“NON-CHEMICAL MANAGEMENT OF FALL ARMYWORM, *Spodoptera frugiperda* (J.E. SMITH) (LEPIDOPTERA: NOCTUIDAE) ON FODDER MAIZE’’

by

Miss. Patil Tejashree Balaso
(Reg. No. 2022/149)

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

in partial fulfillment of the requirements for the degree

of

MASTER OF SCIENCE (AGRICULTURE)

in

ENTOMOLOGY

DEPARTMENT OF ENTOMOLOGY

POST GRADUATE INSTITUTE
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CANDIDATE'S DECLARATION

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

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

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Date : / /2025

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Place : MPKV, Rahuri
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(S. B. Kharbade)

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Date :   /   /2025   *(Tejashree B. Patil)*

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LIST OF ABBREVIATIONS AND SYMBOLS

%	:	Per cent
/	:	Per
&	:	And
@	:	At the rate of
^{o}C	:	Degree Centigrade
ac	:	Acre
AD	:	Anno Domini (Before Christ)
a.i.	:	Active ingredient
ANOVA	:	Analysis of variance
av.	:	Average
BC	:	Benefit cost ratio
Bt	:	*Bacillus thuringiensis*
C.D.	:	Critical difference
CFU	:	Colony-forming unit
CICR	:	Central Institute for Cotton Research
cm	:	Centi meter
C.V.	:	Coefficient of variation
DAS	:	Days after spraying
d.f.	:	Degrees of freedom
EC	:	Emulsifiable concentrate
et al.	:	Et alli (and others)
etc.	:	Et cetera (and so on)
Fb	:	Followed by
Fig.	:	Figure
FAW	:	Fall Armyworm
G	:	Gram (s)
ha	:	Hectare (s)
IPM	:	Integrated Pest Management
ha^{-1}	:	Per hectare
hrs	:	Hours
i.e.	:	id est (that is)
kg	:	Kilogram

kg ha^{-1}	:	Kilogram per hectare
L	:	Litre (S)
LIR	:	Leaf Injury Rating
m	:	Metre
m^2	:	Square metre
Max.	:	Maximum
mg	:	Milligram (s)
Min.	:	Minimum
mm	:	Millimetre
MPKV	:	Mahatma Phule Krishi Vidyapeeth
NRC	:	National Research Centre
N.S.	:	Non-significant
NSKE	:	Neem Seed Kernel Extract
No.	:	Number
kg ha^{-1}	:	Kilogram per hectare
RBD	:	Randomized block design
RH	:	Relative humidity
SAU	:	State Agricultural University
SC	:	Suspension concentrate
S. E. m±	:	Standard error of mean
SG	:	Soluble Granules
SMW	:	Standard Meteorological Week
spp.	:	Species
viz.	:	Videlicet (namely)
WP	:	Wettable Powder

ABSTRACT

"NON-CHEMICAL MANAGEMENT OF FALL ARMYWORM, *Spodoptera frugiperda* (J.E. SMITH) (LEPIDOPTERA: NOCTUIDAE) ON FODDER MAIZE"

by

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A candidate for the degree

of

MASTER OF SCIENCE (AGRICULTURE)

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2025

Research Guide	**:**	**Dr. S. A. Landge**
Department	**:**	**Entomology**

The present investigation entitled "Non-chemical management of fall armyworm *Spodoptera frugiperda* (J.E. Smith) on fodder maize" was conducted at All India Coordinated Research Project on Forage Crops and Utilization, Mahatma Phule Krishi Vidyapeeth, Rahuri during *Kharif,* 2023.

Maize production is generally hampered by biotic and abiotic stresses such as insect pest. The losses of about 10 to 60 % occurred only due to infestation fall armyworm. Farmers uses chemical pesticide to control FAW which causes residues accumulation specially in livestock which depends on fodder and which easily get it into milk which destined for human consumption. Therefore, to minimize the use of chemical pesticide, by determining the efficacy of biopesticides and intercrops against fall armyworm on fodder maize and to identify resistant genotype of maize against fall armyworm, experiments were conducted.

The data obtained from experiment revealed that, entomopathogenic fungi, *Metarhizium anisopliae* @ 5 g/L proved most effective against *Spodoptera frugiperda* and significantly reduced the per cent plant infestation up to 27.78 % with highest fodder yield 468 q/ha followed by *Beauveria bassiana* @ 5 g/L (32.10 %). Next effective treatments were Azadirachtin (40.81 %) and NSKE 5 % @ 50 g/L (43.47 %), but were at par with each other. Intercropping with legumes such as field bean (53.59 %), cowpea (54.52 %) shows that it helps to reduce fall armyworm infestation than sole maize, also it increased the natural enemies population such as coccinellids, spiders in maize. While, intercropping with bajara (58.79 %) was least effective treatment with heavy infestation after untreated control (65.68 %).

The highest incremental cost benefit ratio was recorded in the treatment with spraying of *Metarhizium anisopliae* @ 5 g/L (1:10.00). The next best treatment in order of ICBR was treatment with *Beauveria bassiana* @ 5 g/L which recorded (1: 9.19) ICBR. The treatment with spraying of EPN *Heterorhabditis indica* @ 5g/L recorded lowest ICBR (1: 4.11).

The data obtained from field experiment for screening of maize genotype under natural condition revealed that, among 44 genotypes screened, African tall recorded lowest leaf damage score (4.33) which was used as local check. Among 43 maize genotypes from IGFRI, Jhansi screened with local check African tall, the minimum leaf damage score recorded in MFM-18-9 (4.20) which shows that it was moderately resistant against fall armyworm. While, IGFM-11 (8.83) recorded maximum leaf damage score which shows that it was highly susceptible. Thus, these maize genotypes which are moderately resistant against fall armyworm could be used for breeding programme for further advance research.

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1. INTRODUCTION

Maize or corn (*Zea mays* L.) a miracle crop belongs to the family Poaceae. It was introduced to India from Central America in the beginning of 17th century (Parle and Dhamija, 2013). The cereals *viz.*, maize, rice and wheat meet more than 50 per cent of the worldwide requirement for plant-derived proteins and energetic needs. Globally among cereals, maize is an important staple food and fodder crop for a large segment of population after the rice and wheat (Anandhi *et al.*, 2020). Maize is versatile crop as it is widely used for human consumption, as feed for poultry birds and livestock, for extraction of edible oil and also for starch and glucose industry (Biradar *et al.*, 2011). Thus, maize has attained a major position as industrial crop because 86 per cent of its products are used in various industries (Mooventhan *et al.*, 2019). It contributes over Rs. 112 billion to the agricultural GDP apart from generating employment to over 100 million man-days at the farm and downstream agricultural and industrial sectors of India (Parihar *et al.*, 2011)

Maize traces its origins back to Central Mexico around 5000 BC. Maize is an economically significant cereal crop among the various cereals, which is typically cultivated in tropical as well as in sub-tropical regions of the world. The six major types of maize (corn) are dentcorn, podcorn, flintcorn, popcorn, flourcorn and sweet corn. Maize has been recognized as a crop that has the potential to double the farmer's revenue. Maize is also called as "poor man's nutri-cereal" because it contains a lot of carbohydrates, protein, fat, fiber, sugar, iron, vitamin B, vitamin C and a few minerals. In India, maize is grown in an area of 97.9 lakh ha and rank third in production after rice and wheat with a production of 314.47 lakh tonnes having a productivity of 30.99 q/ha. In Maharashtra, maize is cultivated over the area of 12.26 lakh ha with yielding an annual production of 20.60 lakh tonnes (Anonymous, 2023).

Presently, maize production is hampered by various biotic and abiotic factors. Major key issues such as moisture stress, temperature fluctuation and irregular rainfall and biotic factors such as insect pests and diseases are greatly affecting the crop production and yield to some extent. Apart from these the recently introduced pest fall armyworm is a major problem because of its well-known polyphagous behaviour, which has made it an invasive threat across the world. Montezano *et al*. (2018) reported 360 host species for FAW belonging to 80 plant families.

The fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae), native to the Americas, is found in several countries including Mexico, Argentina and USA (Prowell *et al*., 2004). Outside America, FAW first invaded Africa in 2016. In India, it was first noticed during May 2018 in Shivamogga, Karnataka (Sharanabassappa *et al*., 2018). Since then, it has spread rapidly within the country and infested the maize crop in all growing areas. In Maharashtra, FAW was first reported on sugarcane in September 2018 at Tandulwadi village, Taluka Karmala, District Solapur (Chormule *et al*., 2019). The invasive fall armyworm is a major pest in agriculture. FAW spread within the continents also in the Indian subcontinent in a very short duration which was possible for the pest due to its capacity to migrate long-distance, high fecundity and strong adaptability.

The fall armyworm is a cosmopolitan pest of the maize crop (Wiseman *et al*., 1966). The fall armyworm attacks all growth stages of maize but it is most commonly found in the whorl of young crop up to 45 days old. The larvae typically feed on large amount of foliage and sometimes destroy the growing point of the plants. The adult female lays the eggs in masses, randomly distributed within the crop. During the summer, egg hatching occurs within 3 days. The newly hatched larvae immediately start feeding on the tissues, usually beginning with tender whorl portions. First instar larvae generally eat the green tissue on one side of the leaf, leaving the other sides membranous epidermis intact. As they grow, older instars begin to make holes in leaf and by the fourth to sixth instars, they can completely damage the crop.

Fall armyworm has caused extensive damage to crops, especially in maize registered yield losses to the tune of 40 per cent in Honduras (Wyckhuys and O'Neil, 2006) and 72 per cent in Argentina (Murua *et al*. 2006). The yield losses to the tune of 22, 32, 47 and 67 per cent was estimated from Ghana, Zambia, Kenya and Ethiopia, respectively (Kumela *et al*., 2018). In India, the yield losses of 33 per cent was attributed to FAW infestation in Telangana and 34 per cent in Karnataka (Mooventhan *et al*., 2019)

The recent invasion of fall armyworm threatens the food security of India. Additionally, the pest is highly polyphagous in nature, feeds voraciously and spreading to other crops in the regions it invades (Goergen *et al*., 2016). Chemical insecticides are used indiscriminately by farmers for combating *Spodoptera frugiperda* in Maharashtra. Despite its rapid mode of action, the larvae have developed resistance, as a result of this control approach and use of insecticides results in accumulation of residue in maize which may leads to hazardous health effects on cattle. In the absence of natural control or good management, it is causing significant damage to the crop.

Now-a-days insecticides are an integral part of pest management. The scan of the literature indicated that more stress has been given to insecticidal control of FAW by using synthetic insecticides. The chemical pesticides have its own limitations on its overuse like residues in silage and grains, pest resurgence and resistance in insects. The livestock reared on pesticide contaminated fodder may accumulate pesticide residues in tissue. Moreover, due to lipophilic nature of pesticides, they easily accumulate in milk and other fat rich substances which are predestined for consumption.

Furthermore, the high fecundity and dispersion potential, great physiological and behavioural 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)

Cultural control of insect pests can be achieved by the manipulation of the environment in such a way to render it unfavourable to the pest. It includes techniques such as manipulation of sowing dates, crop rotation, intercropping and management of weeds. Cultural control should be considered as the initial defence around which other management strategies could be built.

Host plant resistance is an important part of IPM, thus finding any maize genotype by screening that are fall armyworm resistant could be key aspect. Hence, screening of germplasm of crop is significant part of developing insect-resistant variety and is done to identify elite sources of resistance and eliminate germplasm that is extremely susceptible before hybrid release. Farmers are growing wide variety of commercial hybrids across the state, but the hybrids with good plant vigour and genetic resistance to crop pests were most preferred to combat the invasive alien insect pests. The use of insect-resistant cultivar is a significant component of Integrated Pest Management (IPM) which provides an economic, stable and environmentally sound approach to minimize damage from pests. The morphological and biochemical trait plays important role in host plant resistance. Morphological traits are responsible for preference of a cultivar for feeding and oviposition.

The use of chemical pesticides is unsustainable because it develops insecticide resistance, leaves pesticide residue, affects natural enemies and carries health risk. Therefore, it is essential to minimize the use of chemical pesticides and need to develop sustainable IPM technologies against *Spodoptera frugiperda.* The fall armyworm larvae are susceptible to entomopathogenic microorganisms, such as bacteria, nematodes, fungi, viruses and protozoa. Also, environment friendly microbial insecticides have also been successful in controlling lepidopteran larvae and it includes the bacteria *Bacillus thuringiensis* var. kurstaki, the fungi *Metarhizium anisopliae* (Metsch.), *Beauveria bassiana* (Bassi.), the nematodes *Heterorhabditis indica* and various Nuclear Polyhedron Viruses (Bateman *et al*., 2018). Hence there is a need to evaluate native and available strains of microorganisms as substitute to chemical pesticides against maize fall armyworm. Studies conducted on screening of maize genotype to find out the source of resistance and susceptibility against fall armyworm. Considering the above facts in view, current investigation was initiated to study the following objectives:

1. To study the non-chemical management of fall armyworm on fodder maize
2. To screen promising genotypes of maize for resistance against fall armyworm on fodder maize

2. REVIEW OF LITERATURE

A brief review on the present investigation entitled "Non chemical management of fall armyworm, *Spodoptera frugiperda* (J. E. Smith) on fodder maize" presented in this chapter.

2.1 Studies on Non-chemical Management of Fall Armyworm on Fodder Maize

Skovgard and Paets (1997) studied the effect of intercropping maize with cowpea on the damage caused by three species of lepidopteran stem borers (*Chilo partellus*, *Chilo orichalcociliellus and Sesamia calamistis*) in Kenya. They found significantly higher fodder yields of maize (27–57 %) and lower numbers (15–25 %) of stem borers in the intercropped maize.

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

Patil (2000) worked on Neem Seed Kernal Extract (NSKE) and evaluated that the minimum lepidopteron larval feeding was observed in irrespective of concentrations of NSKE. At 5 per cent concentration of NSKE the leaf area consumed significantly less followed by NSKE (20%).

Barapatre (2001) evaluated that, among the different indigenous technology the interturn of pongamia + aloe + NSKE + cow urine is useful to manage the lepidopteran pests, because of its highest antifeedant activity. Results showed that, this interturn is responsible for 75.75 per cent larval weight reduction over control followed by interturn of agave + chilli and neem seed kernel extract (65.44 %).

Capalbo *et al.* (2001) observed the effect of *Bacillus thuringiensis* var. tol worth against the fall armyworm. *Bacillus thuringiensis* var. tol worth, 300 L/ha was sprayed in maize field to evaluate the efficacy of this bio pesticide and resulted that, after 24 hours of first application, eggs had hatched and initial instar larvae were feeding on the leaves of the plants. After 48 hours of application only dead, black larvae were found. After twenty days of 1^{st} application of *Bacillus thuringiensis* the same level of initial larvae infestation was recorded.

Agboka *et al*. (2006) studied the effect of intercropping maize with cowpea, lima bean, soybean, three leguminous cover crops namely *Tephrosia vogelii*, *Canavalia ensiformis*, *Sesbania rostrata* and cassava on the infestation of *Mussidia nigrivenella* (Lepidoptera: Pyralidae) and other lepidopteran ear borers. It was found that intercropping reduced the number of eggs (25 %) and larvae (by 17.9 to 53 %) of *M. nigrivenella* compared to that of monocrop. Maize + *C. ensiformis* and maize + *T. vogelii* proved to be the most effective combinations for reducing *M. nigrivenella* populations. Yield loss and ear damage, which were substantially correlated with the number of insects, were significantly affected by the intercrops.

Romero-Arenas *et al*. (2014) studied the mortality of *S. frugiperda* in laboratory conditions by using different concentrations of conidium from a native and a commercial strain of *M. anisopliae*. The concentration of 53×10^4 conidia per ml of the native strain, reported a mortality of 72.5 per cent and the lowest was obtained from the strain of *Metarhizium anisopliae* commercial in concentration of 4×10^4 conidia per ml, equivalent to 32.5 per cent. The highest death rate for both strains occurred at 72 hours post-infection with 11 larval on average of three concentrations of native *Metarhizium anisopliae.* These results demonstrated the feasibility of using *M. anisopliae* for biological control of fall armyworm (*S. frugiperda*) in vitro.

Silva *et al*. (2015) noted that the aqueous extract of neem seed cake is more toxic than the leaf extract which is usually used by farmers to control fall armyworm *S. frugiperda.*

Figueiredo *et al.* (2015) tested the biological control *Trichogramma pretiosum* to reduce *Spodoptera frugiperda* population The yield obtained for parasited plot was increased by 701 kg/ha versus control. They measured plant damage ratings, egg masses parasitized, and grain yield. Results showed that 79.2 % of egg masses were parasited. Maize yields for parasite plot increased of 701 kg/ha versus control plots. This result equals a 19.4 % gain of productivity and US$ 96.5 gain per hectare. Therefore, biological control with egg parasitoid is a promising alternative to control *S. frugiperda* in organic maize.

Rodriguez *et al*. (2016) evaluated the bioefficacy of entomopathogenic fungi, B*eauveria bassiana* against fall armyworm larvae *S. frugiperda* at Departament of Parasitología, Coahuila. Results indicated that the per centage mortality of 3rd instar larvae injected with *B. bassiana* endophytic strain was 4.1 per cent, 26.6 per cent, 48.3 per cent and 75 per cent at 4,7,10, and 14 days, respectively. Result showed that, as compared to pesticides, the usage of this fungus is environmentally friendly.

Lakshmanan *et al.* (2017) studied the different solvents of methanol, ethyl acetate, chloroform and acetone of *Pongamia pinnata* and *Ceiba pentandra* in the experimental analysis in control of lepidopteran pest *Helicoverpa armigera*. They concluded that, the antifeedant activity of *P. pinnata* and *C. Pentandra* against *H. armigera* were 94.6 and 92.4 per cent at 225 ppm and larvicidal activity tested LC_{50} and LC_{90} values were 102.10 and 228.01 ppm, respectively.

Bateman *et al.* (2018) worked on biopesticides such as microbials and semiochemicals are generally considered to be lower risk options for pest management and they are promising avenue for exploration. When used in conjunction with good crop management, they can help to keep pest levels under control. This study provides a basis for designing interventions to make biopesticides more widely available for fall armyworm control in Africa.

Mallapur *et al*. (2018) conducted field survey in North Karnataka and revealed that the entomopathogenic fungi, *Nomuraea rileyi* showed infection on fall armyworm ranged from

1.87 % in Vijaypur, 18.30 % in Dharwad district and further reported that the larval population and leaf injury reduction after 15 days of spraying *N. rileyi* ranged from 62.5 to 66.4 and 66.8 to 73 per cent, respectively. The studies indicated the high potential of *N. rileyi* in combating the *S. frugiperda.*

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.

Patel *et al*. (2020) studied the bio-efficacy of different strains of entomopathogenic fungi *viz.*, *Beauveria bassiana*, *Metarhizium anisopliae* and *Nomuraea rileyi* and entomopathogenic bacteria *Bacillus thuringiensis* against *Spodoptera frugiperda* under laboratory condition at Anand Agricultural University. The results indicated that among different entomopathogenic fungi, AAU 13 strain of *M. anisopliae* @ $2x10^9$ conidia/ml showed the highest larval mortality *i.e*., 57.56 % and 50.63 % against 2nd and 3rd instar larvae respectively. In case of entomopathogenic bacteria, AAU strain of *Bacillus thuringiensis* showed 64.65 % and 59.01 % larval mortality against 2nd and 3rd instar larvae respectively.

Ramanujam *et al*. (2020) evaluated ten indigenous entomofungal strains of *Beauveria bassiana*, *Metarhizium anisopliae* and *M. rileyi* against 2nd instar larvae of *S. frugiperda* on maize in a laboratory bioassay and evidenced that among the ten strains tested, *M. anisopliae* ICAR-NBAIR Ma-35 caused 67.8 per cent mortality, followed by *B. Bassiana*. Field evaluation with these two promising strains were conducted against maize fall armyworm for 2 years (2018 and 2019) at ICAR-NBAIR experimental farm, Bengaluru, Karnataka, India. In 2019, 70 and 76 per cent reduction of FAW infestation were observed in the plots treated with these two entomofungal pathogens, respectively.

Udayakumar *et al*. (2020) was conducted to study the influence of intercropping of leguminous crops in maize for the management of fall armyworm. Five treatments *viz.*, maize + groundnut (*Arachis hypogaea*), maize + broad bean (*Vicia faba*), maize + (*Desmodium* sp), maize + soybean (*Glycine max*) and monocrop of maize were evaluated for the severity of damage caused by fall armyworm. Significantly higher rates of parasitization of egg mass of fall armyworm by *Trichogramma* spp. were recorded in the maize + broad bean compared to the monocrop of maize. The results of the study indicated the definite role of maize-legume intercropping in reducing fall armyworm damage in maize.

Aarthi Helen *et al*. (2021) evaluated the bioefficacy of six bioagents *Metarhizium anisopliae, Nomuraea rileyi, Beauveria bassiana, Bacillus thuringiensis,* Nematode *Steinernema carpocapsae* (Weiser) and *Azardirachtin* at Department of Entomology, College of Agriculture, Pune, Mahatma Phule Krishi Vidyapeeth, Rahuri. The results revealed that *Bt* showed the highest mortality of 85.92 %, 64.44 % and 50.00 % against 1st, 3rd and 5th instar larvae respectively, followed by *Nomuraea rileyi*, 71.48 %, 57.04 % and 36.68 % against 1st, 3rd and 5th instar larvae respectively.

Reddy (2021) studied the biointensive management of fall armyworm during *Rabi*,2020. Treatments were azadirachtin @ 2 ml/L, *Beauveria bassiana* @ 5 g/L, *Metarhizium anisopliae* @ 5 g/L, *Nomuraea rileyi* @ 5 g/L, *Bacillus thuringiensis var-kurstaki* 2 g/L, *Trichogramma pretiosum* 50,000 eggs/acre, application of dry soil in whorls 50 g per plant and spray of sugar solution on maize @ 90 g/L were evaluated. Among the treatments, *Nomuraea rileyi* @ 5 g/L proved to be effective followed by *Metarhizium anisopliae* @ 5 g/L and *Beauveria bassiana* @ 5 g/L.

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 + jaggary 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 bird beetle, predatory bug and earwig. It was followed by *M. anisopliae, B. bassiana,* poison bait and sand + lime.

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* $1x10^8$ cfu/g @ 30 g/10L, *M. anisopliae* $1x10^8$ cfu/ g @ 50 g/ 10L, *B. bassiana* $1x10^9$ cfu/ g @ 40 g/ 10L, NSKE 5%, *Bt* 85% @ 20 g/ 10L, SLNPV $1x10^9$ POB/ ml (500 LE), azadirachtin 1500 ppm @ 50 ml/ 10L 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 %).

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 30 % 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.

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 found effective against FAW which could be used sustainably to manage the invasive fall armyworm in maize cropping systems.

Kumar *et al*. (2022) was found that cultivation of tolerant genotypes, by adjusting sowing windows and practicing specific intercultural and cropping systems measures in addition to chemical and non-chemical pest management strategies showed encouraging results for sustainable management of fall armyworm, which could protect the crop.

Shashank (2023) conducted field experiment on effect of cultural practices on the incidence of fall armyworm *Spodoptera frugiperda* (J. E. Smith) and its natural enemies in maize agro-ecosystem. The results indicated that intercropping of maize with legumes, (Maize+ French bean) was effective in controlling fall armyworm by recording least mean per cent infestation (25.57 %) followed by (Maize + Coriander) which recorded 34.18 mean per cent infestation, also revealed that french bean as intercrop were effective in enhancing population of natural enemies such as coccinellids and spiders etc.

Pagire (2024) studied the field efficacy of different biopesticides against fall armyworm on maize which showed that 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 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 and 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.

2.2 Screening Promising Genotypes of Maize for Resistance against Fall Armyworm

Wisemann *et al*. (1966) conducted a screening experiment in the USA by using visual classifications to measure differences in damage to corn seedlings by the fall armyworm, *S. frugiperda.* Among various genotypes subjected for screening, the genotypes namely, FAW- 1, a selection from Antigua 2D X (BlO X Bl4) and Texas Experimental Hybrid 6417 were found to be the most resistant lines of corn which were studied by using joana sweet corn as the susceptible check.

Davis and Williams (1992) adopted a rating scale of 1-9 based on leaf damage, ear and kernel damage due to fall armyworm for the screening of maize. Rating of 1.00 indicated as highly resistant, 2-3 as resistant, 4-5 as moderately resistant, 6-7 as susceptible and 8-9 as highly susceptible.

Reddy *et al*. (2002) developed a rating scale of 1(healthy plant) to 9 (dead heart) for screening of maize genotypes for resistance to the pink borer, *S. inferens*. The maize plants were separated into three distinct groups namely 1-3 score as least susceptible, 4-6 score as moderately susceptible and 7-9 as highly susceptible based on a systematic study of the nature of symptoms and extent of damage.

Santiago *et al*. (2005) screened 13 genotypes of maize by examining free phenols in maize pith and their relationship with resistance to the infestation of *Sesamia nonagrioides*. They revealed that, the genotypes *viz.*, CM151, CO125, EP39, EP64 and MS1334 were found resistant with higher concentration of p-coumaric acid (17.38µg/g), a free phenol was recorded in these genotypes while the genotypes *viz.*, PB130, A509, CM105, EP42, EP47, F473 and H104W were found susceptible had comparatively less concentration (13.64 µg/g) of similar free phenols.

Arabjafari *et al*. (2007) screened 26 common maize varieties in Karnataka, India in both field and glass-house for resistance to *C. partellus*. The genotypes CM137 and HY4642 were identified as resistant varieties with higher per centages of P (phosphorous), K (potassium), Fe (Iron), nitrogen and sugars.

Ni *et al*. (2008) studied physiological basis of fall armyworm resistance in six maize inbred lines with varying levels of silk maysin by infesting 15-20 neonate larvae per plant and reported that CML333, CML336, CML338, MP708 (with a range of low to high levels of silk maysin) were most resistant, whereas Ab24E and CML335 (without silk maysin) were more susceptible to fall armyworm.

Afzal *et al*. (2009) screened 20 maize genotypes for resistance to *C. partellus in* the field. The genotype DK-6525 was identified as most resistant which was due to its higher leaf trichome density (32.7 %). While genotype Sahiwal 2002 was found most susceptible.

Ni *et al*. (2011) studied foliar resistance to fall armyworm in eight germplasm lines by infesting 15-20 neonate larvae per plant and reported that CRW3 (S1) C6, MP708 and FAW7061 were the most resistant, whereas Ab24E and EPM6 were more susceptible to fall armyworm feeding. Subsequently, they identified three germplasm line as best against fall armyworm and these resistant lines were entry No.9, 15 and 19.

Lella and Srivastava (2013) screened maize genotypes against stem borer in *Kharif* season. About nineteen genotypes were examined on the basis of leaf injury rating and reported that leaf damage score ranged from 2.6 to 6.6, with the incidence being maximum in QPM 169, (6.6) whereas leaf damage was less in HUZQPM242, HUZM 185, HUZM 217 with average leaf injury ratings being 2.6, 2.8, 3.4 respectively. Rest of the genotypes had leaf injury rating between 3.6 to 5.6.

Ni *et al*. (2014) examined ear colonizing pest resistance in 20 USDA (United States Department of Agriculture) maize lines using four inbred lines of maize as the resistant and susceptible controls. Observations of fall armyworm injury and predator abundance were taken at 7 DAS (days after sowing) and 14 DAS. They found that three (UR11003:S0302, CUBA164-1 and DK 7) out of 20 germplasm lines were found to be better resistant lines, derived from genotypes in Uruguay, Cuba and Thailand, respectively.

Aguirre *et al*. (2016) studied the development of genetic modified (GM) corn hybrids for resistance to this insect, with the inclusion of several genes coding for proteins CryAb, Vip3Aa20, and mCry3A of *Bacillus thuringiensis,* offer an alternative to conventional insecticides to control this pest. Resistance to fall armyworms of the GM corn hybrids AGRISURE 3000 GT, Agrisure viptera 3110, and Agrisure viptera 3111 was evaluated in 4 locations at Sinaloa for a 3 year period. Damage evaluation showed that the maize hybrids with the *Bt* gene insertion were not affected by the fall armyworm as compared with their respective damaged. The results reaffirm the insect control benefits provided by this technology and provide a baseline for resistance management.

Kumar *et al*. (2017) studied symptom based artificial screening of maize germplasm against *C. partellus* and reported that among the different maize genotypes screened, IIMRQPMH 1608, FQH 106 and IIMRQPMH 1606 were least susceptible while the genotypes IIMRQPMH 1604, IIMRQPMH 1502 and IIMRQPMH 1602 were susceptible.

Pal *et al*. (2018) studied the resistance and susceptibility of different maize germplasms against maize stem borer, *C. partellus* in Rabi season and reported that fourteen germplasms of maize were resistant against stem borer having 0.0 per cent damage based on leaf injury rating. Three germplasms were found moderately susceptible having 6 to15 per cent damage and twelve germplasms were found susceptible having 16 to 30 per cent of damage. Whereas, seventyone germplasms were observed to be highly susceptible to maize stem borer having more than 30 per cent damage.

Craig *et al*. (2019) studied the foliar damage of fall armyworm in thirteen germplasm lines by infesting 15 to 20 larvae per plant and reported MP708 as resistant with rating of 2.3 and B97 and GEMN-0059 as a susceptible with rating of 7.6 and 7.3, respectively and Saint Croix group 1 and Saint Croix group 3 as moderately susceptible inbred lines.

Soujanya *et al*. (2019) screened maize inbred lines for resistance to stem borers. A set of seventy-six inbred lines were screened against *Chilo partellus* (Swinhoe) and fifty-six against *Sesamia inferens* (Walker) during *Kharif* and *Rabi* seasons, respectively based on the leaf injury rating on 1-9 scale. Among the lines screened, DMRE63/ CML 287-2 46-9 was found to be resistant to *C. partellus* with LIR 2.7 whereas eight lines, *viz.*, BGS 86 (2.17), CM111/Zea diploperennis CM111 (2.8), CML141 (2.4), CML33-4 (2.4), DML 1432 (3.0), EC619101 (2.5), HEY Pool-2011-30-4-1-2-2-1 (2.2) and HEY Pool-2011-41 21-1-1-1 (2.3) were found resistant to *S. inferens.*

Divekar *et al*. (2019) screened maize germplasm against *C. partellus.* Leaf injury rating (1 to 9) was used to study the germplasm susceptibility level. The maximum LIR was recorded in HKI-1128 (8.6) and HKI-193-1 (8.5) whereas LIR was observed in the intermediate range in

BML-6 (7.3), CM-139 (7.46), CM-140 (7.06), HKI-163 (7.2), HKI 161 (6.26) and HKI-1105 (6.4). However, LIR was found lower in the germplasm BML 7 (4.2) HKI-323 (5.06).

Chapwa *et al*. (2020) screened inbred lines of tropical maize for resistance to fall armyworm and yield traits. A set of sixty maize land races, hybrids and open-pollinated varieties and another set of two hundred and fifty-three inbred lines were evaluated and it was reported that genotypes CZL1310C, CML 444-B, CZL15220, TL1512847 and CML 491 showed low fall armyworm leaf damage and cob damage.

Nandita and Sonali (2020) screened twenty-five genotypes and on the basis leaf damage rating, ear damage rating and kernel damage rating reported that DKC-9190 genotype recorded minimum leaf damage of 2.36 and NK-30 genotype recorded maximum leaf damage (8.21). While Heera-1122 genotype recorded minimum ear damage (1.91) and NMH-707 genotype recorded maximum ear damage (5.91) in the crop. Among the twenty-five cultivars, NMH-707 genotype recorded minimum kernel damage (1.59) and LG-34.06 genotype recorded maximum kernel damage (4.31) in the crop and adopted a rating scale of 1 to 9 based on plant injury due to fall armyworm for the screening of maize genotypes.

3. MATERIAL AND METHODS

The present investigation "Studies on the non-chemical management of fall armyworm on fodder maize" was carried out during *Kharif,* 2023 at the farm of All India Coordinated Research Project on Forage Crops and Utilization, Mahatma Phule Krishi Vidyapeeth, Rahuri. The material and methods followed to conduct field experiment are presented in this chapter as under.

3.1 Non-chemical Management of Fall Armyworm on Fodder Maize

3.1.1 Soil

The topography of the field was fairly uniform and leveled. The soil of experimental area was medium black with adequate drainage.

3.1.2 Climatic Conditions

Geographically, the central campus of MPKV is situated between 19° 47' and 19° 57' North latitude and between 74° 32' and 74° 19' East longitude. The altitude varies from 495 to 569 meters above sea level. Climatically, this region falls within the semi-arid tropics, experiencing annual rainfall ranging from 307 to 619 mm, with an average of 520 mm, distributed over 15 to 45 days throughout the year. Approximately 80 per cent of the total annual rainfall is received during the South-West monsoon season, which occurs from June to September. The annual average maximum temperature is 38°C, with a range between 33°C to 43°C, while the mean minimum temperature is 15°C, with a range of 13°C to 17°C. The average maximum and minimum humidity levels vary from 59 to 35 per cent, respectively.

3.1.3 Material

3.1.3.1 Seed

Variety of fodder maize African tall was selected for the studies on the non-chemical management of fall armyworm on fodder maize. For intercropping, field bean, cowpea and bajara were sown as intercrop with maize. The seed was obtained from AICRP on Forage Crops and Utilization. MPKV, Rahuri.

3.1.3.2 Biopesticides and Appliances

The biopesticides were made available by biocontrol unit, Department of Entomology, MPKV, Rahuri. The details of biopesticides used for experiment with their common name, trade name, formulation, and source are given in Table 3.1

Appliance used for spraying of insecticides was knapsack sprayer, which was made available by the AICRP on Forage Crops and Utilization, MPKV, Rahuri.

Table 3.1 Details of the biopesticides with trade name, dose/L and source of product

Sr. No	Insecticide name	Tradename	Dose/L	Source of product
1	Azadirachtin (10000 ppm) EC	Maha Neem	2 ml	Shriram Krishi Seva Kendra, Rahuri
2	*Beauveria bassiana* (1×10^8 cfu/g) 1.15% WP	Phule Beauveria	5 g	Biocontrol laboratory, Department of Entomology, MPKV, Rahuri
3	*Metarhizium anisopliae* (1×10^8 cfu/g) 1.15% WP	Phule Metarhizium	5 g	Biocontrol laboratory, Department of Entomology, MPKV, Rahuri
4	Neem Seed Kernel Extract 5%	NSKE	50 g	Home made
5	Pongamia oil 3% EC	Karanj oil	5 ml	Vijaya Agro Industries, Sangamner
6	EPN *Heterorhabditis indica* (1×10^8 IJs/ac)	Soldier-WP	5g	Multiplex Bio-tech Private Limited

3.1.4 Experimental details

Design	:	Randomized Block Design
Replications	:	3
Treatments	:	10
Crop	:	Maize
Variety	:	African Tall
Seed rate	:	75 kg/ha
Spacing	:	30 cm line sowing
Plot size	:	4 m × 4 m
Season	:	*Kharif*, 2023
Date of sowing	:	28/07/2023
No. of spray	:	2
Date of Harvesting	:	13/10/2023
Location	:	AICRP on Forage Crops and Utilization, MPKV, Rahuri

RI	RII	RIII
T_1	T_{10}	T_4
T_2	T_9	T_5
T_3	T_8	T_6
T_4	T_7	T_{10}
T_5	T_1	T_9
T_6	T_2	T_8
T_7	T_3	T_1
T_8	T_4	T_2
T_9	T_5	T_3
T_{10}	T_6	T_7

N

T_1 *Metarhizium anisopliae* (1×10^8cfu/g) 1.15% WP	T_6 EPN *Heterorhabditis indica* ($1x10^8$ IJs/ac)
T_2 Neem Seed Kernel Extract 5%	T_7 Intercropping maize + cowpea
T_3 *Beauveria bassiana* (1×10^8cfu/g) 1.15% WP	T_8 Intercropping maize + field bean
T_4 Azadirachtin (10000 ppm)	T_9 Intercropping maize + Bajra
T_5 Pongamia oil 3% EC	T_{10} Untreated control

Fig 3. 1 Layout of field experiment for non-chemical management of fall armyworm on fodder maize

3.1.5 Treatment Details:

Tr. No.	Treatment details	Dose (g or ml/litre of water)
T_1	*Metarhizium anisopliae* (1×10^8cfu/g) 1.15% WP	5 g
T_2	Neem Seed Kernel Extract 5%	50 g
T_3	*Beauveria bassiana* (1×10^8cfu/g) 1.15% WP	5 g
T_4	Azadirachtin (10000 ppm)	2 ml
T_5	Pongamia oil 3% EC	3 ml
T_6	EPN *Heterorhabditis indica* ($1x10^8$ IJs/ac)	5 g
T_7	Intercrop cowpea (1:1 row)	–
T_8	Intercrop field bean (1:1 row)	–
T_9	Intercrop bajara (1:1 row)	–
T_{10}	Untreated control	–

3.1.6 Method of Recording Observations:

To find out the effective treatment, observation of plant damage was recorded from each treatment. The data was recorded one day before spraying as a pre-count while post-treatment counts were taken at 3, 7 and 10 days after spraying. Spraying was done at 15 days intervals and observations were recorded at pre and post-sprays per plot. In each Plot, 10 plant randomly selected and number of plants damaged due to fall armyworm were recorded. (Mallapur *et al.*2018) The per cent infestation was calculated by the formula given below:

$$\text{Per cent infestation} \quad \frac{\text{Total number of damaged plants per plot}}{\text{Total number plants per plot}} \times 100$$

3.1.7 Statistical analysis

The experimental data on efficacy was analyzed statistically by applying Randomized Block Design (RBD) and the results obtained from field observation was analyzed statistically. The significance of treatments were assessed by determining critical difference (C.D.) at 5 % level of significance suggested by Panse and Sukhatme (1985). The data on per cent infestation of fall armyworm were transformed into arc sin values. Appropriate statistical methods were employed to work out standard error (SE) and critical difference (CD) for deciding the significance of treatments.

3.1.8 Yield and Economics

The yield data (kg/ ha) of each treatment was recorded according to replication and after conversion in to 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 following formula (Gomez and Gomez, 1984).

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

Where, T = Yield from treated plot.

C = Yield from control plot.

Economics of different treatments was calculated, considering the cost of insecticide, biopesticides and botanical, its application cost, equipment charges etc. during the course of research work. The data on fodder yield per hectare and its prevalent market price were used to work out the benefit derived from each treatment / ha. Based on incremental benefit in yield over control was worked out to establish economic ranking of various treatments.

1. Additional income over control: It was obtained by multiplying the additional yield over control with prevailing minimum local market price of commodity.
2. Cost of plant protection: It was obtained by summing up all the cost of different treatments including labour and charges of hired equipment.
3. Net monetary return: This was calculated by subtracting total cost of treatment (B) from the Additional income over control. (A)
4. Incremental Cost Benefit Ratio: It was calculated by dividing the net monetary return (C) by total cost of plant protection *i.e.* C/B

3.2 Screening of Maize Genotypes for Resistance against Fall Armyworm

The present research work was carried out during *Kharif* 2023 at the farm of All India Coordinated Research Project on Forage Crops and Utilization, Mahatma Phule Krishi, Vidyapeeth, Rahuri, Dist. Ahmednagar, Maharashtra. The material and methods followed for the studies are presented in this chapter as under.

3.2.1 Material:

3.2.1.1 Collection of seed:

The relative resistance or tolerance of different maize genotypes to fall armyworm was studied by screening different genotypes under field conditions. Fourty-three maize genotypes were collected from ICAR- Indian Grassland and Fodder Research Institute, Jhansi-UP India. and one African tall variety as local check collected from AICRP on Forage Crops. MPKV, Rahuri. The details of the maize genotypes are given in the Table 3.2.

Table 3.2 List of maize genotypes used for screening against fall armyworm

Sr No.	Genotype	Sr No.	Genotype
1	JC-1455-1	23	IGFM-10
2	PFM-12	24	IGFM-11
3	JH-20088	25	IGFM-12
4	JC-1465	26	IGFM-13
5	JH-17028	27	IGFM-14
6	JH-19014	28	IGFM-15
7	JC-1463-1	29	IGFM-16
8	PML-368	30	IGFM-17
9	PML-81	31	IGFM-18
10	JC-4	32	IGFM-19
11	PML-1230	33	IGFM-20
12	PML-243	34	IGFM-21
13	J-1007	35	IGFM-22
14	IGFM-1	36	IGFM-23
15	IGFM-2	37	MFM-22-4
16	IGFM-3	38	MFM-18-2
17	IGFM-4	39	MFM-22-3
18	IGFM-5	40	MFM-18-9
19	IGFM-6	41	MFM-316
20	IGFM-7	42	MFM-22-2
21	IGFM-8	43	MFM-22-5
22	IGFM-9	44	African Tall

3.2.2 Preparatory cultivation

The field was thoroughly cultivated with a tractor-drawn cultivator and evenly leveled with a rotavator after removing all the stubbles and weeds. An irrigation channel was formed in between two replications with a spacing of 0.75m.

3.2.3 Fertilizer application

Recommended dose of 100:50:50 kg of NPK per hectare for fodder maize was applied through urea, single super phosphate and muriate of potash. On the basis of nutrient content of these fertilizers, the quantity to be applied was computed for one ha then for gross plot. Half dose of N, full dose of P and K were applied as basal at the time of sowing. Remaining nitrogen was top dressed in two equal splits.

3.2.4 Weed management

Atrazine WP @1.5 kg/ ha was used as a pre-emergence herbicide just one day after sowing for the management of broad leaved weeds and then by manual weeding with hand hoe at necessary intervals.

3.2.5 Irrigation

For ensuring proper germination and plant stand, irrigation was given immediately after sowing. Subsequent irrigations were provided as and when required.

3.2.6 Experimental details

Design	:	Randomized Block Design
Replications	:	2
Treatments	:	44
Crop	:	Maize
Seed rate	:	75 kg/ha
Spacing	:	30 cm x 10 cm
Plot size	:	4 m × 4 m
Season	:	*Kharif*, 2023
Date of sowing	:	28/07/2023
Location	:	AICRP on Forage Crops and Utilization, MPKV, Rahuri

3.2.7 Method of recording observations:

Damage to the plants was scored by evaluating the severity of pinholes, shot holes, lesions and irregular leaf feeding damage. The data regarding foliar damage induced by the fall armyworm was scored as per damage scale given by Davis and Williams (1992) modified by CIMMYT (Table 3.3) at 15, 30 and 45 days after sowing (DAS). Later the genotypes were categorized into moderately resistant, susceptible and highly susceptible.

3.2.8 Statistical analysis

During the current investigation, the mean leaf damage score of all plants within the genotype was calculated. The data collected from all genotypes were subjected to (RBD). The significance of treatments were assessed by determining critical difference (C.D.) at 5 % level of significance as given by Panse and Sukhatme (1985).

Table 3.3 Visual rating scale based on leaf damage (Davis *et al.*, 1992)

Score	Damage symptoms/ Description	Response
1	No visible leaf feeding damage	Highly resistant (HR)
2	Few pinholes on 1 to 2 older leaves	Resistant (R)
3	Several shot-hole injuries on a few leaves (< 5 leaves) and small circular hole damage on leaves	
4	Several shot-hole injuries on a several leaves (6 to 8 leaves) or small lesions/pin holes, small circular lesions and a few small elongated rectangular- shaped lesions of up to 1.3 cm in length present on whorl and furl leaves	Moderately resistant (MR)
5	Elongated lesions (>2.5 cm long) on 8 to 10 leaves, plus a few small- to mid-sized uniform to irregular- shaped holes (basement membrane consumed eaten from the whorl and/or furl leaves).	
6	Several large elongated lesions present on several whorl and furl leaves and /or several large uniform to irregular- shaped holes eaten from the whorl and furl leaves	Susceptible (S)
7	Many elongated lesions of all sizes present on several whorl and furl leaves plus several large uniform to irregular- shaped holes eaten from the whorl and furl leaves	
8	Many elongated lesions of all sizes present on most whorl and furl leaves plus many mid-to large sized uniform to irregular- shaped holes eaten from the whorl and furl leaves	Highly Susceptible (HS)
9	Whorl and furl leaves almost totally destroyed and plant dying as a result of extensive foliar damage	

T1		T44
T2		T43
T3		T42
T4		T41
T5		T40
T6		T39
T7		T38
T8		T37
T9		T36
T10		T35
T11		T34
T12		T33
T13		T32
T14		T31
T15		T30
T16		T29
T17		T28
T18		T27
T19		T26
T20		T25
T21		T24
T22		T23
T23		T22
T24	IRRIGATION CHANNEL	T21
T25		T20
T26		T19
T27		T18
T28		T17
T29		T16
T30		T15
T31		T14
T32		T13
T33		T12
T34		T11
T35		T10
T36		T9
T37		T8
T38		T7
T39		T6
T40		T5
T41		T4
T42		T3
T43		T2
T44		T1

Fig 3.2 Layout of field experiment for screening of maize genotypes against fall armyworm

4. RESULTS AND DISCUSSION

The studies on non-chemical management of fall armyworm, *Spodoptera frugiperda* (J. E. Smith) on fodder maize and screening of promising genotypes of maize for resistance against fall armyworm on fodder maize were conducted on the farm of All India Coordinated Research Project on Forage Crops and Utilization, Mahatma Phule Krishi Vidyapeeth, Rahuri, during the *Kharif,* 2023. The results of these experiments are presented and discussed in this chapter:

4.1 Effect of different biopesticides and intercrops against *Spodoptera frugiperda* on fodder maize

The data pertaining to effect of different biopesticides and intercropping treatments on per cent plant infestation due to *S. frugiperda* are presented in Table 4.1. It reveals that per cent plant infestation before the application of biopesticides (pre-count) ranged between 49.73 to 60.56 per cent and were statistically significant due to effect of intercropping with legumes from sowing.

4.1.1 First application

At 3 days after first spray, the range of per cent plant infestation due to *S. frugiperda* was 44.25 to 61.93 %. The data indicated that all biopesticides and intercropping treatments were significantly superior over untreated control in reducing per cent plant infestation due to fall armyworm. The treatment with azadirachtin (10000 ppm) was the most promising treatment with lowest per cent plant infestation (44.25 %). Next promising treatments in order of their merit were, *M. anisopliae* @ 5 g/L (50.03 %), NSKE 5% @ 50 g/L (51.03 %) and intercropping of maize with field bean (1:1) (52.25 %) which were at par with each other. Intercropping of maize with cowpea (1:1) (53.32 %), *B. bassiana* @ 5g/L (54.61 %), pongamia oil 3 % @ 3ml/L (54.68 %) and EPN *Heterorhabditis indica* @ 5g/L (55.27 %) were next in order of effectiveness and were at par with each other. This was followed by intercropping of maize with bajara (1:1) (57.34 %). However, untreated control recorded maximum per cent infestation (61.93 %).

At 7 days after first spray, the treatment with *M. anisopliae* @ 5 g/L (36.11 %) was superior and was at par with *B. bassiana* @ 5g/L (39.14 %) as against untreated control (63.02). Next promising treatments in order of their effectiveness were azadirachtin (10000 ppm) (43.07 %) and NSKE 5% @ 50 g/L (44.40 %) which were at par with each other. Pongamia oil 3% @ 3ml/L (48.37%) and EPN *Heterorhabditis indica* @ 5g/L (50.05%) were next in order of effectiveness and being at par with each other. This was followed by intercropping of maize with field bean (1:1) (54.95%), intercropping of maize with cowpea (1:1) (55.32 %) and intercropping of maize with bajara (1:1) (58.34 %) were next in order.

Table 4.1 Evaluation of biopesticides and intercrops against *Spodoptera frugiperda* on fodder maize (first spray)

Treatment No	Treatment details	Dose g or ml/L	Per cent plant infestation				
			Precount	3 DAS	7 DAS	10 DAS	Mean
T_1	*Metarhizium anisopliae* (1×10^8cfu/g) 1.15% WP	5 g	57.71 (49.44)	50.03 (45.02)	36.11 (36.93)	20.05 (26.59)	35.40 (36.18)
T_2	Neem Seed Kernel Extract 5%	50 g	58.01 (49.61)	51.03 (45.59)	44.40 (41.78)	47.76 (43.71)	47.73 (43.69)
T_3	*Beauveria bassiana* (1×10^8cfu/g) 1.15% WP	5 g	59.58 (50.53)	54.61 (47.65)	39.14 (38.72)	24.15 (29.43)	39.30 (38.60)
T_4	Azadirachtin (10000 ppm)	2 ml	58.40 (49.84)	44.25 (41.69)	43.07 (41.01)	46.62 (43.06)	44.65 (41.92)
T_5	Pongamia oil 3% EC	3 ml	60.20 (50.89)	54.68 (47.69)	48.37 (44.07)	50.27 (45.16)	51.11 (45.64)
T_6	EPN *Heterorhabditis indica* ($1x10^8$ IJs/ac)	5 g	60.56 (51.10)	55.27 (48.02)	50.05 (45.03)	55.26 (48.03)	53.53 (47.03)
T_7	Intercrop cowpea (1:1 row)	–	51.23 (45.70)	53.32 (46.91)	55.32 (48.06)	56.35 (48.65)	55.00 (47.87)
T_8	Intercrop field bean (1:1 row)	–	49.73 (44.85)	52.25 (46.29)	54.95 (47.85)	55.69 (48.27)	54.30 (47.47)
T_9	Intercrop bajara (1:1 row)	–	55.10 (47.93)	57.34 (49.23)	58.34 (49.81)	59.54 (50.51)	58.41 (49.85)
T_{10}	Untreated control	–	59.70 (50.60)	61.93 (51.93)	63.02 (52.58)	66.01 (54.37)	63.66 (52.96)
S.E.(m)±			0.43	0.58	0.60	0.68	0.62
CD at 5%			1.29	1.71	1.80	2.03	1.85
CV %			7.27	8.20	8.66	9.13	8.66

Figures in the parentheses are arc sin transformed values.   DAS: Days after spraying

The effect of biopesticides and intercropping treatments at 10 days after spraying revealed that again *M. anisopliae* @ 5 g/L proved its superiority against plant infestation due to *S. frugiperda* (20.05 %). It was followed by *B. bassiana* @ 5g/L (24.15 %). Next effective treatments in order of their effectiveness were azadirachtin (3000 ppm) (46.62 %) and NSKE 5 % @ 50 g/L (47.76 %) which were at par with each other followed by pongamia oil 3 % @ 3ml/L (50.27 %). The rest of the treatments *viz.,* EPN *Heterorhabditis indica* @ 5g/L, intercropping of maize with field bean (1:1), intercropping of maize with cowpea (1:1) and intercropping of maize with bajara (1:1) recorded 55.26 %, 55.69 %, 56.35 % and 59.54 % plant infestation respectively. However, untreated control recorded maximum per cent infestation (66.01 %).

Based on the mean per cent infestation among biorationals, it was found that *Metarhizium anisopliae* @ 5 g/L was the most effective treatment recording lowest infestation (35.40 %) followed by *Beauveria bassiana* @ 5 g/L (39.30 %). Azadirachtin (10000 ppm) (44.65 %) and NSKE 5 % @ 50 g/L (47.73 %) were next in the order, but were at par with each other. This was followed by pongamia oil 3 % @ 3ml/L (51.11 %), EPN *Heterorhabditis indica* @ 5g/L (53.53 %) and intercropping of maize with field bean (1:1) (54.30 %) were next in order of effectiveness and being at par with each other. This was followed by intercropping of maize with cowpea (1:1) (55.00 %) and intercropping of maize with bajara (1:1) recorded (58.41 %). Whereas, untreated control recorded maximum infestation (63.66 %).

4.1.2 Second application

The data recorded on per cent infestation of *Spodoptera frugiperda* per plot after second spray is presented in Table 4.2.

At 3 days after first spray, the range of per cent plant infestation due to *S. frugiperda* was 25.07 to 68.41 %. The treatment with *M. anisopliae* @ 5 g/L was the most promising treatment with lowest per cent plant infestation (25.07 %). Next promising treatments in order of their merit were *Beauveria bassiana* @ 5 g/L (30.30 %), azadirachtin (10000 ppm) (37.40 %) and NSKE 5 % @ 50 g/L (40.82 %). Pongamia oil 3 % @ 3ml/L (48.04 %) and EPN *Heterorhabditis indica* @ 5g/L (50.91 %) which were at par with each other. Intercropping of maize with field bean (1:1) (55.22 %), intercropping of maize with cowpea (1:1) (56.11 %) were next in order of effectiveness and were at par with each other followed by intercropping of maize with bajara (1:1) (60.20 %). However, untreated control recorded maximum per cent infestation (68.41 %).

At 7 days after second spray, the treatment with *M. anisopliae* @ 5 g/L was superior over rest of the treatments by recording (20.15 %) as against untreated control (67.08 %). Next best treatment was *B. bassiana* @ 5g/L (23.16 %). Next promising treatments in order of their effectiveness were azadirachtin (10000 ppm) (33.72 %) and NSKE 5 % @ 50 g/L (36.04 %)

Table 4. 2 Evaluation of biopesticides and intercrops against *Spodoptera frugiperda* on fodder maize (second spray)

Treatment No	Treatment details	Dose g or ml/L	Per cent plant infestation				
			Precount	3 DAS	7 DAS	10 DAS	Mean
T_1	*Metarhizium anisopliae* (1×10^8cfu/g) 1.15% WP	5 g	29.36 (32.80)	25.07 (30.04)	20.15 (26.67)	15.25 (22.98)	20.16 (26.56)
T_2	Neem Seed Kernel Extract 5%	50 g	55.02 (47.88)	40.82 (39.90)	36.04 (36.89)	39.76 (30.09)	39.21 (38.76)
T_3	*Beauveria bassiana* (1×10^8cfu/g) 1.15% WP	5 g	35.24 (36.41)	30.30 (33.29)	23.16 (28.76)	21.23 (27.43)	24.90 (29.86)
T_4	Azadirachtin (10000 ppm)	2 ml	53.04 (46.75)	37.40 (37.70)	33.72 (35.48)	39.83 (39.13)	36.98 (37.43)
T_5	Pongamia oil 3% EC	3 ml	57.71 (49.44)	48.04 (43.88)	40.10 (39.28)	44.82 (42.02)	44.32 (41.73)
T_6	EPN *Heterorhabditis indica* ($1x10^8$ IJs/ac)	5 g	59.40 (50.43)	50.91 (45.52)	43.70 (41.38)	46.79 (43.15)	47.13 (43.35)
T_7	Intercrop cowpea (1:1 row)	–	57.31 (49.21)	56.11 (48.51)	54.00 (47.30)	52.03 (46.16)	54.05 (47.32)
T_8	Intercrop field bean (1:1 row)	–	56.11 (48.51)	55.22 (48.00)	52.23 (46.28)	51.23 (45.70)	52.89 (46.66)
T_9	Intercrop bajara (1:1 row)	–	62.79 (52.42)	60.20 (50.89)	58.11 (49.67)	59.20 (50.31)	59.17 (50.29)
T_{10}	Untreated control	–	67.37 (55.24)	68.41 (55.88)	67.08 (55.00)	67.61 (55.32)	67.70 (55.40)
S.E. (m)±			0.70	0.75	0.64	0.69	0.69
CD at 5%			2.11	2.25	1.90	2.07	2.07
CV %			7.75	8.55	8.35	8.76	8.55

Figures in the parentheses are arc sin transformed values. DAS: Days after spraying which were at par with each other and followed by pongamia oil 3 % @ 3ml/L (40.10 %) and EPN *Heterorhabditis indica* @ 5g/L (43.70 %). This was followed by intercropping of maize with field bean (1:1) (52.23 %), intercropping of maize with cowpea (1:1) (54.00 %) and intercropping of maize with bajara (1:1) (67.08 %) were next in order.

Metarhizium anisopliae @ 5 g/L maintained its superiority even at 10 DAS by recording significantly lowest plant infestation due to *Spodoptera frugiperda* (15.25 %). It was followed by *B. bassiana* @ 5g/L (21.23 %). Next effective treatments in order of their effectiveness were NSKE 5 % @ 50 g/L (39.76 %) and azadirachtin (10000 ppm) (39.83%) which were at par with each other followed by pongamia oil 3 % @ 3ml/L (44.82 %) and EPN *Heterorhabditis indica* @ 5g/L (46.79 %). The rest of the treatments *viz.*, intercropping of maize with field bean (1:1), intercropping of maize with cowpea (1:1) and intercropping of maize with bajara (1:1) recorded 51.23 %, 52.03 % and 59.20 % plant infestation respectively. However, untreated control recorded highest per cent infestation (67.61%).

Based on the mean per cent infestation among biorationals it was found that *Metarhizium anisopliae* @ 5 g/L was the most effective treatment recording lowest infestation (20.16 %) followed by *Beauveria bassiana* @ 5 g/L (24.90 %). Azadirachtin (10000 ppm) (36.98 %) and NSKE 5 % @ 50 g/L (39.21 %) were next in the order, but were at par with each other. This was followed by pongamia oil 3 % @ 3ml/L (44.32 %) and EPN *Heterorhabditis indica* @ 5g/L (47.13 %) which were being at par with each other. The rest of the treatments *viz.*, intercropping of maize with field bean (1:1), intercropping of maize with cowpea (1:1) and intercropping of maize with bajara (1:1) recorded 52.89 %, 54.05 % and 59.17 % plant infestation respectively. Whereas, untreated control recorded maximum infestation (67.70 %).

4.1.3 Cumulative effect of two application

The data on cumulative effect of different treatments on per cent infestation of *Spodoptera frugiperda* per plot ` after three sprays are presented in Table 4.3

Among the biopesticides and intercropping treatments, *Metarhizium anisopliae* @ 5 g/L proved highly effective against *Spodoptera frugiperda* with lowest per cent infestation (27.78 %) per plot which indicates that mycoinsecticide have taken their time for mycosis in first 3 days and actual reduction was observed in 7 to 10 days after spray. It was also noticed that per cent infestation per plot was reduced as increase in the number of sprays progressed, it is due to cumulative effect of fungal pathogen in plot. Thus, mycoinsecticide *Metarhizium anisopliae* @ 5 g/L proved to be the best biointensive option for the suppression of *S. frugiperda* under field conditions. The present findings are in agreement with those of earlier researchers which are Wayal *et al.* (2021) also revealed that *M. anisopliae* @ 50 g/ 10 L was the most effective

Table 4.3 Overall effect of biopesticides and intercrops on *Spodoptera frugiperda* on fodder maize (cumulative mean)

Treatment No	Treatment details	Dose g or ml/L	Per cent plant infestation				
			Precount	3 DAS	7 DAS	10 DAS	Mean
T_1	*Metarhizium anisopliae* (1×10^8cfu/g) 1.15 % WP	5 g	43.53 (41.12)	37.55 (37.53)	28.13 (31.80)	17.65 (24.79)	27.78 (31.37)
T_2	Neem Seed Kernel Extract 5 %	50 ml	56.51 (48.75)	46.42 (42.94)	40.22 (39.34)	43.76 (41.40)	43.47 (41.23)
T_3	*Beauveria bassiana* (1×10^8cfu/g) 1.15 % WP	5 g	47.41 (43.47)	42.45 (40.52)	31.15 (33.74)	22.69 (28.43)	32.10 (34.23)
T_4	Azadirachtin (10000 ppm)	2 ml	55.72 (48.30)	40.82 (39.69)	38.39 (38.25)	43.23 (41.09)	40.81 (39.68)
T_5	Pongamia oil 3 % EC	3 ml	58.95 (50.17)	51.36 (45.78)	44.23 (41.68)	47.55 (43.59)	47.71 (43.68)
T_6	EPN *Heterorhabditis indica* ($1\text{x}10^8$ IJs/ac)	5 g	59.98 (50.76)	53.09 (46.77)	46.88 (43.20)	51.03 (45.59)	50.33 (45.19)
T_7	Intercrop cowpea (1:1 row)	…..	54.27 (47.46)	54.72 (47.71)	54.66 (47.68)	54.19 (47.41)	54.52 (47.60)
T_8	Intercrop field bean (1:1 row)	…..	52.92 (46.68)	53.73 (47.14)	53.59 (47.06)	53.46 (46.99)	53.59 (47.06)
T_9	Intercrop bajara (1:1 row)	…..	58.94 (50.18)	58.77 (50.06)	58.22 (49.74)	59.37 (50.41)	58.79 (50.07)
T_{10}	Untreated control	…..	63.54 (52.92)	65.17 (53.91)	65.05 (53.79)	66.81 (54.85)	65.68 (54.18)
S.E. (m)±			0.57	0.67	0.62	0.69	0.66
CD at 5 %			1.70	1.98	1.85	2.05	1.96
CV %			7.51	8.38	8.51	8.95	8.61

Figures in the parentheses are arc sin transformed values. DAS: Days after spraying.

biopesticide in reducing the plant damage (57.04 %) due to *S. frugiperda.* 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.

Next superior treatment is *Beauveria bassiana* @ 5 g/L (32.10 %) which is a good biofungicide option for reducing the per cent infestation of *S. frugiperda* in maize under field condition. In addition to the results of mycoinsecticide the present experiment were in conformity with the results of Shinde *et al*. (2021) under field conditions. It was observed in the present research that there was decrease in per cent infestation of pest through improved pathogenicity at successive sprays which may be due to cumulative effect of fungal pathogen.

Next effective treatments were azadirachtin (10000 ppm) (40.81 %) and NSKE 5 % @ 50 g/L (43.47 %) but were at par with each other and followed by pongamia oil 3 % @ 3ml/L (47.71 %) and EPN *Heterorhabditis indica* @ 5g/L (50.33 %) found to be moderately effective. Inter cropping with legumes such as field bean (53.59 %), cowpea (54.52 %), shows that it helps to reduce fall armyworm infestation than sole maize, also it increased the natural enemies population such as coccinellids, spiders in maize. While, inter cropping with bajara (58.79 %) was least effective treatment with heavy infestation after untreated control (65.68 %).

4.1.4 Fodder yield of maize

The results pertaining to the marketable fodder yield of maize are presented in Table 4.4. The effectiveness of the different treatments was reflected in yield. All the biopesticidal treatments were found superior over untreated control in terms of the yield. The data recorded that the treatment *Metarhizium anisopliae* @ 5 g/L represents highest yield of 468 q/ha with maximum (61.37 %) increase in the yield over control and superior over all other treatments. It was followed by *Beauveria bassiana* @ 5 g/L (455 q/ha) and azadirachtin (10000 ppm) @ 2 ml/L (435 q/ha) and NSKE 5 % @ 50 g/L (427q/ha) recorded with 56.89 %, 50.00 % and 47.24 % increase in fodder yield over control.

Based on yield registered by different treatments, the sequence in descending order was given below:

Metarhizium anisopliae @ 5 g/L > *Beauveria bassiana* @ 5 g/L > Azadirachtin (10000ppm) > NSKE 5 % > Pongamia oil 3 % > EPN *Heterorhabditis indica* > Intercrop field bean (1:1) > Intercrop cowpea (1:1) > Intercrop bajara (1:1).

Table 4.4 Effect of biopesticides and intercrops tested against *S. frugiperda* on fodder yield of maize

Tr. No	Treatment details	Dose g or ml/lit	Green fodder yield		(%) Percent increase in yield over control
			Kg/plot	q/ha	
T_1	*Metarhizium anisopliae* (1×10^8cfu/g) 1.15% WP	5 g	74.88	468	61.37
T_2	Neem Seed Kernel Extract 5%	50 g	68.32	427	47.24
T_3	*Beauveria bassiana* (1×10^8cfu/g) 1.15% WP	5 g	72.82	455	56.89
T_4	Azadirachtin (10000 ppm)	2 ml	69.60	435	50.00
T_5	Pongamia oil 3% EC	3 ml	65.28	408	40.68
T_6	EPN *Heterorhabditis indica* ($1x10^8$ IJs/ac)	5 g	63.84	399	37.58
T_7	Intercrop cowpea (1:1 row)	_	60.16	376	29.65
T_8	Intercrop field bean (1:1 row)	–	61.60	385	32.75
T_9	Intercrop bajara (1:1 row)	–	49.76	311	7.24
T_{10}	Untreated control		46.40	290	_
	S.E. (m)±		0.41	3.42	–
	CD at 5%		1.24	10.20	–

The results of present investigations are in confirmatory with results of Ramanujam *et al.* (2020) reported that *M. anisopliae* ICAR-NBAIR Ma 35 strain with 70 % reduction in per cent infestation and 44 increase in yield. Also, Lakshmi *et al*. (2011) reported that *Metarhizium anisopliae* could be a good plant yield promoter by increasing the yield of 45 % more aside from the pest management. 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* (567 q/ha).

4.1.5 Incremental Cost-Benefit Ratio

The data pertaining to effect of different biopesticides and intercrops on fodder yield of maize is presented in Table 4.5 which was assessed through net profit and incremental cost benefit ratio (ICBR).

The cost of control of *Spodoptera frugiperda* of maize due to various biopesticides varied from Rs. 3535 to 4685/ha, which include cost of biopesticides and labour charges for 2 sprays. The highest protection cost per ha was observed in the treatment EPN *Heterorhabditis indica* @ 5g/L, while minimum cost in the treatment pongamia oil 3 % @ 3ml/L.

The highest additional yield (178 q/ha) over untreated control was recorded due to application of *Metarhizium anisopliae* @ 5 g/L. Whereas, inter cropping with bajara (1:1) recorded least (21 q/ha) additional yield over control.

The highest incremental cost benefit ratio (1:10.00) was recorded in the treatment with spraying of *Metarhizium anisopliae* @ 5 g/L. The next best treatment in order of ICBR was treatment with *Beauveria bassiana* @ 5 g/L which recorded 1: 9.19 ICBR. The treatment with spraying of EPN *Heterorhabditis indica* @ 5g/L recorded lowest ICBR *i.e* 1: 4.11. Based on ICBR registered by different treatments, the sequence in descending order was given: *Metarhizium anisopliae* @ 5 g/L > *Beauveria bassiana* @ 5 g/L > NSKE 5 % > Azadirachtin (10000 ppm) > Pongamia oil 3 % > EPN *Heterorhabditis indica.*

The results of present study in respect of ICBR of fodder yield are in corroboration with many early workers. Shinde *et al*. (2021) reported that *M. anisopliae* @ 2.5 kg/ha and *B. bassiana* @ 2.5 kg/ha recorded the ICBR of 1:5.9 and 1:2.9 respectively.

Table 4.5 Incremental cost benefit ratio of different biopesticides and intercrops against maize fall armyworm.

Tr. No	Treatment details	Maize fodder yield q/ha	Additional yield over control q/ha (A)	Additional income over control Rs/ha (A)	Cost of treatment Rs/ha (B)	Total cost of cultivation Rs/ha	Gross monitory return Rs/ha	Net returns Rs/ha (C)	B:C ratio	ICBR (C/B)
T_1	*Metarhizium anisopliae* (1×10^8cfu/g) 1.15 % WP	468	178	39160	3560	40610	102960	35600	2.53	10.00
T_2	Neem Seed Kernel Extract 5%	427	137	30140	3810	40860	93940	26330	2.29	6.91
T_3	*Beauveria bassiana* (1×10^8cfu/g) 1.15 % WP	455	165	36300	3560	40610	100100	32740	2.46	9.19
T_4	Azadirachtin (10000 ppm)	435	145	31900	4154	41204	95700	27746	2.32	6.67
T_5	Pongamia oil 3 % EC	408	118	25960	3535	40585	89760	22425	2.13	6.34
T_6	EPN *Heterorhabditis indica* (1x10^8 IJs/ac)	399	109	23980	4685	41735	87780	19295	2.10	4.11
T_7	Intercrop cowpea (1:1 row)	376	86	18920	–	37050	82720	–	2.23	–
T_8	Intercrop field bean (1:1 row)	385	95	20900	–	37050	84700	–	2.28	–
T_9	Intercrop bajara (1:1 row)	311	21	4620	–	36605	68420	–	1.86	–
T_{10}	Untreated control	290	0	0	0	37050	63800	–	1.72	–

Market price: Selling price of maize fodder Rs. 220/ q

Cost of cultivation of fodder maize Rs. 37050/ ha

Table 4.6 Details of cost of plant protection used in different treatments

Treatment No.	Treatment details	Dose	Quantity of pesticide kg/ha	Rate (Rs)	Cost of insecticide (Rs/ha)	Labour charges (Rs.320/day)	Cost of treatment (Rs)
T_1	*Metarhizium anisopliae* (1×10^8cfu/g) 1.15 % WP	5 g	2.5 kg	200/kg	1000	2560	3560
T_2	Neem Seed Kernel Extract 5 %	50 g	25 kg	50/kg	1250	2560	3810
T_3	*Beauveria bassiana* (1×10^8cfu/g) 1.15 % WP	5 g	2.5 kg	200/kg	1000	2560	3560
T_4	Azadirachtin (10000 ppm)	2 ml	1 lit	1594/kg	1594	2560	4154
T_5	Pongamia oil 3 % EC	3 ml	1.5 lit	650/lit	975	2560	3535
T_6	EPN *Heterorhabditis indica* ($1x10^8$ IJs/ac)	5 g	2.5 kg	850/kg	2125	2560	4685
T_7	Intercrop cowpea (1:1 row)	_	–	–	–	–	–
T_8	Intercrop field bean (1:1 row)	–	–	–	–	–	–
T_9	Intercrop bajara (1:1 row)	–	–	–	–	–	–
T_{10}	Untreated control	–	–	–	–	–	–

4.2 Screening of Promising Genotypes of Maize for Resistance against Fall Armyworm on Fodder Maize.

The results pertaining to leaf damage due to *S. frugiperda* on 44 maize genotypes are depicted in Table 4.7 and Fig.4.5. The results revealed that there was a significant difference among the genotypes in leaf damage by *S. frugiperda*, which are expressed in leaf damage score.

4.2.1 15 days after sowing

At 15 days after sowing, the leaf damage score ranged from 2.04 to 6.90 leaf injury rating due to fall armyworm. Among 44 maize genotypes screened, the minimum leaf damage score 2.04 recorded in JC-1463-1, IGFM-1, IGFM-5, IGFM-15 and MFM-22-2 which shows that they were resistant against fall armyworm. While, IGFM-11 (6.90) recorded maximum leaf damage score which shows that it was susceptible.

Next effective maize genotypes during first 15 days of sowing were MFM-18-9 (2.39), African Tall (2.40), MFM-22-4 (2.60), MFM-316 (2.70), IGFM-4 (2.88) and IGFM-8 (2.90) which were at par with each other and categorized as resistant genotypes. The rest of the genotypes ranged between 4 to 5 leaf damage score recorded as moderately resistant while genotypes MFM-22-3 (6.50) and IGFM-11(6.90) observed as susceptible.

4.2.2 30 days after sowing

On the basis of visual symptoms according to leaf injury rating scale, at 30 days after sowing, the leaf damage score ranged from 4.20 to 9.91 due to fall armyworm. Among 44 maize genotypes screened, the minimum leaf damage score recorded in African tall which was significantly superior over the rest of the genotype with leaf damage score 4.20 which shows that it was moderately resistant against fall armyworm. While, PML-243 (9.91) recorded maximum leaf damage score which shows that it was highly susceptible.

Next effective maize genotypes during first 30 days of sowing were MFM-18-9 (5.70) and IGFM-22 (5.88) which were at par with each other and categorized as moderately resistant genotypes. This was followed by the genotypes ranged between 6 to 7 leaf damage score recorded as susceptible which were listed as: IGFM-14 (6.20), JC-1463-1 (6.57), MFM-18-9 (5.70), MFM-18-9 (5.70), MFM-18-9 (6.57), JH-17028 (6.72), MFM-22-2 (6.88), MFM-22-4 (6.88) and JC-1465 (6.93). The remaining genotypes categorized as highly susceptible in natural condition.

4.2.3 45 days after sowing

At 45 days after sowing, the leaf damage score ranged from 5.04 to 9.89 due to fall armyworm. Among 44 maize genotypes screened, the minimum leaf damage score recorded in African Tall which was superior over the rest of the genotype with leaf damage score 5.04

Table 4.7 Response of maize genotypes to *S. frugiperda* based on leaf injury rating scale.

Sr. No	Genotype	Leaf damage score per plant			Mean	Reaction
		15 DAS	30 DAS	45 DAS		
1	JC-1455-1	3.75	8.90	8.40	7.02	S
2	PFM-12	3.13	7.88	7.43	6.14	S
3	JH-20088	4.00	8.99	8.00	7.00	S
4	JC-1465	3.27	6.93	6.53	5.58	MR
5	JH-17028	3.08	6.72	6.34	5.38	MR
6	JH-19014	4.99	7.62	6.24	6.28	S
7	JC-1463-1	2.04	6.57	7.00	5.20	MR
8	PML-368	5.40	9.82	9.32	8.18	HS
9	PML-81	3.45	8.88	7.43	6.58	S
10	JC-4	4.03	8.77	7.33	6.71	S
11	PML-1230	4.70	9.51	8.90	7.70	S
12	PML-243	5.22	9.91	8.90	8.01	HS
13	J-1007	3.78	7.88	7.43	6.36	S
14	IGFM-1	2.04	6.57	7.00	5.20	MR
15	IGFM-2	3.89	9.88	8.43	7.40	S
16	IGFM-3	4.90	9.70	8.77	7.79	S
17	IGFM-4	2.88	7.80	7.73	6.14	S
18	IGFM-5	2.04	6.57	7.00	5.20	MR
19	IGFM-6	4.89	9.72	8.22	7.61	S
20	IGFM-7	5.98	9.80	9.89	8.56	HS
21	IGFM-8	2.90	7.90	7.61	6.13	S
22	IGFM-9	4.95	9.88	8.80	7.88	S
23	IGFM-10	3.89	9.88	8.43	7.40	S
24	IGFM-11	6.90	9.70	9.89	8.83	HS
25	IGFM-12	5.70	9.81	9.02	8.17	HS
26	IGFM-13	4.41	8.19	8.72	7.11	S
27	IGFM-14	5.61	6.20	5.84	5.88	MR
28	IGFM-15	2.04	6.57	7.00	5.20	MR
29	IGFM-16	4.99	9.51	9.61	8.04	HS
30	IGFM-17	3.78	8.30	8.82	6.97	S
31	IGFM-18	4.20	9.70	8.90	7.60	S
32	IGFM-19	3.50	9.88	8.66	7.35	S
33	IGFM-20	4.90	8.80	8.82	7.51	S
34	IGFM-21	3.90	9.70	8.77	7.46	S
35	IGFM-22	5.32	5.88	5.54	5.58	MR
36	IGFM-23	5.60	9.69	9.80	8.36	HS
37	MFM-22-4	4.87	9.30	8.82	7.66	S
38	MFM-18-2	5.60	9.50	9.88	8.33	HS
39	MFM-22-3	6.50	8.61	8.12	7.74	S
40	MFM-18-9	2.39	5.70	6.60	4.90	MR
41	MFM-316	2.70	7.88	7.00	5.86	MR
42	MFM-22-2	2.04	6.88	7.88	5.60	MR
43	MFM-22-5	2.60	6.88	7.88	5.79	MR
44	African Tall	2.40	4.20	5.04	4.33	MR
S.E.(m) ±		0.13	0.14	0.27	0.18	…
CD at 5%		0.39	0.42	0.77	0.53	…
CV %		8.44	10.40	11.65	10.16	…

DAS: Days after sowing, MR: Moderately Resistant, S: Susceptible, HS: Highly Susceptible which shows that it was moderately resistant against fall armyworm. However, IGFM-11 (9.89) recorded maximum leaf damage score which shows that it was highly susceptible. This was followed by the genotypes African Tall (5.70), JC-1463-1 (5.84) and JH-19014 (6.24) which were at par with each other. The rest of the genotypes categorized as susceptible and highly susceptible in natural condition.

4.2.4 Mean leaf damage score

The mean leaf damage score of the maize genotypes based on the 1 to 9 Davis scale was ranged from 4.33 to 8.83 and differed markedly from each other. Among 44 genotypes screened, the local variety African tall recorded lowest leaf damage score (4.33) which was used as local check. Among 43 maize genotypes from IGFRI, Jhansi screened with local check, the minimum leaf damage score recorded in MFM-18-9 (4.90) which shows that it was moderately resistant against fall armyworm. While, IGFM-11 (8.83) recorded maximum leaf damage score which shows that it was highly susceptible.

The next effective genotypes were JC-1463-1 (5.20), IGFM-1 (5.20), IGFM-5 (5.20), IGFM-15 (5.20) and JH-17028 (5.38) which were statistically at par with MFM-18-9 (4.90). This was followed by JC-1465 (5.58), IGFM-22 (5.58), MFM-22-2 (5.60), MFM-22-4 (5.79), MFM-316 (5.86) and IGFM-14 (5.88) which were statistically at par with each other.

The remaining mean leaf damage score of maize genotypes in Ascending order was: IGFM-8 (6.13), IGFM-4 (6.14), PFM-12 (6.14), JH-19014 (6.28), J-1007 (6.36), PML-81 (6.58), JC-4 (6.71), IGFM-17 (6.97), JH-20088 (7.00), JC-1455-1 (7.02), IGFM-13 (7.11), IGFM-19 (7.35), IGFM-2 (7.40), IGFM-10 (7.40), IGFM-21 (7.46), IGFM-20 (7.51), IGFM-18 (7.60), IGFM-6 (7.51), MFM-22-4 (7.66), PML-1230 (7.70), MFM-22-3 (7.74), IGFM-3 (7.79) and IGFM-9 (7.88) which ranged between 6.13 to 7.88 categorized under susceptible.

The next maize genotypes PML-243 (8.01), IGFM-16 (8.04), IGFM-12 (8.17), PML-368 (8.18), MFM-18-2 (8.33), IGFM-23 (8.36) and IGFM-7 (8.56) were categorized under highly susceptible condition which ranged between 8.01 to 8.83 leaf damage score.

Among 43 genotypes screened, the mean leaf damage score ranged between 4.90 to 8.83 of which MFM-18-9 (4.90) was considered as best genotype against *S. frugiperda*. 13 genotypes had mean leaf injury rating ranging from 4 to 5 which was considered as moderately resistant to *S. frugiperda.* Whereas, 23 genotypes had mean leaf injury rating ranged from 6 to 7 *i.e.* susceptible to *S. frugiperda*. 8 genotypes had mean leaf injury rating ranged from 8 to 9 *i.e.* highly susceptible to *S. frugiperda.* Thus, all the genotypes grouped as shown in Table 4.8 and depicted in Fig 4.5.

Based on the above results, it was clear that the leaf damage began to increase from 15 days after sowing (V4 leaf stage) and the most susceptible plant stage was 30 days after sowing

Table 4.8 Classification of maize genotypes on the basis of leaf damage score according to Davis and Williams scale.

Sr. No.	Genotypes	Davis Scale	Category	No. of Genotype
1	Nil	1	Highly Resistant	0
2	Nil	2-3	Resistant	0
3	JC-1465, JH-17026, JG-1463-1, IGFM-1, IGFM-5, IGFM-14, African tall, IGFM-15, IGFM-22, MFM-18-9, MFM-316, MFM-22-2, MFM-22-5.	4-5	Moderately Resistant	13
4	JC-1455-1, PFM-12, JH20088, JH-19014, PML-81, JC-4, PML-1230, J-1007, IGFM2, IGFM-3, IGFM-4, IGFM-6, IGFM-8, IGFM-9, IGFM-10, IGFM-16, IGFM-17, IGFM18, IGFM-19, IGFM-20, MFM-22-4, MFM-18-2, IGFM-13.	6-7	Susceptible	23
5.	PML-368, PML-243, IGFM-7, IGFM-11, IGFM-12, IGFM-16, IGFM-23, MFM-18-2.	8-9	Highly Susceptible	8

when plants were more succulent and the larval stage progresses. This suggested that there might be a significant relationship between the number of larvae surviving on plants and the amount of leaf damage caused.

The present findings were in accordance with Wiseman *et al*. (1981), who reported that more larvae survived after 20 days of sowing. The less severe damage in moderately resistant genotypes might be attributable to either antixenosis or antibiosis mechanisms. Similar results were also reported by Paul and Deole (2020) when they screened maize genotypes against fall armyworm. The genotype DKC-9190 had the lowest leaf damage score of 2.36 indicating that it was resistant. While, the NK-30 had the highest leaf damage score of 8.21 indicating that it was highly susceptible. Matova *et al*. (2022) also confirmed that the maximum foliar damage due to fall armyworm was observed four weeks after crop emergence.

5. SUMMARY AND CONCLUSION

5.1 Summary

The studies on non-chemical management of fall armyworm, *Spodoptera frugiperda* (J.E. Smith) on fodder maize and screening of promising genotypes of maize for resistance against fall armyworm on fodder maize were conducted on the farm of All India Coordinated Research Project on Forage Crops and Utilization, Mahatma Phule Krishi Vidyapeeth, Rahuri, during *Kharif* 2023. The findings of these studies are summarized and concluded in this chapter.

5.1.1 Non-chemical Management of Fall Armyworm on Fodder Maize

The treatments consist of spraying of different bio-pesticides were given at 15 days interval as pest appearance after 30 days after sowing. Among the biopesticides and intercropping treatments against fall armyworm, data revealed that spraying of *Metarhizium anisopliae* @ 5 g/L was the most effective in reducing the per cent plant infestation (27.78 %) due to fall armyworm followed by *Beauveria bassiana* @ 5 g/L (32.10 %).

Next effective treatments were azadirachtin (10000 ppm) (40.81 %) and NSKE 5 % @ 50 g/L (43.47 %) but were at par with each other and followed by pongamia oil 3 % @ 3ml/L (47.71 %) and EPN *Heterorhabditis indica* @ 5g/L (50.33 %) found to be moderately effective. Intercropping with legumes such as field bean (53.59 %), cowpea (54.52 %) shows that it helps to reduce fall armyworm infestation than sole maize. While, intercropping with bajara (58.79 %) was least effective treatment with heavy infestation after untreated control (65.68 %).

5.1.1.1 Fodder yield of maize

In the present investigation difference in the effectiveness of various treatments was reflected in the fodder yield of maize which ranged between 290 to 468 q/ha. The treatment *Metarhizium anisopliae* @ 5 g/L recorded maximum yield of 468 q/ha with 61.37 per cent higher yield over control, followed by *Beauveria bassiana* @ 5 g/L with yield 455 q/ha.

5.1.1.2 Incremental Cost-Benefit Ratio

The data further revealed that *Metarhizium anisopliae* @ 5 g/L emerged as the most economical recording highest ICBR 1:10.00 followed by *Beauveria bassiana* @ 5 g/L recording ICBR of 1:9.19. The treatment with spraying of EPN *Heterorhabditis indica* @ 5g/L recorded lowest ICBR (1: 4.11) among biopesticides.

5.1.2 Screening of Promising Genotypes of Maize for Resistance against Fall Armyworm on Fodder Maize

The resistance of maize genotypes against fall armyworm was studied by screening genotypes under field conditions. Fourty-three maize genotypes were collected from ICAR-Indian Grassland and Fodder Research Institute, Jhansi was screened with local check African Tall. The mean leaf damage score of 15, 30 and 45 days after sowing the maize genotypes based on the 1 to 9 Davis scale ranged from 4.33 to 8.83. Among 43 maize genotypes from IGFRI, Jhansi screened with local check, the minimum leaf damage score recorded in MFM-18-9 (4.90) which shows that it is moderately resistant against fall armyworm. While, IGFM-11 (8.83) recorded maximum leaf damage score which shows that it was highly susceptible.

5.2 Conclusion

1. Studies on non-chemical management of fall armyworm proved that, the lowest per cent leaf infestation was recorded in *Metarhizium anisopliae* @ 5 g/L among all the treatment and it was significantly superior over all the treatments followed by *Beauveria bassiana* @ 5 g/L.
2. Intercropping with legumes shows that it helps to reduce FAW infestation than sole maize, While, intercropping with bajara was least effective treatment with heavy infestation after untreated control.
3. Effectiveness of various treatments was reflected in fodder yield of maize which ranged between 290 to 468 q/ha. The treatment with *Metarhizium anisopliae* @ 5 g/L recorded maximum yield followed by *Beauveria bassiana* @ 5 g/L and azadirachtin (10000 ppm)
4. The highest ICBR ratio was registered by *Metarhizium anisopliae* @ 5 g/L followed by *Beauveria bassiana* @ 5 g/L and NSKE 5 %, while EPN had lowest ICBR.
5. Among the 43 maize genotypes screened with local check, MFM-18-9 shows minimum leaf damage score with 4.90 which shows that it was moderately resistant and 13 genotypes had mean leaf injury rating ranged from 4 to 5 which was considered as moderately resistant to *S. frugiperda* which can be further used for advance research in breeding programmes.
6. It may be concluded that, biopesticide like *M. anisopliae*, intercropping with legumes and use of resistant variety can be most effective strategy for management of fall armyworm.

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7. VITAE

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MASTER OF SCIENCE (AGRICULTURE)

IN

ENTOMOLOGY

2025

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