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Research article

Efficacy of chemicals, botanicals and biopesticides against fall armyworm (*Spodoptera frugiperda*) on fodder maize (*Zea mays* L.)

Sandip Landge[1], Harpreet K. Cheema[2], Arabinda Dhal[3], N. R. Bhardwaj[4], N. S. Kulkarni[5], Ashlesha Atri[2*], Subhash Chand[6*], Ajoy Kumar Roy[6] and Vijay Kumar Yadav[6]

[1]Mahatma Phule Krishi Vidyapeeth, Rahuri-413722, India
[2]Punjab Agricultural University, Ludhiana-141004, India
[3]Odisha University of Agriculture and Technology, Bhubaneswar-751003, India
[4]ICAR-Indian Institute of Rapeseed-Mustard Research, Bharatpur-321303, India
[5]ICAR-Indian Grassland and Fodder Research Institute, Regional Research Station, Dharward-580005, India
[6]ICAR-Indian Grassland and Fodder Research Institute, Jhansi-284003, India
[*]Corresponding author email: ashlesha-atri@pau.edu, subhashchand5415@gmail.com

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Abstract

The efficacy of selected chemicals, botanicals and biopesticides against fall armyworm (FAW; *Spodoptera frugiperda*) on fodder maize var. African Tall was conducted from 2019 to 2021 at five locations in India. The pooled data revealed that at 3 days after spraying, the FAW population was lowest (16.53% infestation of plants) in T1 treatment (Emamectin benzoate 5 SG @ 5 ml/10 L of water), significantly superior to the rest of the treatments. In addition, the other best treatments were T2 (chlorpyriphos 20 EC @ 20 ml/10 L; 26.36%) followed by T8 (*Metarhizium rileyi* (Nomuraea) 1.15% WP@ 75 g/10 L; 30.73%), T4 (*M. anisopliae* 1.15% WP @ 75 g/10 L; 31.30%), T6 (*Beauveria bassiana* 1.15% WP@ 75 g/10 L; 32.13%), and T5 (*B. bassiana* 1.15% WP@ 50 g/10 L; 32.96%). Moreover, a similar trend was observed at 7 and 10 days after spraying. The highest green fodder yield (GFY; 37.49 t/ha) was recorded in treatment T1 as compared to the control (22.42 t/ha). Likewise, T1 was the best economical treatment (BC ratio: 1:1.55), followed by T2 (BC ratio: 1:1.31) and T8 (BC ratio: 1:1.23).

Keywords: Biopesticides, Botanicals, Fall armyworm, Fodder maize, *Spodoptera frugiperda.*

Introduction

Maize (*Zea mays* L.) belongs to the grass family Poaceae and originated in central Mexico. High productivity and versatile growth habits make it popular globally. Being a C_4 plant, it has a high growth rate and productivity (Halli *et al.*, 2023). Globally, maize is grown in an area of 203.5 million hectares, with a maize kernel production of 1163.5 million tonnes and a productivity of 5.72 tonnes per hectare (FAO, 2023). Maize is a multipurpose crop consumed globally as a food, fodder and feed. It covers around 11 Mha area in India, producing 34.6 MMT in 2023–24. The kernel is mainly consumed as food in Rajasthan, Gujarat, Himachal Pradesh, Bihar and the Union territory of Jammu and Kashmir, predominantly by the tribal populations (Yatish *et al*., 2024; Das *et al.*, 2025). Besides, it is widely used as fodder and feed, hay and silage, and a potential bioenergy source (Anonymous, 2022). Biotic and abiotic factors adversely affect crop productivity, and their severity varies with agroclimatic conditions and host-pathogen relationships. There are 141 insect pests causing damage with different levels of seriousness to maize at various stages from sowing to harvesting to storage; however, about a dozen are more severe and must be controlled on time to avoid heavy losses (Reddy and Trivedi, 2008; Kumar *et al*., 2015). Amongst the introduced pests, the fall armyworm (FAW; *Spodoptera frugiperda*) is a serious threat globally owing to its polyphagous, notorious and invasive behavior. FAW is native to tropical and sub-tropical America and was recognized as a pest in the USA long ago, in 1797. In India, FAW was first reported as an invasive pest by Sharanabasappa *et al*. (2018). It affects the crop at all phenological phases, from seedling to ear development. FAW larvae feed on opening leaves by scraping and skeletonizing the top epidermis, resulting in a silvery translucent membrane and papery patches. Pinhole symptoms appear on the leaves as a result of the injury. Late instar damage (3rd instar onwards) causes severe defoliation of leaves as well as the appearance of vast fecal pellets in whorls (Reddy *et al*., 2021; Kulkarni *et al*., 2023). The development and survival of FAW larvae vary with the host.

FAW moth populations can migrate so quickly- nearly 500 km before laying eggs and approximately 100 km every night- they may swiftly encroach on new places overnight (Johnson, 1987). The pest's life cycle is around 30 to 45 days, depending on climatic circumstances. The life cycle may last up to 60 to 90 days in cool climates. The mother moth lays nearly 1500 eggs on the attached leaves. In warmer climates, the egg stage lasts for two or three days. Generally, FAW passes through six larval instars, or stages, before pupating. Depending on the weather, particularly the humidity and temperature, the larval stage lasts between 14 and 30 days (Manjula *et al*., 2019). Extensive use of chemical pesticides has resulted in widespread insect resistance to pesticides and adverse effects on beneficial insects, soil properties, wildlife and human health worldwide. In contrast, using biopesticides to control pests is an ideal alternative as they have long-term effects without harming the environment or animals. Therefore, the experiment was conducted to test the efficacy of different doses of chemicals, microbial biopesticides, and one botanical to control the FAW under field conditions.

Materials and Methods

***Experimental sites*:** The on-field experiment was conducted at five different agro-climatic locations, *viz*., Mahatma Phule Krishi Vidyapeeth (MPKV), Rahuri; ICAR-Indian Grassland and Fodder Research Institute (IGFRI), Jhansi and its southern regional research station (IGFRI-SRRS), Dharwad; Punjab Agricultural University (PAU), Ludhiana; and Odisha University of Agriculture and Technology (OUAT), Bhubaneswar, under the ICAR-All India Coordinated Research Project on Forage Crops & Utilization (AICRP FCU) during the *Kharif* seasons of the years 2019, 2020 and 2021. Four centers (MPKV, IGFRI, IGFRI-SRRS, and PAU) are located in semi-arid regions of India where annual rainfall falls between 25 and 50 cm. However, the OUAT center falls under a tropical savanna climate, characterized by high temperatures, high humidity, and distinct dry and wet seasons.

Field experimentation and treatments: The field experiment was conducted to evaluate the comparative efficacy of selected chemicals, botanicals, and biopesticides against fall armyworm on maize. The experiment followed a randomized complete block design (RCBD) with ten treatments and three replications (Table 1). Maize variety African Tall was sown, with a spacing of 30 cm between two rows and 10 cm within the row and a net area of 4.0 x 3.0 m. All the standard agronomical practices, except pest control measures, were followed to raise the proper plant stand. The first spray was applied when the larval population reached the economic threshold level (ETL), and the second spray was applied at 15-day intervals based on pest population.

Recording of FAW and yield parameters: For recording FAW percent infestation counts, the number of infested plants per plot was recorded before spray (precount) and 3, 7 and 10 days after spray. Data was recorded in percent damage. The green fodder yield (GFY) was recorded from each net plot and converted into t/ha. In addition, the benefit-cost ratio of the treatments was calculated to understand the best economic method to manage the FAW infestation in the field.

Data analysis: The data on percent infestation were transformed into arcsin transformation before statistical analysis to determine the significance of differences among the treatments. The data obtained were subjected to statistical analysis after appropriate transformation to draw valid conclusions, as per Steel and Torrie (1980).

Results and Discussion

Evaluation of FAW infestation under different treatments during 2019: The mean data from MPKV–Rahuri, IGFRI–Jhansi and IGFRI RRS–Dharwad locations in *Kharif* 2019 revealed that FAW's pre-count before spray was non-significant (Table 2). At 3 days after

Table 1. Details of selected treatments with their concentrations applied

Code	Treatments	Dose (per 10 L water)
T1	Emamectin benzoate 5 SG	5 g
T2	Chlorpyriphos 20 EC	20 mL
T3	*Metarhizium anisopliae* 1.15% WP (1×10^8 CFU/g)	50 g
T4	*Metarhizium anisopliae* 1.15% WP (1×10^8 CFU/g)	75 g
T5	*Beauveria bassiana* 1.15% WP (1×10^8 CFU/g)	50 g
T6	*Beauveria bassiana* 1.15% WP (1×10^8 CFU/g)	75 g
T7	*Metarhizium rileyi* (*Nomuraea*) 1.15% WP (1×10^8 CFU/g)	50 g
T8	*Metarhizium* (*Nomuraea*) *rileyi* 1.15% WP (1×10^8 CFU/g)	75 g
T9	Azadirachtin 10,000 ppm	20 mL
T10	Untreated Control	--

spray (3 DAS), the lowest FAW infestation was noticed in T1 (16.54%), followed by treatment T2 (28.91%), which was found significantly lower than the control (52.03%). However, the remaining treatments were not significantly different from each other.

Likewise, after seven days of spray (7 DAS), FAW infestation was found to be lowest in T1 (9.70%), significantly superior to the rest of the treatments. In addition, the subsequent best treatment was T8 (20.95%), followed by T7 (21.30%), T2 (22.55%), T5 (24.75%), T6 (24.76%), T4 (26.29%) and T3 (26.68%) in treated plots, respectively, which were statistically at par with each other. Ten days after spraying (10 DAS), the lowest FAW infestation was recorded in treatment T1 (7.16%), followed by treatment T8 (17.22%), both of which were found significantly superior to the untreated control with 53.68% infestation. These treatments were statistically at par with each other (Table 2; Fig 1).

Evaluation of FAW infestation under different treatments during 2020: In 2020, the initial FAW infestation (pre-count) was similar across all experimental sites (MPKV-Rahuri, IGFRI-Jhansi, and PAU-Ludhiana). Three days after spray, the lowest FAW infestation was observed in T1 (13.10%), followed by T2 (21.82%), which were statistically similar. Other treatments showed slightly higher infestation: T8 (25.22%), T7 (26.71%), T4 (26.84%), T6 (27.15%), T3 (27.28%), T9 (28.24%) and T5 (28.41%). These treatments were significantly better than the control (Table 3). Seven days after spray, the lowest FAW infestation was recorded in T1 (9.52 %), followed by T2 (18.57%), T8 (18.99%), T7 (20.37%), T4 (21.13%), T6 (22.62%), T3 (22.65%), T5 (24.23%) and T9 (26.28). These treatments differed significantly from each other (Table 3; Fig 2). Ten days after spray, the lowest FAW infestation was in T1 (6.72 %), followed by T2 (16.68%), T8 (17.44%) and T4 (18.28%) than control (53.45%). The rest of the treatments were significantly at par with each other (Table 3; Fig 2).

Evaluation of FAW infestation under different treatments during 2021: The mean result of three locations, *viz*., MPKV-Rahuri, OUAT-Bhubaneshwar and PAU-Ludhiana in *Kharif* 2021, stated that the pre-count

Table 2. Pooled mean analysis of selected treatments against fall armyworm on maize at three locations during 2019

Treatments*	Plant infestation (%)				GFY (t/ha)	%Increase over control
	Pre-count	3 DAS	7 DAS	10 DAS		
T1	44.23 (41.68)	16.54 (24.00)	9.70 (18.14)	7.16 (15.52)	43.51	94.03
T2	45.43 (42.38)	28.91 (32.53)	22.55 (28.35)	19.76 (26.39)	32.50	44.86
T3	47.12 (43.35)	36.28 (37.04)	26.68 (31.10)	22.58 (28.37)	25.91	15.30
T4	43.82 (41.45)	34.72 (36.10)	26.29 (30.84)	20.90 (27.20)	28.24	25.69
T5	44.26 (41.71)	34.52 (35.98)	24.75 (29.84)	21.18 (27.40)	27.01	20.10
T6	45.12 (42.20)	35.74 (36.72)	24.76 (29.84)	21.38 (27.54)	28.34	26.39
T7	44.96 (42.11)	36.93 (37.42)	21.30 (27.48)	17.24 (24.53)	28.33	26.25
T8	46.30 (42.88)	35.26 (36.43)	20.95 (27.24)	17.22 (24.52)	29.72	32.73
T9	47.85 (43.77)	38.30 (38.24)	33.12 (35.13)	31.80 (34.32)	26.41	17.59
T10	47.65 (43.65)	52.03 (46.16)	55.15 (47.96)	53.68 (47.11)	22.42	0.00
SE	0.88	2.13	2.32	2.60	0.57	
CD @5%	NS	6.33	6.99	7.73	1.59	
CV%	3.58	8.18	13.47	16.07	8.18	

*Refer to Table1 for treatment details; Values in parentheses are arc sin transformed values; DAS: Days after spray; GFY: Green fodder yield (t/ha)

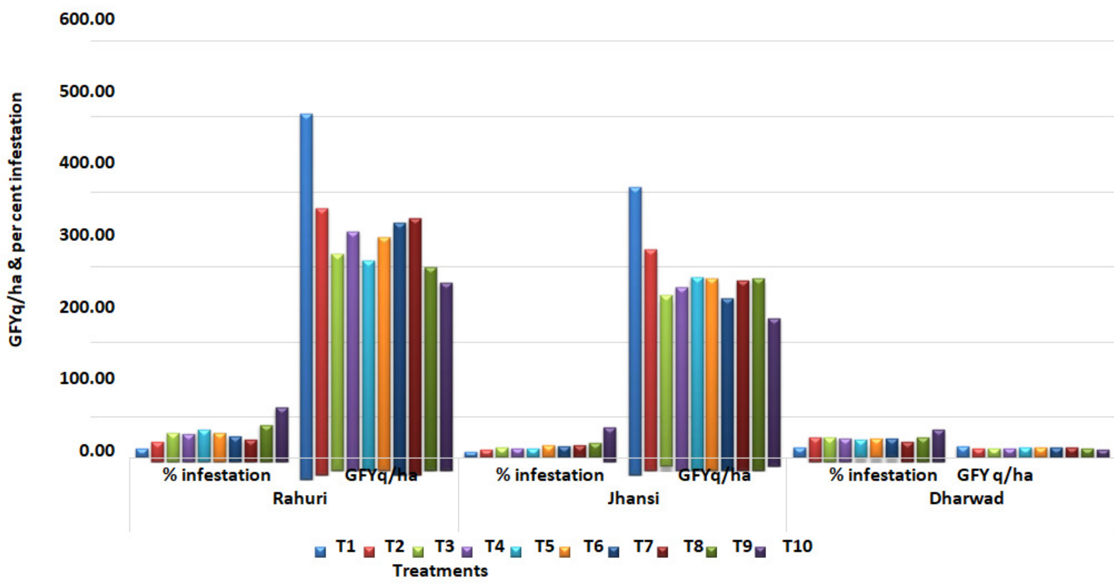

Fig 1. Efficacy of selected treatments against fall armyworm on maize at three locations in 2019

of FAW was found non-significant before spray. In line with previous years, the lowest percent infestation of FAW was recorded in T1 (19.95 %), which was significant and at par with T2 (28.37%). Further, T8 (31.70%), followed by T4 (32.33%), T6 (33.51%), T7 (35.56%), T3 (35.64%), T9 (35.68) and T5 (35.94%) were effective against FAW. All the treatments were statistically at par with each other (Table 4; Fig 3). Seven days after spray, the lowest FAW infestation was recorded in T1 (13.90%), which was significantly lower than all other treatments. The next best treatment was T2 (22.61%), followed by T8 (23.39%), T4 (24.12%), T7 (25.00%), T6 (26.72%), T5 (28.13%), T3 (28.18%), and T9 (30.84%). These treatments were significantly better than the control (Table 4; Fig 3). Ten days after spray, the lowest percent infestation of FAW was observed in T1 (6.01 %), followed by T2 (16.18%), T8 (14.85%) and T4 (16.23%) as compared to the untreated control (50.40%). Other treatments were statistically at par with each other (Table 4; Fig 3).

Pooled data evaluation of FAW infestation under different treatments: The pooled data from five locations over three years (2019–2021) showed that the initial FAW infestation (pre-count) was similar across all experimental plots, indicating a uniform pest population. After spraying, there were significant differences among treatments compared to the control. Three days after spray (3 DAS), the lowest FAW infestation was observed in T1 (16.53%), which was significantly lower than all other treatments. Other effective treatments were T2 (26.36%), T8 (30.73%), T4 (31.30%), T6 (32.13%), T5 (32.96%) and T7 (33.07%). These treatments were significantly better than the least effective ones but similar to each other (Table 5). Seven days after spray (7 DAS), T1 again showed the lowest infestation (11.04%), significantly lower than all other treatments. The next most effective treatments were T8 (21.11%), T2 (21.24%), T7 (22.22%), T4 (23.85%), T6 (24.70%), T5 (25.70%) and T3 (25.84%), which were statistically similar to each other. In contrast, the highest infestation was recorded in T9 (30.08%) and T10 (50.74%) (Table 5). Ten days after spray (10 DAS), the lowest FAW infestation was recorded in T1 (6.63%), followed by T8 (16.51%), T2 (17.54%), T7 (17.63%), T4 (18.47%), T3 (21.21%) and T5 (21.42%). T1 remained significantly better than all other treatments (Table 5). Overall, T1 consistently showed the lowest FAW infestation at all time points, followed by T2 and T8. This trend indicates that these treatments were the most effective in controlling FAW over multiple years and locations.

Green fodder yield under different treatments: The higest green fodder yield was recorded in T1 (37.49 t/ha) with 67.26% increase in green fodder yield followed by T2 (30.57 t/ha), T4 (27.80 t/ha), T7 (27.59 t/ha) and T6 (27.40 t/ha) as compared to control (22.42 t/ha). Green fodder yield in rest of the treatments was at par with each other (Table 5).

Benefit-cost ratio under different treatments: When the cost-benefit ratio was worked out, among the treatments studied (Table 6), the best and most economical treatment was T1 (1:1.55), followed by T2 (1:1.31), T8 (1:1.23), T7 (1:1.18), T6 (1:1.16), as compared to control (T10; 1:0.83).

Table 3. Pooled mean analysis of selected treatments against fall armyworm on maize at three locations during 2020

Treatments*	Plant infestation (%)				GFY (t/ha)	%Increase over control
	Pre-count	3 DAS	7 DAS	10 DAS		
T1	34.22 (35.80)	13.10 (21.22)	9.52 (17.97)	6.72 (15.03)	33.44	53.43
T2	35.00 (36.27)	21.82 (27.85)	18.57 (25.53)	16.68 (24.10)	29.40	34.90
T3	33.85 (35.58)	27.28 (31.49)	22.65 (28.42)	21.52 (27.64)	26.60	22.04
T4	34.20 (35.79)	26.84 (31.20)	21.13 (27.37)	18.28 (25.31)	27.04	23.88
T5	33.93 (35.62)	28.41 (32.21)	24.23 (29.49)	22.45 (28.28)	25.19	15.57
T6	34.68 (36.08)	27.15 (31.40)	22.62 (28.40)	20.67 (27.04)	25.34	16.31
T7	33.63 (35.45)	26.71 (31.12)	20.37 (26.83)	18.54 (25.50)	27.21	24.87
T8	32.85 (34.97)	25.22 (30.15)	18.99 (25.83)	17.44 (24.69)	28.01	28.54
T9	33.58 (35.42)	28.24 (32.10)	26.28 (30.84)	33.62 (35.44)	24.35	11.72
T10	34.20 (35.79)	42.89 (40.91)	48.06 (43.89)	53.45 (46.98)	21.80	0.00
SE	2.42	2.77	3.02	3.02	1.41	
CD @5%	7.20	8.22	8.98	8.95	4.20	
CV%	13.82	17.08	18.92	8.92	9.49	

* Refer to Table 1 for treatment details; Values in parentheses are arc sin transformed values; DAS: Days after spray; GFY: Green fodder yield (t/ha)

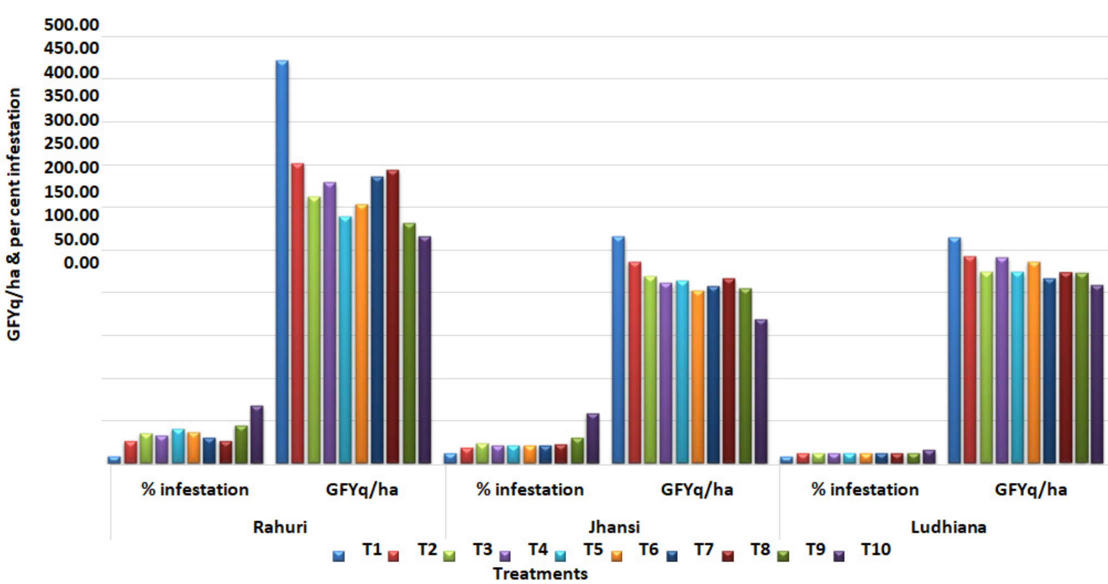

Fig 2. Efficacy of selected treatments against fall armyworm on maize at three locations in 2020

Table 4. Pooled mean analysis of selected treatments against fall armyworm on maize at three locations during 2021

Treatments*	Plant infestation (%)				GFY (t/ha)	%Increase over control
	Pre-count	3 DAS	7 DAS	10 DAS		
T1	45.42 (42.37)	19.95 (26.53)	13.90 (21.89)	6.01 (14.19)	35.55	54.31
T2	47.17 (43.38)	28.37 (32.18)	22.61 (28.39)	16.18 (23.72)	29.85	29.57
T3	46.77 (43.15)	35.64 (36.65)	28.18 (32.06)	19.54 (26.23)	27.73	20.36
T4	46.39 (42.93)	32.33 (34.65)	24.12 (29.41)	16.23 (23.76)	28.22	22.47
T5	47.18 (43.38)	35.94 (36.83)	28.13 (32.03)	20.62 (27.01)	26.01	12.91
T6	46.79 (43.16)	33.51 (35.37)	26.72 (31.13)	17.99 (25.10)	28.52	23.78
T7	45.91 (42.66)	35.56 (36.61)	25.00 (30.00)	17.10 (24.43)	27.27	18.37
T8	46.59 (43.04)	31.70 (34.27)	23.39 (28.92)	14.85 (22.67)	29.31	27.23
T9	46.42 (42.95)	35.68 (36.68)	30.84 (33.73)	26.92 (31.25)	27.17	17.93
T10	45.63 (42.49)	48.27 (44.01)	48.99 (44.42)	50.40 (45.23)	23.04	0.00
SE	0.53	1.92	2.01	2.26	1.45	
CD @5%	NS	5.70	5.98	6.71	4.33	
CV%	2.16	9.57	11.41	15.08	8.94	

* Refer to Table 1 for treatment details; Values in parentheses are arc sin transformed values; DAS: Days after spray: GFY: Green fodder yield (t/ha)

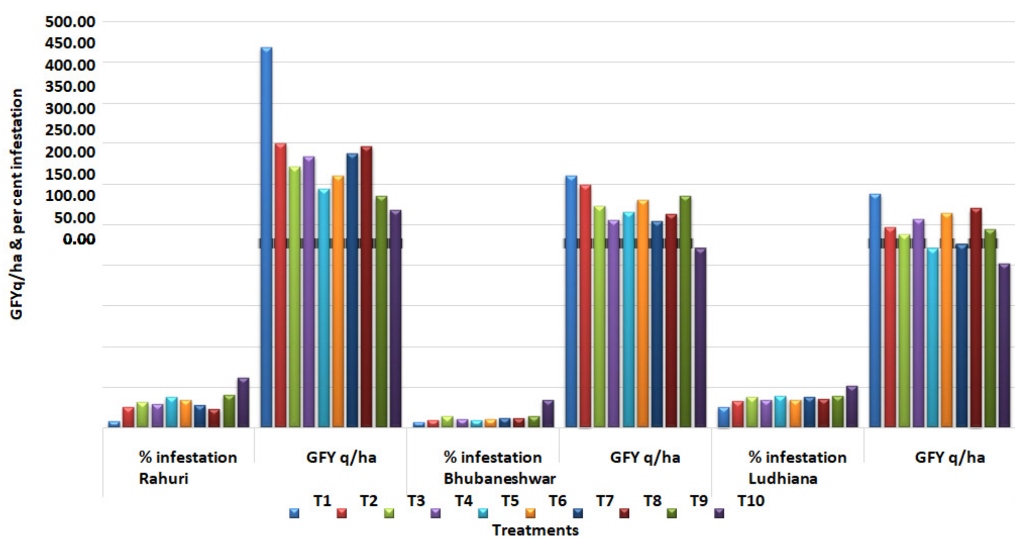

Fig 3. Efficacy of selected treatments against fall armyworm on maize at three locations in 2021

Entomopathogenic fungi and neem-based biopesticides are natural products that effectively control pests while minimizing harm to humans, animals, microbial flora, fauna, and the environment. These products exhibit eco-friendly and sustainable properties, impacting a wide range of pests, especially FAW (Varshney *et al*., 2021). In our study, all the treatments were superior to those used to control FAW. However, using the insecticide Emamectin benzoate was the most effective management measure against FAW in the maize crop. In the past, Satanarayana *et al*. (2010) found that Emamectin benzoate 0.00725% was the most effective insecticide for reducing the larval population of *S. litura*. Bharadwaj *et al.* (2020) reported that Spinetoram 11.7 SC @ 0.011 (4.67 larvae/25 plants), followed by Emamectin benzoate 5 WG @ 0.002% (7.87 larvae/25 plants), were effective in reducing the larval population of *S. frugiperda* in maize. Nashwa and Aziza (2023) found that spraying Emamectin benzoate 5SG reduced 72.62% of FAW infestation and residual toxicity. Furthermore, Chandar and Tayde (2023) experimented and reported that Emamectin benzoate 5 SG (0.40 g/kg) recorded the minimum larval population (2.24 /10

Table 5. Pooled mean analysis of nine locations of selected treatments against fall armyworm on maize from 2019 to 2021

Treatments*	Plant infestation (%)				GFY (t/ha)	%Increase over control
	Pre-count	3 DAS	7 DAS	10 DAS		
T1	41.29 (39.98)	16.53 (23.99)	11.04 (19.41)	6.63 (14.92)	37.49	67.26
T2	42.54 (40.71)	26.36 (30.89)	21.24 (27.45)	17.54 (24.76)	30.57	36.40
T3	42.58 (40.73)	33.07 (35.10)	25.84 (30.55)	21.21 (27.42)	26.72	19.22
T4	41.47 (40.09)	31.30 (34.02)	23.85 (29.23)	18.47 (25.45)	27.80	24.00
T5	41.79 (40.27)	32.96 (35.03)	25.70 (30.46)	21.42 (27.57)	26.04	16.17
T6	42.20 (40.51)	32.13 (34.53)	24.70 (29.80)	20.01 (26.58)	27.40	22.23
T7	41.50 (40.11)	33.07 (35.10)	22.22 (28.13)	17.63 (24.82)	27.59	23.10
T8	41.91 (40.35)	30.73 (33.66)	21.11 (27.35)	16.51 (23.97)	29.02	29.49
T9	42.62 (40.75)	34.07 (35.71)	30.08 (33.26)	30.78 (33.70)	25.96	15.80
T10	42.49 (40.68)	47.73 (43.70)	50.74 (45.42)	52.51 (46.44)	22.42	0.00
SE	0.34	0.47	0.67	0.44	0.97	
CD @5%	NS	1.40	1.99	1.32	2.89	
CV%	1.48	7.40	8.85	9.79	6.00	

* Refer to Table 1 for treatment details; Values in parenthesis are arc sin transformed values; DAS: Days after spray; GFY: Green fodder yield (t/ha)

Table 6. The benefit-cost ratio of different pesticides against fall armyworm on maize

Treatments*	GFY (t/ha)	Additional yield over control (t/ha)	Gross monetary return (Rs/ha)	Cost of treatment (Rs/ha)	Net monetary return (Rs/ha)	Additional income over control (Rs/ha)	B:C Ratio	ICBR
T1	37.49	15.07	84361.5	54260	30102	29666	1:1.55	1:6.96
T2	30.57	8.15	68791.5	52542	16250	15814	1:1.31	1:6.22
T3	26.72	4.30	60129	52656	7473	7037	1:1.14	1:2.65
T4	27.80	5.38	62541	53156	9385	8949	1:1.18	1:2.84
T5	26.04	3.62	58590	52656	5934	5498	1:1.11	1:2.07
T6	27.40	4.98	61647.75	53156	8492	8056	1:1.16	1:2.55
T7	27.59	5.17	62088.75	52656	9433	8997	1:1.18	1:3.39
T8	29.02	6.60	65308.5	53156	12153	11717	1:1.23	1:3.71
T9	25.96	3.54	58407.75	54354	4054	3618	1:1.07	1:0.83
T10	22.42	0.00	50436	50000	436	--	--	--

*Refer to Table 1 for treatment details; GFY: Green fodder yield (t/ha); The price of green fodder: Rs. 2250/t, Azadirachtin (10,000ppm): Rs. 1349/L, Chloropyriphos (20 EC): Rs. 443/L, *Metarhizium anisopliae*: Rs. 200/kg, *Beauveria bassiana*: Rs. 200/kg, Emamectin benzoate (5 SG) Rs. 521/100 g, *Metarhizium rileyi*: Rs. 200/kg; Labor cost for one spray- Rs. 827/ha/spray @ (Rs. 331/labor/day); B:C Ratio-Benefit Cost Ratio; ICBR: Incremental Cost-Benefit Ratio

plants) on maize amongst the 12 treatments. Emamectin benzoate's efficacy in reducing FAW percent infestation on maize has been studied earlier. For example, Panigrahi *et al.* (2023) examined the insecticide's effectiveness and reported that Emamectin benzoate 5SG (1.178%) was most effective in reducing FAW larval population with the highest yield of 42.5 q/ha and cost-benefit ratio (1:2.42) in maize. Our studies were consistent with those of Deshmukh *et al.* (2024), who also reported the ability of fungicides to fight FAW over 3rd instar larvae. This fungicide was effective against FAW as it is known for its ability to bind with multiple sites in insect chloride channels and cause a halt in feeding and an irreversible paralysis of insects (Jansson *et al.*, 1997).

Among biocontrol agents, *Metarhizium rileyi, M. anisopliae,* and *Beauveria bassiana* also showed their effectiveness against FAW as a non-chemical management strategy. Some researchers have also reported that entomopathogenic fungi are effective against FAW (Helen *et al*., 2021; Zalte *et al*., 2024). They found *B. bassiana* lethal against 3rd instar larvae of *S. frugiperda*. Entomopathogenic fungi were observed to cause insect mortality by entering their bodies through cuticles and killing the insects (Khanal *et al*., 2024). Some other workers also reported the ability of entomopathogenic fungi to produce toxins such as beauvericin and bassianin and secondary metabolites like oxalic acid that parasitize the larvae of insects (Idrees *et al*., 2021; Wang *et al*., 2021). Likewise, neem-based biopesticides like Azadirachtin also exhibited good results against FAW in maize. Neem-based products act by disabling pests rather than killing them outright, ultimately leading to mortality through feeding inhibition and developmental disruption (Maredia *et al*., 1992).

Benefit:cost ratio (B:C) is one of the most important factors in studying the scope and popularity of any insecticide among the end users. The safe and eco-friendly insecticide has the potential to replace synthetic pesticides and provide cost-effective benefits to maize agroecosystems (Sharma *et al*., 2018). For example, Ahir *et al*. (2021) reported a high benefit-cost ratio (1:1.87) after three sprays of Emamectin benzoate 5SG in maize. Likewise, Tayde and Ramesh (2022) reported that Emamectin benzoate was the most economical treatment, which recorded a B:C ratio of 1:1.74 in maize. Likewise, Mora and Metzler (2017) reported that botanical insecticides are effective against fall armyworm and are more cost-efficient for small farmers.

Although conventional pesticides are effective, their intensive use poses challenges such as pest resistance, secondary pest outbreaks, and adverse effects on other organisms and the environment (Maredia *et al*., 1992). Integrating new and bio-pesticides into an integrated pest management (IPM) module offers a sustainable solution for managing fall armyworm.

Conclusion

In this study, emamectin benzoate 5 SG was the most effective insecticide for controlling fall armyworm (*Spodoptera frugiperda*) larval populations. This was followed by chlorpyriphos 20 EC and *Metarhizium rileyi* (Nomuraea) 1.15% WP @ 75 g per 10 L of water, both of which demonstrated the highest cost–benefit ratio among the treatments. In contrast, *Metarhizium anisopliae* (1.15%) and *Beauveria bassiana* (1.15%) WP showed moderate effectiveness as biopesticides, while azadirachtin 10,000 ppm was the least effective in managing the pest.

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References

Ahir, K.C., M.K. Mahla, K. Sharma and S.R. Babu. 2021. A Bio-efficacy of insecticides against fall armyworm. *The Indian Journal of Agricultural Sciences* 91: 1796-1800.

Anonymous. 2022. ANGRAU *Maize Outlook Report*-January to December 2021, ANGRAU Crop Outlook Reports of Andhra Pradesh.

Bharadwaj, G. S., D. S. Mutkule, B. A. Thakre and A. S. Jadhav. 2020. Bio-efficacy of different insecticides against fall armyworm, *Spodoptera frugiperda* (J.E. Smith) on maize. *Journal of Pharmacognosy and Phytochemistry* 9: 603-607.

Chandar, A. S. and A. R. Tayde. 2023. Field efficacy of insecticides against fall armyworm, *Spodoptera frugiperda* (JE, Smith) on maize (*Zea mays* L.). *International Journal of Environment and Climate Change* 13: 3010-3020.

Das, A. K., S. Dixit, D. Bhamare, R. Kumar, K. R. Yatish, S. Singh, B. Kumar, S. B. Suby, Z. A. Dar, A. Arora and S. Kumar. 2025. Genetic diversity and structure analysis of white maize populations. *Range Management and Agroforestry* 46(1): 62-69.

Deshmukh, S., A. H. B. Pavithra, C. M. Kalleshwaraswamy, B. K. Shivanna, M. S. Maruthi and D. Mota-Sanchez. 2024. Field efficacy of insecticides for management of invasive fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) on maize in India. *Florida Entomologist* 103: 221-227.

FAO, 2023. *World Food and Agriculture- Statistical Yearbook* 2023. Rome. https:// doi. Org/10.4060/cc8166en.

Halli, H. M., V. K. Wasnik, B. G. Shivakumar, A. K. Singh, V. K. Yadav, S. Swami, S. S. Manjanagouda and S. Gurumurthy. 2023. Influence of detopping practices on green fodder availability, seed yield and economics of fodder maize (*Zea mays* L.) in central and southern plateau regions of India. *Range Management and Agroforestry* 44(2): 315-322.

Helen, P. A., N. D. Tamboli, S. A. More and S. R. Kulkarni. 2021. Bio-efficacy of biocontrol agents against Fall armyworm *Spodoptera frugiperda* (J. E. Smith) under laboratory conditions. *Journal of Entomology and Zoology Studies* 9: 277-280.

Idrees, A., Z. A. Qadir, K. S. Akutse, A. Afzal, M. Hussain, W. Islam, M. S. Waqas, B. S. Bamisile and J. Li. 2021. Effectiveness of entomopathogenic fungi on immature stages and feeding performance of fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae) Larvae. *Insects* 12: 1044.

Jansson R. K., R. Brown, B. Cartwright, D. Cox, D. M. Dunbar, R. A. Dybas, C. Eckel, J. A. Lasota, P. K. Mookerjee, J. A. Norton and R. F. Peterson. 1997. Emamectin benzoate: a novel avermectin derivative for control of lepidopterous pests. In: *Proceedings of the 3rd International Workshop on Management of Diamondback Moth and Other Crucifer Pests*. MARDI, Kuala Lumpur, Malaysia 29: 171-177.

Johnson, S. J. 1987. Migration and the life history strategy of the fall armyworm, *Spodoptera frugiperda* in the western hemisphere. *International Journal of Tropical Insect Science* 8: 543-549.

Khanal, D., D. Subedi, G. Banjade, M. Lamichhane, S. Shrestha and P. Chaudhary. 2024. Efficacy of different pesticides against fall armyworm (*Spodoptera frugiperda* (J.E. Smith) Lepidoptera: Noctuidae) under laboratory conditions in Rupandehi, Nepal. *International Journal of Agronomy* 7140258: 1- 9. https://doi.org/10.1155/2024/7140258

Kulkarni, N. S., M. C. Keerthi and B. G. Shivakumar. 2023. Seasonal incidence, biology and management of fall armyworm (*Spodoptera frugiperda*, JE Smith) on fodder maize. *Range Management and Agroforestry* 44(2): 397-402.

Kumar, P., M. K. Mahla, O. P. A. Lekha and A. Mordia. 2015. Seasonal incidence of insect pest's fauna in maize. *Indian Journal of Entomology* 29:45-49.

Manjula, K., Y. P. Saheb, M. J. Sudheer and A. R. Rao. 2019. Studies on biology, feeding habits and natural enemies of fall armyworm, *Spodoptera frugiperda*, a new invasive pest in India. *Journal of Entomology and Zoology Studies* 7: 1245-1250.

Maredia, K. M., O. L. Segura and J. A. Mihm. 1992. Effects of neem, *Azadirachta indica* on six species of maize insect pests. *Tropical Pest Management* 38: 190-195.

Mora, J. and H. B. Metzler. 2017. Evaluation of botanical insecticides in controlling the population of fall armyworm, *Spodoptera frugiperda* present on corn crops (*Zea mays*) located in Santa Cruz, Guanacaste. In *IOP Conference Series: Earth and Environmental Science* 215: 012013. DOI 10.1088/1755-1315/215/1/012013

Nashwa, S. A. and E. S. A. Aziza. 2023. Effectiveness of teflunenzuron, emamectin benzoate, and alf-cypermethrin on fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Noctuidae: Lepidoptera), under laboratory and field conditions. *Egyptian Academic Journal of Biolog*ical *Sciences* 16: 133-139.

Panigrahi, C. K., U. Yadav and D. Sarangi. 2023. Field efficacy of certain insecticides against fall armyworm, *Spodoptera frugiperda (J. E. Smith)* on maize (*Zea mays* L.) under Prayagraj region of India. *International Journal of Environment and Climate Change* 13: 1207-1215.

Reddy, N., Y. S. Anil, C. S. Saindane, Chaudhari and S. A. Landage. 2021. Biology of fall armyworm *Spodoptera frugiperda* (J.E. Smith) on maize under laboratory conditions. *The Pharma Innovation Journal* 10: 1997-2001.

Reddy, Y. Y. R. and S. Trivedi. 2008. *Maize Production Technology.* Academic Press. pp. 1-192.

Satanarayana, N. V. V., G. R. Rao and P. Rao. 2010. Incidenc and management *Spodoptera litura*of (Fab.) on post rainy season groundnut. *Annals of Plant Protection Sciences* 18(1): 22-25.

Sharanabasappa, S. D., C. M. Kalleshwaraswamy, R. Asokan, H. M. Mahadeva, M. S. Swamy, Maruthi, H. B. Pavithra, K. Hegde, S. Navi, S. T. Prabhu and G. Goergen. 2018. First report of the fall armyworm, *Spodoptera frugiperda* (J E Smith) (Lepidoptera: Noctuidae), an alien invasive pest on maize in India. *Pest Management in Horticultural Ecosystem* 24: 23-29.

Sharma, G. S., S. Bhandari, A. Neupane and T. S. Pathak. 2018. Bio-rational management of armyworm (*Mythimna separata*) (lepidoptera: noctuidae) in chitwan condition of Nepal. *Journal of Insect Agriculture Animal Science* 35: 143-150.

Steel, R. G. D. and J. H. Torrie. 1980. *Principles and Procedures of Statistics*. Publishing McGraw Hill Book Company, New York.

Tayde, A. R. and M. Ramesh. 2022. Comparative efficacy of selected chemicals and biopesticides against fall armyworm, *Spodoptera frugiperda* (JE Smith) on maize (*Zea mays* L.). *International Journal of Plant and Soil Science* 34: 466-470.

Varshney, R., B. Poornesha, A. Raghavendra Y. Lalitha, V. Apoorva, B. Ramanujam, R. Rangeshwaran, K. Subaharan, A. N. Shylesha, N. Bakthavatsalam and M. Chaudhary. 2021. Biocontrol-based management of fall armyworm, *Spodoptera frugiperda* (J E Smith) (Lepidoptera: Noctuidae) on Indian maize. *Journal of Plant Diseases and Protection* 128 (1): 87-95.

Wang, H., H. Peng, W. Li, P. Cheng and M. Gong. 2021. The toxins of *Beauveria bassiana* and the strategies to improve their virulence to insects. *Frontiers in Microbiol*ogy 12: 2375.

Yatish, K. R., S. Kumar, T. V. Rao, P. Kumar, M. Karthik, A. K. Das, G. K. Chikappa, P. Singh, S. K. Mahantha, J. C. Sekhar, B. Bhushan, B. S. Jat and S. Rakshit. 2024. GGE biplot and AMMI analysis for stability and adaptability of dual-purpose maize hybrids tested across multi-environments for baby corn and fodder yield. *Range Management and Agroforestry* 45(01): 49-56.

Zalte, O. P., P. R. Panchbhai, T. Pillai, N. V. Lavhe, V. Deshmukh, V. Shah, B. B. Fand, R. Pande, T. Prabhulinga, A. Nikoshe and S. Thube. 2024. Bio-efficacy evaluation of *Beauveria bassiana* against fall armyworm, *Spodoptera frugiperda* (J.E. Smith). *Hexapoda Insecta indica* 31 (6): 44-48. DOI: 10.55446/hexa.2023-2024.12.