ 5g/whorl as observed in the present investigation are in conformity with Bhandari *et al.* (2021) who reported that some of the farmers used locally available material like lime powder was toxic to fall armyworm in Nepal. Likewise, Hruska (2019) reported that many smallholder farmers around the world used locally available substance like lime for control of FAW. According to the report of CABI (2017) stated that smallholder farmers practices putting sand mixed with lime in the whorl of infested maize to kill the larvae of FAW.

The results in respect of the efficacy of wood ash are in line with Varma *et al.* (2021) who reported that the whorl application of ash @ 5 g/plant (3.48 larvae/10 plants) was found effective for the control of *S. frugiperda* larvae. Similarly, Tambo *et al.* (2020b) reported that 17.7 per cent of farmers in five African countries apply ash to the whorl of maize crop and noted the efficacy of 48 -77 per cent compared to 92 -97 per

cent of synthetic insecticides. Wyckhuys and O'Neil (2007) also reported that ash was used for the control of FAW for a long time by smallholder farmers in the Americas. Many smallholder farmers in Africa used ash against *S. frugiperda* in maize as reported by Stevenson *et al.* (2017). Similarly, Abrahams *et al.* (2017) proved that placing ash in the whorls reduced the yield losses by the fall armyworm in maize.

Efficacy of whorl application of soil @ 5 g/plant are in agreement with Varma *et al.* (2021) who reported that the whorl application of soil @ 5 g/plant recorded the lowest (16.84 %) plant damage. Similarly, Abate *et al.* (2000) described that most subsistence farmers in Africa deter or kill pests via application of soil in leaf whorls of maize. Likewise, Hruska (2019) reported that many smallholder farmers around the world used soil to control FAW. Similarly, soil was used by many small holder farmers in Americas for control of FAW as reported by Wyckhuys and O'Neil (2007).

Kumela *et al.* (2019) illustrated that whorl application of dry sand was effective and widely used by smallholder farmers in Ethiopia and Kenya for controlling the FAW. Similarly, Firake *et al.* (2019) reported that the application of dry sand into the whorl of affected maize plants soon after observation of FAW incidence in the field was reported as another control measure. According to Tambo *et al.* (2020b), farmers of five African countries added sand to the whorl of maize crop for the control of FAW in maize. Likewise, Varma *et al.* (2021) reported that whorl application of sand @ 5 g/plant (20.30 %) was found effective against the *S. frugiperda*.

All these reports lend support to the present finding.

In the present investigation chlorantraniliprole registered the highest yield (65.10 q/ha). These findings are in corroboration with Ramesh and Tayde (2022) who reported that the chlorantraniliprole 18.5 % SC registered grain yield of 35.91 q/ha. Similarly, maximum grain yield was recorded by chlorantraniliprole 0.004 per cent (34.87 q/ha) in soybean crop against the *S. litura* as reported by Bhamare *et al.* (2020).

Next effective treatment in the order of effectiveness with respect of yield was neem seed powder @ 2 g/whorl (52.57 q/ha) which registered the highest yield in maize. These findings are in agreement with Adeye *et al.* (2018) who found that neem oil at 4.5 l/ ha reduced the loss of maize yield by 42.80 to 57.00 per cent.

The grain yield in respect of wood ash @ 5g/plant is in agreement with Varma *et al.* (2021) who reported 26.34 q/ha grain yield of maize. Furthermore, Sakhinetipalli (2012) found that the application of ash @ 50kg/ha generated a maximum benefit cost ratio of 4.8:1 in brinjal for the control of *L. arbonalis*.

In the present investigation results in respect of grain yield of next effective treatments are in agreement with Varma *et al.* (2021) reported that grain yield recorded in the treatment of whorl application of soil @ 5 g/plant (29.58 q/ha) and sand @ 5 g/plant (29.52 q/ha).

During the present investigation, the effect of whorl application of neem seed powder @ 2 g/whorl was observed the phytotoxicity on leaves of maize and these observations are in agreement with Dreyer (1986) who described that the neem powder should always be applied as a mixture with inert materials, such as sawdust, rice hulls or dry fine clay, as the powder alone can cause phytotoxicity owing to its oil content. Therefore, it's essential to note that the whorl application of neem seed powder emphasizing the need for caution in its application.

4.5 Evaluation of different IPM strategies against fall armyworm, *S. frugiperda* in maize

IPM plays a critical role in the management of fall armyworm by promoting a balanced and sustainable approach that minimizes the environmental impact, reduces resistance development and supports the long-term viability of agriculture.

In the present investigation, three modules were evaluated for their efficacy in the field against *S. frugiperda* in maize during *kharif* and *rabi* 2022. These modules were farmer's practices, the proposed (formulated) IPM module and the existing IPM module. The results of the observations on the per centage of plant damage, the larval population and grain yield are presented and discussed below.

4.5.1 Plant damage (*kharif* 2022)

The data on plant damage during *kharif* 2022 are presented in Table 53.

At 10 days after emergence (DAE) the existing IPM module and proposed IPM were effective by recording minimum plant damage of 42.57 and 43.14 per cent, respectively. This minimum plant damage could be due to installation of pheromone traps in maize field. Farmer's practice module recorded highest (54.29 %) plant damage.

Table 53. Evaluation of different IPM strategies on damaged plants due to *S. frugiperda* in maize (kharif 2022)

Sr. No.	Treatments	Per cent plant damage						Mean of Modules
		10 DAE	20 DAE	30 DAE	40 DAE	50 DAE	60 DAE	
1	Farmer's Practice	54.29 (47.48)	34.57 (35.78)	26.00 (30.20)	21.43 (27.22)	38.86 (38.44)	59.14 (50.40)	39.05 (38.25)
2	Proposed IPM module	43.14 (40.97)	32.57 (34.59)	33.71 (35.28)	27.43 (31.37)	23.43 (28.72)	18.86 (25.59)	29.86 (32.75)
3	Existing IPM module	42.57 (40.73)	38.86 (38.47)	33.91 (35.30)	30.00 (32.96)	26.86 (31.03)	19.71 (25.97)	33.29 (34.42)
	Mean of DAE	46.67 (43.09)	35.33 (36.28)	31.14 (33.56)	26.29 (30.52)	29.71 (32.73)	32.57 (33.99)	
		S.E.m. ±			CD @ 5 %			
	Modules	0.80			2.25			
	DAE	1.13			3.18			
	Modules x DAE	1.96			5.51			

Figures in the parentheses are arc sin transformed values, DAE = Days after emergence

At 20 DAE, lowest plant damage (32.57 %) was recorded by proposed module due to spraying of azadirachtin 1500 ppm @ 5 ml /lit. It was, however, at par with farmer's practice and existing module which recorded plant damage of 34.57 and 38.86 per cent, respectively.

At 30 DAE, lowest plant damage (26.00 %) was recorded by farmer's practice module due to spraying of emamectin benzoate 5 % SG @ 0.4 gm /l and chlorantraniliprole 18.5 SC @ 0.3 ml/l. This was followed by proposed IPM module which recorded plant damage of 33.71 per cent due to the spraying of *Metarhizium rileyi* @ 5 gm/lit. It was, however, at par with existing IPM module by recording plant damage of 33.91 per cent.

At 40 DAE, lowest plant damage (20.29 %) was recorded by farmer's practice module due to spraying of chlorantraniliprole 18.5 SC @ 0.3 ml/l. This was followed by proposed IPM module and existing IPM module which recorded plant damage of 20.57 and 23.71 per cent, respectively.

At 50 DAE, lowest plant damage (23.43 %) in proposed IPM module could be due to whorl application of poison bait of chlorantraniliprole 18.5 % SC @ 1.88 ml/kg of bait and proved to be significantly superior over the rest of the modules. This was followed by existing and farmer's practice module which recorded 26.86 and 38.86 per cent plant damage, respectively.

At 60 DAE, lowest plant damage (18.86 %) was recorded by proposed IPM module. It was, however, at par with existing module which recorded 19.71 per cent plant damage. The farmer's practice module recorded the highest (59.14 %) plant damage in maize.

On the basis of mean, the least plant damage (29.86 %) was recorded by proposed IPM module. It was, however, at par with existing module with plant damage of 33.29 per cent. The highest per cent of plant damage (39.05 %) was recorded by farmer's practice module.

4.5.2 Plant damage (*rabi* 2022)

The data on plant damage during *rabi* 2022 are presented in Table 54.

At 10 DAE, the proposed IPM module and existing IPM module were effective in reducing plant damage of 32.57 and 34.43 per cent, respectively. Farmer's practice module recorded the highest (47.14 %) plant damage.

At 20 DAE, due to the spraying of azadirachtin 1500 ppm @ 5 ml /lit the proposed module recorded lowest (26.00 %) plant damage. It was, however, at par with farmer's practice which recorded 26.57 per cent plant damage. The highest plant damage (32.57 %) was recorded by existing module.

At 40 DAE, lowest plant damage (20.29 %) was recorded by farmer's practice module due to spraying of chlorantraniliprole 18.5 SC @ 0.4 ml/l. It was, however, at par with proposed module which recorded 20.57 per cent plant damage. The existing module recorded highest (23.71 %) plant damage.

At 50 DAE, the proposed module proved to be significantly superior over rest of the modules by recording least plant damage (16.29 %) due to the whorl application of chlorantraniliprole 18.5 % SC @ 1.88 ml/kg of bait. This was followed by existing and farmer's practice module which recorded 20.57 and 37.14 per cent plant damage, respectively. Almost a similar trend was noticed at 60 DAE.

On the basis of mean, the proposed IPM module proved to be significantly superior over other modules by recording least plant damage (22.14 %). This was followed by existing module and farmer's practice module which recorded plant damage of 25.55 and 34.76 per cent, respectively.

Table 54. Evaluation of different IPM strategies on damaged plants due to *S. frugiperda* in maize (*rabi* 2022)

Sr. No.	Treatments	Per cent plant damage						Mean of Modules
		10 DAE	20 DAE	30 DAE	40 DAE	50 DAE	60 DAE	
1	Farmer's Practice	47.14 (43.34)	26.57 (30.72)	22.57 (27.86)	20.29 (26.62)	37.14 (37.17)	54.86 (47.80)	34.76 (35.59)
2	Proposed IPM module	32.57 (34.71)	26.00 (30.49)	22.86 (28.43)	20.57 (26.77)	16.29 (23.32)	14.57 (22.17)	22.14 (27.65)
3	Existing IPM module	34.43 (35.93)	32.57 (34.75)	24.29 (29.29)	23.71 (29.05)	20.57 (26.71)	17.71 (24.40)	25.55 (30.36)
	Mean of DAE	38.05 (38.09)	28.38 (31.99)	23.24 (28.53)	21.52 (27.48)	24.67 (29.07)	29.05 (31.46)	
		S.E.m. \pm			CD @ 5 %			
	Modules	0.73			2.04			
	DAE	1.03			2.89			
	Modules x DAE	1.78			5.00			

Figures in the parentheses are arc sin transformed values, DAE = Days after emergence

4.5.3 Pooled data of two seasons (*kharif* and *rabi* 2022)

The cumulative effect of different modules on plant damage caused by *S. frugiperda* infesting maize during *kharif* and *rabi* 2022 (Table 55) was compared and the results are discussed below.

Table 55. Evaluation of different IPM strategies on damaged plants due to *S. frugiperda* in maize (*kharif* and *rabi* 2022-Pooled)

Sr. No.	Treatments	Per cent plant damage						Mean of Modules
		10 DAE	20 DAE	30 DAE	40 DAE	50 DAE	60 DAE	
1	Farmer's Practice	50.71 (45.39)	30.57 (33.39)	24.29 (29.09)	20.86 (26.96)	38.00 (37.91)	57.00 (49.04)	36.91 (36.96)
2	Proposed IPM module	37.86 (37.91)	29.29 (32.64)	28.29 (32.01)	24.00 (29.19)	19.86 (26.23)	16.71 (24.00)	26.00 (30.33)
3	Existing IPM module	38.50 (38.33)	35.71 (36.65)	29.00 (32.36)	26.86 (31.07)	23.71 (28.98)	18.71 (25.41)	28.75 (32.43)
	Mean of DAE	42.36 (40.61)	31.86 (34.23)	27.19 (31.15)	23.91 (29.07)	27.19 (31.04)	30.81 (32.82)	
		S.E.m. \pm			CD @ 5 %			
	Modules	0.60			1.69			
	DAE	0.85			2.39			
	Modules x DAE	1.48			4.15			

Figures in the parentheses are arc sin transformed values, DAE = Days after emergence

The pooled data of two seasons revealed that the proposed IPM module showed overall superiority in recording the lowest (26.00 %) plant damage in maize. This

was followed by existing module which recorded 28.75 per cent plant damage. Highest (36.91 %) plant damage due to *S. frugiperda* was observed in the farmer's practice plot.

4.5.4 Larval population (*kharif* 2022)

The data (Table 56) on the field evaluation of different modules on larval populations during *kharif* 2022 are presented below.

At 10 DAE, existing IPM module and proposed IPM module were effective by recording the larval population of 1.64 and 1.66 larvae per plant, respectively and this could be due to the installation of pheromone traps in maize field. This was followed by proposed module which recorded 1.66 larvae per plant. Farmer's practice plot recorded the highest i.e. 2.13 larvae per plant.

At 20 DAE, proposed IPM module recorded lowest (1.09 larvae /plant). This could be due to application of azadirachtin 1500 ppm @ 5 ml /lit. Existing IPM module was the next effective treatment which recorded 1.36 larvae per plant. Maximum number (1.37 larvae/ plant) was recorded by farmer's practice module.

At 30 DAE, lowest larval population (0.96 larvae /plant) was recorded due to spraying of emamectin benzoate 5 % SG @ 0.4 gm /l and chlorantraniliprole 18.5 SC @ 0.4 ml/l in farmer's practice plot. It was, however, at par with proposed IPM and existing IPM module which recorded 0.99 and 1.00 larvae per plant, respectively.

At 40 DAE, least larval population (0.63 larvae/plant) was recorded by farmer's practice plot due to spraying of chlorantraniliprole 18.5 SC @ 0.4 ml/l. This was followed by proposed IPM module and existing IPM module which recorded larval population of 0.73 and 0.87 larvae per plant, respectively.

At 50 DAE, the whorl application of chlorantraniliprole 18.5 % SC @ 1.88 ml/kg of bait in proposed IPM module was effective by recording least (0.50 larvae /plant) larval population. This was followed by existing module which recorded 0.73 larvae per plant. The highest (1.19) number of larvae per plant was recorded by farmer's practice plot. Almost a similar trend was noticed at 60 DAE.

On the basis of mean, the proposed IPM module proved to be significantly superior over existing module and farmer's practice module by recording least larval population (0.90 larvae/plant). This was followed by existing module which recorded 1.03 larvae per plant. Farmer's practice plot recorded the highest i.e. 1.41 larvae per plant.

Table 56. Evaluation of different IPM strategies on the larval population of *S. frugiperda* in maize (kharif 2022)

Sr. No.	Treatments	Larval population						Mean of Modules
		10 DAE	20 DAE	30 DAE	40 DAE	50 DAE	60 DAE	
1	Farmer's Practice	2.13 (1.77)	1.37 (1.54)	0.96 (1.40)	0.63 (1.28)	1.19 (1.48)	2.17 (1.78)	1.41 (1.54)
2	Proposed IPM module	1.66 (1.62)	1.09 (1.44)	0.99 (1.41)	0.73 (1.31)	0.50 (1.22)	0.41 (1.19)	0.90 (1.37)
3	Existing IPM module	1.64 (1.46)	1.36 (1.53)	1.00 (1.41)	0.87 (1.37)	0.73 (1.31)	0.57 (1.25)	1.03 (1.41)
	Mean of DAE	1.75 (1.50)	1.27 (1.50)	0.98 (1.40)	0.74 (1.32)	0.81 (1.34)	1.05 (1.41)	
		S.E.m. ±			CD @ 5 %			
	Modules	0.02			0.04			
	DAE	0.02			0.06			
	Modules x DAE	0.04			0.11			

Figures in parenthesis are $\sqrt{x + 0.05}$ transformed values, DAE = Days after emergence

4.5.5 Larval population (rabi 2022)

The data on the field evaluation of different modules on larval population during rabi 2022 are presented in Table 57.

At 10 DAE, the installation of pheromone traps in proposed IPM module was effective by recording least (0.97 larvae /plant) larval population. This was followed by existing module which recorded 1.14 larvae per plant. Farmer's practice plots recorded the highest i.e.1.81 larvae per plant.

At 20 DAE, lowest larval population (0.76 larvae /plant) was recorded by proposed module due to application of azadirachtin 1500 ppm @ 5 ml /lit. It was, however, at par with existing and farmer's practice plot which recorded 0.81 larvae per plant.

At 30 DAE, lowest larval population (0.69 larvae /plant) was recorded by farmer's practice module may be spraying of emamectin benzoate 5 % SG @ 0.4 gm/l and chlorantraniliprole 18.5 SC @ 0.4 ml/l. It was, however, at par with proposed IPM and existing IPM module which recorded 0.79 and 0.80 larvae per plant, respectively.

At 40 DAE, the application of chlorantraniliprole 18.5 SC @ 0.4 ml/l in farmer's practice module reduced the larval population (0.56 larvae /plant) of *S. frugiperda* infesting maize. It was, however, at par with proposed IPM and existing IPM module which recorded 0.57 and 0.64 larvae per plant, respectively.

Table 57. Evaluation of different IPM strategies on the larval population of *S. frugiperda* in maize (rabi 2022)

Sr. No.	Treatments	Larval population						Mean of Modules
		10 DAE	20 DAE	30 DAE	40 DAE	50 DAE	60 DAE	
1	Farmer's Practice	1.81 (1.68)	0.81 (1.35)	0.69 (1.30)	0.56 (1.25)	1.34 (1.52)	2.00 (1.73)	1.20 (1.48)
2	Proposed IPM module	0.97 (1.40)	0.76 (1.32)	0.79 (1.33)	0.57 (1.25)	0.46 (1.21)	0.40 (1.18)	0.67 (1.28)
3	Existing IPM module	1.14 (1.28)	0.81 (1.35)	0.80 (1.34)	0.64 (1.28)	0.49 (1.22)	0.47 (1.21)	0.72 (1.30)
	Mean of DAE	1.31 (1.35)	0.80 (1.34)	0.76 (1.32)	0.59 (1.26)	0.76 (1.31)	0.96 (1.37)	
		S.E.m. ±			CD @ 5 %			
	Modules	0.01			0.04			
	DAE	0.02			0.05			
	Modules x DAE	0.03			0.09			

Figures in parenthesis are $\sqrt{x + 0.05}$ transformed values, DAE = Days after emergence

At 50 DAE, proposed IPM module recorded lowest (0.46 larvae/plant) larval population due to whorl application of chlorantraniliprole 18.5 SC @ 1.88 ml/kg of bait in maize. This was followed by existing IPM module to which it was on par by recording 0.49 larvae per plant. The farmer's practice plot recorded highest (1.34 larvae/plant).

At 60 DAE, proposed module was most effective by recording least larval population (0.40 larvae/plant). It was, however, at par with existing module which recorded 0.47 larvae per plant. The farmer's practice plot recorded highest (2.00 larvae/plant).

On the basis of mean, the proposed IPM module recorded lowest larval population by recording larval population (0.67 larvae/plant). It was, however, at par with existing module which recorded 0.72 larvae per plant. The highest (1.20 larvae per plant) larval population was observed in the farmer's practice plot.

4.5.6 Pooled data of two seasons (*kharif* and *rabi* 2022)

According to pooled data (Table 58), the average fall armyworm larvae were found to be significantly reduced by IPM modules as compared to the farmer's practice plot. The plots treated with proposed IPM module recorded the least number of larvae (0.77 larvae/plant). This was followed by existing module which recorded 0.83

larvae per plant. The maximum (1.32 larvae/plant) larval population was found in the farmer's practice plot

Table 58. Evaluation of different IPM strategies on the larval population of *S. frugiperda* in maize (kharif and rabi 2022-Pooled)

Sr. No.	Treatments	Larval population						Mean of Modules
		10 DAE	20 DAE	30 DAE	40 DAE	50 DAE	60 DAE	
1	Farmer's Practice	1.97 (1.72)	1.09 (1.44)	0.87 (1.37)	0.60 (1.28)	1.26 (1.50)	2.09 (1.75)	1.32 (1.51)
2	Proposed IPM module	1.31 (1.52)	0.93 (1.38)	0.84 (1.35)	0.65 (1.28)	0.48 (1.22)	0.41 (1.19)	0.77 (1.33)
3	Existing IPM module	1.13 (1.45)	1.09 (1.44)	0.90 (1.37)	0.76 (1.33)	0.61 (1.27)	0.52 (1.23)	0.83 (1.34)
	Mean of DAE	1.47 (1.40)	1.03 (1.42)	0.87 (1.37)	0.67 (1.29)	0.78 (1.33)	1.01 (1.39)	
		S.E.m. \pm			CD @ 5 %			
	Modules	0.01			0.03			
	DAE	0.02			0.05			
	Modules x DAE	0.03			0.08			

Figures in parenthesis are $\sqrt{x + 0.05}$ transformed values, DAE = Days after emergence

4.5.7 Effect of different modules on natural enemies

In the present investigation, natural enemies (NEs) of *Spodoptera frugiperda* such as earwig, spiders and coccinellids were recorded during experiment. Observations on natural enemies were recorded from 10 days after emergence (DAE) to 60 DAE of maize crop.

4.5.7.1 Effect of different modules on the population of earwig.

The data (Table 59) on the observation of earwig population in different modules are presented below.

At 10 DAE, population of earwig were highest (0.36/plant) in existing IPM module and farmer's practice module. This was followed by proposed IPM module which recorded 0.34 per plant, respectively.

At 20 DAE, highest number of earwig (0.46/plant) were found in existing IPM module. This was followed by proposed IPM module (0.43) to which it was on par. However, lowest number of earwig (0.04/plant) was found in farmer's practice module. This could be due to the spraying of insecticide in maize field.

Table 59. Effect of different IPM strategies on the population of earwig in maize (kharif and rabi 2022)

Sr. No.	Treatments	Earwig per plant						Mean of Modules
		10 DAE	20 DAE	30 DAE	40 DAE	50 DAE	60 DAE	
1	Farmer's Practice	0.36 (1.16)	0.04 (1.02)	0.00 (1.00)	0.04 (1.02)	0.00 (1.00)	0.00 (1.00)	0.07 (1.03)
2	Proposed IPM module	0.34 (1.16)	0.43 (1.20)	0.54 (1.24)	0.57 (1.25)	0.40 (1.18)	0.30 (1.14)	0.43 (1.20)
3	Existing IPM module	0.36 (1.16)	0.46 (1.21)	0.47 (1.21)	0.49 (1.22)	0.34 (1.16)	0.09 (1.04)	0.37 (1.16)
	Mean of DAE	0.35 (1.16)	0.31 (1.14)	0.34 (1.15)	0.37 (1.16)	0.25 (1.11)	0.13 (1.06)	
		S.E.m. \pm			CD @ 5 %			
	Modules	0.01			0.03			
	DAE	0.02			0.05			
	Modules x DAE	0.03			0.08			

Figures in parenthesis are $\sqrt{x + 0.05}$ transformed values, DAE = Days after emergence

At 30 DAE, highest number of earwig population (0.54/plant) were recorded in proposed IPM module. It was however at par with existing IPM module (0.47 /plant). This increase in population of NEs could due to application of botanicals like azadirachtin and biopesticides *Metarhizium rileyi* and *Metarhizium anisopliae* in maize.

A similar trend was found in recording the earwig population even at 40 DAE.

At 50 DAE, maximum population of earwig (0.40 /plant) was recorded in proposed IPM module. This was followed by existing IPM module (0.34 /plant) to which it was on par. None of the earwigs were found in farmer's practice module.

At 60 DAE, minimum number of earwig (0.30/plant) was observed in proposed IPM module. It was followed by existing IPM module (0.09/plant). Earwigs were not found in farmer's practice module.

On the basis of mean, highest earwigs (0.43 / plant) were recorded in proposed IPM module. This was followed by existing IPM module (0.37/plant). The lowest earwigs (0.07 /plant) were found in farmer's practice module.

Table 60. Effect of different IPM strategies on the population of spiders in maize (kharif and rabi 2022)

Sr. No.	Treatments	Spiders per plant						Mean of Modules
		10 DAE	20 DAE	30 DAE	40 DAE	50 DAE	60 DAE	
1	Farmer's Practice	0.17 (1.08)	0.07 (1.03)	0.00 (1.00)	0.07 (1.03)	0.00 (1.00)	0.00 (1.00)	0.05 (1.03)
2	Proposed IPM module	0.14 (1.07)	0.44 (1.20)	0.47 (1.21)	0.54 (1.24)	0.37 (1.17)	0.16 (1.07)	0.36 (1.16)
3	Existing IPM module	0.13 (1.06)	0.45 (1.20)	0.33 (1.15)	0.37 (1.17)	0.27 (1.13)	0.11 (1.05)	0.28 (1.13)
	Mean of DAE	0.15 (1.07)	0.32 (1.15)	0.27 (1.12)	0.33 (1.15)	0.21 (1.10)	0.09 (1.04)	
		S.E.m. \pm			CD @ 5 %			
	Modules	0.01			0.03			
	DAE	0.02			0.04			
	Modules x DAE	0.03			0.07			

Figures in parenthesis are $\sqrt{x + 0.05}$ transformed values, DAE = Days after emergence

4.5.7.2 Effect of different modules on the population of spiders.

The data on the observation of spider population in different modules are presented in Table 60.

At 10 DAE, populations of spider were highest (0.17/plant) in farmer's practice module. It was, however, at par with proposed IPM module and existing IPM module which recorded 0.14 and 0.13 spider per plant, respectively.

At 20 DAE, highest number of spiders (0.45/plant) were found in existing IPM module. This was followed by proposed IPM module (0.44) to which it was on par. However, lowest number of spiders (0.07/plant) were found in farmer's practice module. This could be due to the spraying of insecticide in maize field.

At 30 DAE, highest number of spider population (0.47/plant) were recorded in proposed IPM module. This was followed by existing IPM module (0.33/plant).

A similar trend was found in recording the spider population even at 40 and 50 DAE.

At 60 DAE, minimum number of spider (0.16/plant) were observed in proposed IPM module. It was followed by existing IPM module (0.11/plant). Spiders were not found in farmer's practice module.

On the basis of mean, highest spiders (0.36 / plant) were recorded in proposed IPM module. This was followed by existing IPM module (0.28 /plant) to which it was on par. The lowest spiders (0.05 /plant) were found in farmer's practice module.

4.5.7.3 Effect of different modules on the population of coccinellids

The data on the observation of population of coccinellids in different modules are presented in Table 61.

At 10 DAE, population of coccinellids were highest (0.26/plant) in farmer's practice module. It was, however, at par with proposed IPM module and existing IPM module which recorded 0.24 and 0.23 coccinellids per plant, respectively.

At 20 DAE, highest number of coccinellids (0.29/plant) was found in existing IPM module. This was followed by proposed IPM module (0.26) to which it was on par. However, lowest number of coccinellids (0.03/plant) was found in farmer's practice module. This could be due to the spraying of insecticide in maize field.

At 30 DAE, highest number of coccinellids population (0.41/plant) was recorded in proposed IPM module. This was followed by existing IPM module (0.31 /plant).

At 40 and 50 DAE, a similar trend was found by recording the population of coccinellids.

At 60 DAE, minimum number of coccinellids (0.19/plant) was observed in proposed IPM module. It was followed by existing IPM module (0.10/plant). The least coccinellids (0.01plant) were found in farmer's practice module.

On the basis of mean, highest coccinellids (0.32/ plant) were recorded in proposed IPM module. This was followed by existing IPM module (0.25 /plant) to which it was on par. The lowest coccinellids (0.06 /plant) were found in farmer's practice module.

Table 61. Effect of different IPM strategies on the population of coccinellids in maize (*kharif and rabi* 2022)

Sr. No.	Treatments	Coccinellids per plant						Mean of Modules
		10 DAE	20 DAE	30 DAE	40 DAE	50 DAE	60 DAE	
1	Farmer's Practice	0.26 (1.12)	0.03 (1.02)	0.00 (1.00)	0.04 (1.02)	0.00 (1.00)	0.01 (1.01)	0.06 (1.03)
2	Proposed IPM module	0.24 (1.11)	0.26 (1.12)	0.41 (1.19)	0.54 (1.24)	0.29 (1.13)	0.19 (1.09)	0.32 (1.15)
3	Existing IPM module	0.23 (1.11)	0.29 (1.13)	0.31 (1.14)	0.33 (1.15)	0.26 (1.12)	0.10 (1.05)	0.25 (1.12)
	Mean of DAE	0.24 (1.11)	0.19 (1.09)	0.24 (1.11)	0.31 (1.14)	0.18 (1.08)	0.10 (1.05)	
		S.E.m. \pm			CD @ 5 %			
	Modules	0.01			0.02			
	DAE	0.01			0.03			
	Modules x DAE	0.02			0.06			

Figures in parenthesis are $\sqrt{x + 0.05}$ transformed values, DAE = Days after emergence

4.5.8 Yield of maize (Pooled *kharif* and *rabi* 2021)

The data (Table 62) on the average yield of two seasons reveals that all the modules registered significantly higher yield over the farmer's practice module (54.65 q/ha). The highest yield was recorded by proposed IPM module (73.90 q/ha). This was followed by the plot treated with existing IPM module which recorded 72.70 q/ha.

The data also indicated that the highest (35.22 %) increase in yield over farmer's practice module was registered by proposed IPM module. It was followed by existing IPM module which recorded maximum increase in yield by 33.01 per cent.

Table 62. Effect of different modules tested against *S. frugiperda* on grain yield of maize

Tr. No.	Treatments	Grain Yield (q/ha)			Increase in yield over farmer's practice module (%)
		<i>kharif</i> (2022)	<i>rabi</i> (2022)	Average of two seasons	
T ₁	Proposed IPM module	69.78	78.02	73.90	35.22
T ₂	Existing IPM module	68.66	76.74	72.70	33.01
T ₃	Farmer's practice module	52.26	57.04	54.65	-

4.5.8.1 Cost economics of different modules during *kharif* and *rabi* - 2022

The pooled data (*kharif* and *rabi*-2022) on modules for managing fall armyworm in maize are presented in Table 63. It revealed that the cost of plant protection was Rs.14373/- per ha for the proposed IPM module, Rs.15928/- for existing IPM module and Rs. 9597/- per ha for the farmer's practice module. Differential efficacy of modules reflected in the maize yield. However, the data also reveals that both the IPM modules recorded significantly higher yield over the farmer's practice module.

The benefit derived from every rupee investment on plant protection was highest in proposed IPM module (1:1.63). It was followed by existing IPM module (1:1.22).

Table 63. Economics of different modules for the management of fall armyworm on maize

Tr. No.	Treatments	Grain yield (q/ha)	Additional yield farmer's practice module (q/ha)	Total cost (Rs/ha)	Value of additional yield farmer's practice module (Rs/ha)	Net Profit (Rs/ha)	ICBR
T ₁	Proposed IPM module	73.90	19.25	14373	37769	23396	1:1.63
T ₂	Existing IPM module	72.70	18.05	15928	35414	19486	1:1.22
T ₃	Farmer's practice module	54.65	-	9597	-	-	-

Cost of cultivation of maize	: Rs. 39500/ha.	Thiodicarb	: Rs. 980/250 gm
Maize grain selling rate	: Rs. 1962/qtl	<i>B. thuringiensis</i> var. <i>kurstaki</i>	: Rs. 385/250 gm
Labour	: Rs. 299/labour	Emamectin benzoate	: Rs. 1300/250 gm
Wheat bran	: Rs. 20/kg	<i>Metarhizium rileyi</i>	: Rs. 200/250 gm
Jaggary	: Rs. 40/ kg	<i>Metarhizium anisopliae</i>	: Rs. 200/250 gm
Pheromone lure	: Rs. 50/lure	Azadirachtin	: Rs. 230/250 ml
Coriander seed	: Rs. 180/kg	Chlorantraniliprole	: Rs. 2796/150 ml
Marigold seedlings	: Rs. 1.5/seedling	Spinetoram	: Rs. 2295/ 150 ml
NSKE 5 %	: Rs.120/kg		

In the present investigation the results of different modules indicated that the plant damage and larval population were maximum in farmer's practice module as compared to proposed IPM and existing IPM module during both the seasons.

However, the lowest plant damage and larval population were noticed in proposed IPM module. This can be attributed to spraying of *M. rileyi* and poison bait of chlorantraniliprole which effectively checked the larval population of FAW. Further, the

proposed IPM module recorded lowest larval population which could be due to pheromone traps, intercropping of marigold and hence resulted in enhancing the population of natural enemies in proposed IPM module. Subsequently, at later stages of crop growth the incidence of larval population reached its peak in farmer's practice module compared to proposed IPM and existing IPM module which could be due to elimination of natural enemies by the insecticide application.

The results of the present finding of proposed IPM module consistently excelled over existing IPM module and significantly superior over farmer's practice module are in conformity with Varshney *et al.* (2021) who observed that IPM strategy comprising installation of pheromone traps, four releases of *T. pretiosum* Riley, two sprays of neem oil, one spray of each *B. thuringiensis* and *M. anisopliae* resulted in 76 and 71.64 per cent egg mass, 80 and 74.44 per cent larval population reduction during *rabi* and *kharif* season, respectively. Badhai *et al.* (2020) found that the integrated management of *S. frugiperda* was found effective as compared to farmer's practice. Likewise, Neelima *et al.* (2020) reviewed that IPM approaches like the combination of the physical, biological and chemical methods adopted by the majority of the corn producers to reduce the impact of the pest on the crops and also these practices were safe for the environment and human health as against the synthetic insecticides used by many farmers.

Yurina *et al.* (2023) reported that IPM of *S. frugiperda* in maize was economically profitable and environmentally friendly than Non -IPM plot. Similarly, Balabantaray and Samal (2021) concluded that the integrated management approach for control of *S. frugiperda* was an effective measure to reduce the menace of this pest. Warkad *et al.* (2021) revealed that IPM including seed treatment was found superior to other modules by recording the lowest plant damage (10.30 %).

Similarly, Chitti *et al.* (2021) reported that the pest incidence was 11-12 per cent in IPM plots in *kharif* and 4-5 per cent during *rabi*. Whereas the pest incidence was 30-32 per cent in *kharif* and 16-17 per cent during *rabi* in non-IPM followed fields. Further, Prasanna *et al.* (2018) reported that larval population could be efficiently controlled either by beneficial insects or through biopesticides such as *Metarhizium*, *Beauveria*, *Baculovirus*, *B. thuringiensis*, fungi, or plant extracts such as neem products.

Effectiveness of poison bait of chlorantraniliprole a component of proposed IPM module as observed in the present investigation is in conformity with Deshmukh *et al.* (2020) who reported that the chlorantraniliprole was suitable as one of the component of IPM of FAW in India.

According to Ram and Tanweer (2017) highest yield was observed due to application of chlorantraniliprole in IPM plot of maize. The highest yield of maize obtained under TNAU technology capsule compared to farmers' practice reflected in the additional return was reported by Usharani *et al.* (2020). Also, Chitti *et al.* (2021) registered 8-10 per cent increase in yield of maize and the incremental cost-benefit ratio was 1: 5.2 and concluded that IPM module against fall armyworm gave efficient control of fall armyworm and reduced the economic loss of the farmers.

Thilagam *et al.* (2020) reported that the reduction in the larval population was reflected in the highest grain yield in the IPM technology capsule (42.00 q/ha) followed by farmer's practice (29.90 q/ha) and zero practice (17.00 q/ha).

As evidenced in the present investigation, effectiveness of the proposed IPM module is in agreement with Chhetri and Acharya (2019) who reported that combination of maize + marigold (Row intercrop) seemed more effective for sustainable management as marigold act as push crop which repels fall armyworm population. Also, Upreti (2022) reported that maize + marigold intercropping showed lowest larval population (1.75 larvae /5 plant) as compared to Maize + coriander (2.56 larvae /5 plant) and sole maize crop (3.56 larvae/5 plant). Further, certain flowering plants like marigold, coriander, sesame, niger, sunflower, fennel etc. were found effective to attract natural enemies as reported by Sekhar *et al.* (2019) and Singh *et al.* (2020). All these results of earlier workers are in support to present finding.

5. SUMMARY AND CONCLUSION

The present investigation titled 'Ecofriendly management of Fall armyworm, *Spodoptera frugiperda* (J. E. Smith) in Maize' was conducted during the *kharif* and *rabi* season 2020-21 and 2021-22. The field experiments were conducted at Maize improvement project, MPKV, Rahuri, Dist. Ahmednagar, Maharashtra. The laboratory studies were carried out at Ecofriendly laboratory, Department of Entomology, MPKV, Rahuri. The results obtained during present investigation are summarized below in this chapter.

5.1 Studies on the natural enemy complex of *Spodoptera frugiperda* infesting maize

During *kharif* 2021, the data on natural enemies revealed that highest parasitism (27.50 %) was recorded by *Telenomus remus*. This was followed by *M. rileyi* and *C. chloridae* with 14.33 and 10.61 per cent, respectively. Among the predators earwigs recorded the highest population (0.38 adults/plant) followed by spiders (0.36 adults /plant). During *rabi* 2021, *C. chloridae* was the dominant species which recorded parasitism of 21.33 per cent. Among the predators, highest population was recorded by earwigs (0.33 adults/plant) followed by spiders (0.28 adults/plant). The field survey data of Rahuri Tahsil and experimental plot on the natural enemies indicated that, eight different natural enemies affecting various life stages of fall armyworm were recorded, including three predators, four parasitoids and one entomopathogenic fungus. These included two species of *Telenomus remus* Nixon and *Trichogramma* spp. as egg parasitoids, *Chelonus formosanus* as an egg/larval parasitoid, *C. chloridae* as a larval parasitoid, the fungal pathogen *M. rileyi* and three species of earwigs, spiders and coccinellids as predators. A parasitism rate of 23.75 per cent was found in the maize ecosystem out of 145 egg masses that were collected, 34 of which were parasitized by the egg parasitoids. The larval parasitism of fall armyworm by *C. chloridae* contributing to a total larval parasitism of 16.75 per cent in maize.

5.2 Evaluation of efficacy of biopesticides against *Spodoptera frugiperda*

5.2.1 Efficacy of different biopesticides against *S. frugiperda* under laboratory condition

The data on laboratory evaluation of biopesticides revealed that the treatment *B. thuringiensis* @ 2 g/l was the most effective against *S. frugiperda* in which more than 82 per cent mortality of larvae was obtained at 8 DAT. The next best treatment, *M. rileyi* 5 g/l recorded more than 75 per cent mortality at 8 DAT and more than 82 per cent mortality at 12 DAT.

5.2.2 Field efficacy of different biopesticides against *S. frugiperda* in maize.

Among various bio-pesticides and insecticide against fall armyworm, data revealed that spraying of chlorantraniliprole @ 0.4 ml/l was the most effective in reducing the plant damage, larval population and leaf damage score by recording 18.15 per cent, 0.86 larvae per plant and 2.60, respectively due to *S. frugiperda* infesting maize. Among the biopesticides, *B. thuringiensis* @ 2 g/l was the most effective by recording the lowest (28.78 %) plant damage followed by *M. rileyi* @ 5 g/l (31.36 %). In respect of larval population the *B. thuringiensis* @ 2 g/l was found most effective treatment which recorded 1.03 larvae per plant followed by *M. rileyi* @ 5 g/l and *M. anisopliae* @ 5 g/l to which it was on par. In respect of leaf damage score, *B. thuringiensis* @ 2 g/l was the most effective in reducing leaf damage score (3.31) followed by *M. rileyi* @ 5 g/l (3.39). The untreated plots recorded the highest per centage of plant damage (60.02 %) as well as highest larval population (2.25 larvae/ plant) and leaf damage score (6.39).

The good quality marketable corn yield of maize was registered by chlorantraniliprole 0.4 ml/l (65.42q/ha). The next best treatments were *B. thuringiensis* @ 2 g/l, *M. rileyi* @ 5 g/l, *M. anisopliae* @ 5 g/l, azadirachtin 5 ml/l, karanj oil 3 ml/l and *B. bassiana* 5 g/lit. The data further revealed that the *B. thuringiensis* @ 2 g/l emerged as the most economical recording highest ICBR 1:4.45 followed by *M. rileyi* @ 5 g/l recording ICBR of 1:3.31.

5.3 Field evaluation of whorl application of poison baits against *S. frugiperda* in maize

It was noticed that whorl application of bait GF -4867@ 0.1 % was the most effective in reducing plant damage (17.40 %) followed by chlorantraniliprole 18.5

% SC @ 1.88 ml/kg (19.71 %) to which it was on par. Similarly, the whorl application of poison bait GF-4867@ 0.1 per cent recorded the lowest larvae (0.83 larvae/plant) followed by chlorantraniliprole 18.5 % SC @1.88 ml/kg (0.86 larvae/plant) to which it was on par. Studies on leaf damage score assessment of fall armyworm revealed that least leaf damage (2.42) was observed in GF @ 4867- 0.1 per cent followed by the chlorantraniliprole 18.5 % SC @ 1.88 ml/kg (2.59).The untreated plots showed the highest per centage of plant damage (61.89 %) as well as highest larval population (1.57 larvae/plant) and leaf damage score (6.58) caused by *S. frugiperda*

Significantly highest grain yield was registered from the plots treated with GF-4867@ 0.1 per cent (75.56 q/ha). Poison bait of chlorantraniliprole 18.5 % SC @1.88 ml/kg (74.06 q/ha) was emerged as second best treatment. The next best treatments were thiodicarb 75 WP @ 12.50 g/kg, emamectin benzoate 5 % SG @ 2.50 g/kg, *B. thuringiensis* @ 25 g/kg and *B. thuringiensis* @ 12.50 g/kg. The least grain yield (46.65 q/ha) was registered by the untreated plots. Similarly, increase in yield over control was highest in treatment of GF-4867@ 0.1 per cent (61.96 %). This was followed by chlorantraniliprole 18.5 % SC @ 1.88 ml/kg (58.76 %).

The highest net realization over control and Incremental Cost Benefit Ratio (ICBR) was registered in treatment of chlorantraniliprole 18.5 % SC @ 1.88 ml/kg (1: 2.44). The next best treatment was emamectin benzoate 5 % SG @ 2.50 g/kg, which recorded the ICBR of 1:1.89.

5.4 Field evaluation of farmer's practices against *Spodoptera frugiperda*

Data reveals that chlorantraniliprole @ 0.4 ml/l excelled over rest of the treatments for both the seasons with least plant damage, larval population and leaf damage score with 24.05 per cent, 0.85 larvae per plant and 2.57 , respectively. Among the farmer's practices, neem seed powder @ 2 g/whorl was most effective treatment by recording plant damage 33.07 per cent. Also, neem seed powder @ 2 g/whorl recorded the lowest larval population (0.91 larvae/plant) as well as most effective in reducing leaf damage (3.27) by *S. frugiperda*. The next effective treatments in the order effectiveness were lime @ 5 g/whorl, wood ash @ 5 g/whorl, soil @ 5 g/whorl and sand @5 g/whorl. The highest per cent of plant damage (61.24 %) was recorded by untreated plots.

Similarly, the highest larval population of 2.11 larvae per plant as well as highest leaf damage score (6.56) recorded in untreated plots.

All treatments recorded significantly higher yields compared to the untreated control (42.44 q/ha). The highest yield (64.01 q/ha) was registered by chlorantraniliprole @ 0.4ml/ l with maximum per cent increase over untreated control (50.84 %). Among the farmer's practices, effectiveness of neem seed powder @ 2 g/whorl also reflected in registering highest yield of 56.33 q/ha with maximum per cent increase over control (32.73 %).

5.5 Effect of different IPM strategies against fall armyworm, *S. frugiperda* in maize

The pooled data of two seasons revealed that the proposed IPM module showed overall superiority in recording the lowest (26.00 %) plant damage and least number of larvae (0.77 larvae/plant) in maize. This was followed by existing module which recorded 28.75 per cent plant damage and 0.83 larvae per plant. Highest (36.91 %) plant damage and maximum (1.32 larvae/plant) larval population due to *S. frugiperda* was observed in the farmer's practice plot.

Studies were undertaken to observe predator population under treatment of different modules. It was evident that highest population of earwigs (0.43/plant), spiders (0.36/plant) and coccinellids (0.32/plant) were recorded in proposed IPM module. This was followed by existing IPM module in which population of earwigs, spiders and coccinellids with 0.37, 0.28 and 0.25 adults per plant, respectively. Lowest population count of earwigs (0.07/plant), spiders (0.05 /plant) and coccinellids (0.06 /plant) were recorded in farmer's practice module.

The average yield over the two seasons showed that every module outperformed as compared to the farmer's practice module. Proposed IPM module recorded the maximum yield (73.90 q/ha) followed by existing IPM module, which registered 72.70 q per ha. In the proposed IPM module, the return on investment for each rupee spent on plant protection was highest (1:1.63). It was followed by existing IPM module (1:1.22).

Conclusions

Eco-friendly management of fall armyworm, *S. frugiperda* in maize was an attempt with the objective of sustainable pest management. On the basis of scientific data generated on various aspects viz., biopesticides, poison baits, farmer's practices, natural enemies and IPM modules following conclusions are made.

1. Studies on natural enemies of *S. frugiperda* infesting maize revealed that *Telenomus remus* and *Campoletis chloideae* were found dominant species during *kharif* 2021 and *rabi* 2021, respectively. In the interaction studies between weeks and natural enemies the *Telenomus remus* was found effective in parasitism to the rest of the natural enemies.
2. The diverse array of natural enemies recorded in this investigation emphasizes the importance of understanding and conserving natural enemies for effective biological control strategies against fall armyworm.
3. It is concluded that *Bacillus thuringiensis* var. *kurstaki* 0.5 % WP was the most effective against the larvae of *S. frugiperda* as a biointensive option.
4. Chlorantraniliprole 18.5 % SC was found to be highly effective by significantly reducing plant damage, larval population and leaf damage score. Among the biopesticides, *Bacillus thuringiensis* var. *kurstaki* 0.5 % WP was the most effective and economical against fall armyworm.
5. Poison bait GF -4867 @0.1 % was found most effective treatment with highest grain yield (75.56 q/ha). However, bait of chlorantraniliprole 18.5 % SC was most economical with highest ICBR (1:2.44) over control.
6. Chlorantraniliprole 18.5 % SC was proved significantly effective by suppressing plant damage, larval population and leaf damage in maize with highest yield (64.01 q/ha). Among the farmer's practices, neem seed powder was the most effective for controlling larval population.
7. It may be inferred that proposed IPM module (Use of pheromones traps, intercropping with marigold, *Bacillus thuringiensis* var. *kurstaki* 0.5 % WP@2 g/l, *Metarhizium rileyi* 1.15 % WP@5 g/l and whorl application of poison bait of chlorantraniliprole 18.5 % SC@1.88 ml/kg of bait as major components of IPM)

was most effective against *S. frugiperda* by suppressing plant damage and larval population with realizing highest yield (73.90 q/ha) and ICBR (1:1.63).

Future line of work

1. Studies on conservation and mass multiplication of dominant natural enemies *viz.*, *Telenomus remus* and *Campoletis chlorideae* in maize ecosystem.
2. Studies on extraction, isolation and mass multiplication of nucleopolyhedrosis virus (NPV) of fall armyworm.
3. Studies on assessment of efficacy of combination of botanicals and biopesticides against fall armyworm.

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7. VITA

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