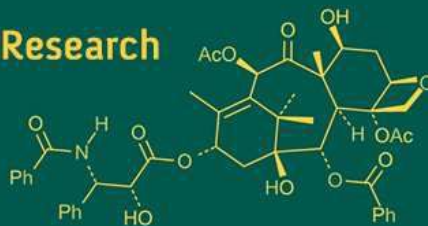
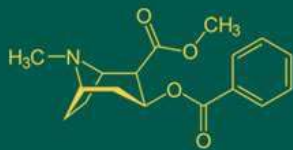


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Evaluation of biopesticides against the fall armyworm, *Spodoptera frugiperda* in maize

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Abstract

Fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae), is a serious invasive insect pest affecting global maize production. The use of chemical control extensively results in repeated control failure posing a need for alternate control options. A field trial was conducted in the winter season (November – February) of 2023-24 with an objective to evaluate different biopesticides namely Azadirachtine, *Bacillus thuringiensis* var kurstaki, and entomopathogenic fungi native to the Chhattisgarh region, India. Among the different treatments evaluated *Bacillus* showed the most effective control with the highest percent reduction over control in larval population reduction (63.95%, 75.00%) and leaf damage reduction (39.44%, 61.18%) after two rounds of treatment application. Among the native entomopathogenic fungi strains evaluated, *Metarrhizium anisopliae* 2% 1×10^7 CFU has shown greater potential in controlling FAW maize with larval population (58.53%, 63.16%) and leaf damage reduction (43.90%, 58.22%). The same above treatments are well performed concerning cob damage (21.67%, 21.88%) and yields (1942 kg/ha, 1930 kg/ha) of maize respectively. The present biopesticides evaluated possess great potential in further extensive studies and testing under different conditions.

Keywords: Fall Armyworm (FAW), *Spodoptera frugiperda*, invasive insect pest, biopesticides

Introduction

The fall armyworm (FAW), scientifically known as *Spodoptera frugiperda* (J. E. Smith), is an invasive insect pest that poses a serious threat to global food security, particularly for maize. Originally from neotropical areas of America, the pest migrated to West Africa in early 2016 and has since spread to numerous countries in sub-Saharan Africa. It has further invaded various countries in the western world (Prasanna *et al.*, 2021; CABI, 2022) ^{[1], [4]}. In India, Karnataka experienced the first outbreak of FAW in 2018, leading to significant economic yield losses in maize, with subsequent spread to major maize-growing areas within a year (Sharanabasappa *et al.*, 2018; Shylesha *et al.*, 2018; Rakshit *et al.*, 2019; Suby *et al.*, 2020) ^{[12], [13], [15]}. This highly polyphagous insect pest attacks more than 350 host plants and can complete up to 12 generations in a year in tropical climates (Busato *et al.*, 2005) ^[3]. The larvae feed on various parts of the plant, causing substantial yield losses. The impact of fall armyworm damage on maize yield has been reported to be about 50–80%, resulting in the loss of millions of dollars (Adhikari *et al.*, 2020) ^[1]. In Africa, without effective FAW management options, the pest causes significant maize yield losses ranging from 8.3 to 20.6 million tonnes per year, resulting in significant economic losses of \$2.5–6.2 million (Mendesil *et al.*, 2023) ^[9]. In 2017, maize production in India declined by 3.2%, with a production of 27.8 million tonnes due to infestation by insect pests, including the fall armyworm (Manupriya, 2019) ^[8]. The preliminary studies on yield losses due to FAW are attributed to 33-36% in Indian conditions, (Jagdish *et al.*, 2019; Aruna *et al.*, 2019) ^{[7], [2]}. Presently, FAW is established in over 42 countries, with an estimated annual impact of \$13 billion (Stokstad, 2017) ^[14].

In Indian conditions, the FAW control is primarily focused on synthetic insecticides which evolved as effective control options. According to the Arthropods Pesticide Resistance Database, there are 42 active ingredients and 182 resistance cases were reported for FAW worldwide (Gutiérrez-Moreno *et al.*, 2019). The overuse and misuse of these synthetic insecticides result in rapid resistance development and control failure.

Thus, utilization of biocontrol agents like as myco-pesticides have been seen as an alternative to these hazardous chemical insecticides to effectively manage FAW. This strategy lessens the detrimental effects of chemical pesticides on natural enemies while simultaneously helping to mitigate the problem of insecticide resistance in FAW population. The biopesticides like entomopathogenic fungi are reported to be controlling the FAW population up to 45% in natural conditions of native regions (Guo *et al.*, 2020). In invading countries, the search for native biocontrol agents and utilization of native biocontrol agents provides valuable control options. In view of above context, we framed an experiment to evaluate the native entomopathogenic fungi strains against FAW in field conditions.

Material and Methods

Experimental design

The study was conducted during the winter season (November 2023 – February 2024) at Research farm (21° 14' 55.8312" N latitude and 81° 38' 24.324" E longitude), ICAR – National Institute of Biotic Stress Management, Raipur, Chhattisgarh, India. The maize hybrid JKMH - 4222 was sown at a spacing of 60×20 cm in a 5 m row length with a plot size of 60 m² for each module. The experiments were laid out in randomized block design with three replications. Five different treatments were evaluated and compared the effectiveness along with a control treatment. Recommended package and practices were followed to raise the maize crop

except for pest control treatments and a good crop stand was maintained. The EPF (Entomopathogenic Fungi) strains were native to the Chhattisgarh region, India. A total of five different bio-pesticide (Table No. 1) treatments along with untreated check were replicated four times and two rounds of treatment application were taken in the crop duration with sufficient pre-treatment infestation levels, initially at the knee height stage and the second application 15 days after the initial application. Spraying was carried out during calm and warm evenings using a high-volume knapsack sprayer equipped with a hollow cone nozzle. Application rates were set at 400 L per hectare for the first spray and 500 L per hectare for the second. During the first spray, insecticides were distributed on both leaves and whorls, while the second application targeted only the whorls by adjusting the hollow cone nozzle.

Data collection

Visual assessments of live larvae and damaged leaves (%) were recorded from 10 plants per treatment plot excluding border rows, one day before treatment and at 1, 3, 5, 7, 10, and 14 days after the application of treatments. The final observation data of initial spraying was considered as pre-treatment observation for the second round of application. Cob damage (%) was taken once at 90 days of crop growth as the number of damaged cobs to the total number of cobs in each treatment plot. Marketable grain yield was measured for each treatment and expressed in kilograms per hectare.

Table 1: Treatment details

S. No	Bio-pesticides	Trade name@/Strain	Source	Dose (g/ml per lit)
1	Azadirachtin 1500 ppm	Neem 1500	PJ Margo Pvt. Ltd. India	5
2	<i>Bacillus thuringiensis</i> var. <i>kurstaki</i> 1% WG	Delfin	PJ Margo Pvt. Ltd. India	3
3	<i>Beauveria bassiana</i> 1.15% AS (1×10 ⁷ CFU)	Bilaspur strain	ICAR - IGKV, Raipur, India.	10
4	<i>Metarhizium anisopliae</i> 2% AS (1×10 ⁷ CFU)	Bilaspur strain	ICAR - IGKV, Raipur, India.	10
5	<i>Lecanicillium lecanii</i> 1.15% AS (1×10 ⁷ CFU)	Bilaspur strain	ICAR - IGKV, Raipur, India.	10

Statistical analysis

All the observations recorded were subjected to appropriate statistical transformations with subsequent ANOVA analysis. Tukey's test was employed for the mean separation with a significance level set at $P \leq 0.01$. IBM SPSS 2.0 statistical software is used for data analysis.

Results

Population reduction

All the treatments evaluated in controlling the larval population of FAW showed a significant superiority over the untreated check. The larval population of FAW recorded after a day of treatment application resulted in no significant difference among the treatments in continuation to pre-treatment observations with 5.25 to 3.5 larvae/plant ($F = 0.41$; $df = 5, 15$; $P = 0.82$). A larval population 1.75 larvae/plant was reported at 3 DAT simultaneously in both treatments Azadirachtin and *B.t* var. *kurstaki* ($F = 0.79$; $df = 5, 15$; $p < 0.001$). The larval population in *M. anisopliae* (2) was significantly the next best lowest population which was on par with *B. bassiana* (3.5). At 5 DAT, *B.t* var. *kurstaki* was effective among the treatments with 1 larva / 5 plants, however, it was at par with *M. anisopliae* (1.25). A similar level of control was reported in treatments Azadirachtin and *B. bassiana* which are on par with each other having 2.75 larvae/plant ($F = 10.13$; $df = 5, 15$; $p < 0.0001$). At 7 DAT, similar trends of previous observation were recorded with

the lowest level of larval population in *B.t* var. *kurstaki* (1) among the treatments ($F = 8.73$; $df = 5, 15$; $p < 0.0001$). The treatments Azadirachtin and *M. anisopliae* were reported to be the next best performing with a larval population of 2.25 and 1.5 larvae/plant respectively and they are on par with each other. *B. bassiana* (3) and *L. lecanii* (4.75) were on par with each other showing a moderate level of larval population. The final observation on larval population was taken 14 DAT, reporting lowest level of larval population in *B.t* var. *kurstaki* (2.5) and *M. anisopliae* (2.75) was on par with *B.t* var. *kurstaki* showing next best treatment ($F = 7.36$; $df = 5, 15$; $p < 0.01$). The initial population reduction in Azadirachtin treated plots was effective which was gradually reduced to 4.00 larvae/plant showing an average level of control. A similar and least control among the treatments applied was reported in *B. bassiana* (5.00) and *L. lecanii* (5.25), which are similar to the control plot population (5.50) (Table No. 2).

The pooled data of all the observations taken after respective treatment application has exhibited, the most effective treatment of all the treatments applied was *B.t* var. *kurstaki* (1.92) with 63.95% reduction over control and it is on par with the *M. anisopliae* 2% (2.21) showing 58.53% reduction over control, which is the next best effective treatment in controlling the larval population of FAW ($F = 26.70$; $df = 5, 24$; $p < 0.001$). The control of larval population achieved from *B. bassiana* (3.50) and Azadirachtin (3.13)

was mediocre and on par with each other. *L. lecanii* (4.92) performance was proved to be worse among all the treatments and it is on par with the untreated check plot (5.33) (Fig No. 1).

The population of FAW larvae recorded a day after the application of treatment for the second time was significantly less compared to the control and differed among the treatments. Likewise, the first spray, *B.t var. kurstaki* (2.25) and *M. anisopliae* (2.75) are effective of all treatments and on par with each other. With 3.25 larvae/plant an average level of control was reported in plots treated with Azadirachtin. *B. bassiana* (4.5) and *L. lecanii* (4.25) at par with each other reporting least effectiveness in controlling larval population ($F = 6.01$; $df = 5, 15$; $p < 0.001$). The control efficacy trend continued to 3 DAT, showing a lesser larval population in plots treated with *B.t var. kurstaki* (1.5) and *M. anisopliae* (1.75) ($F = 5.44$; $df = 5, 15$; $p < 0.01$). At 5 DAT, the FAW larval incidence in plots treated with *B.t var. kurstaki* (0.83), *M. anisopliae* (1.16) and Azadirachtin (1.5) was statistically on par although the lowest population is reported in *B.t var. kurstaki* ($F = 18.94$; $df = 5, 15$; $p < 0.01$). Azadirachtin (2.25) and *M. anisopliae* (2.50) are equally effective in controlling larval population at 7 DAT where the most effective being *B.t var. kurstaki* (1.25) even though the larval count in the same plot of previous observation (5 DAT) was higher than the 7 DAT (F

$= 20.75$; $df = 5, 15$; $p < 0.001$). A slight peek in larval population was reported in *B.t var. kurstaki* (1.5), *M. anisopliae* (2.50) and Azadirachtin (3.50) at 10 DAT compared to the previous observation, still being the effective treatments of all respectively ($F = 9.95$; $df = 5, 15$; $p < 0.001$). The 14 DAT observations showed the effective treatment as *B.t var. kurstaki* with a larval population of 1.75 and *M. anisopliae* (2.25) as the next best treatment in controlling the larval population ($F = 22.73$; $df = 5, 15$; $p < 0.001$). The treatments Azadirachtin (3.75), *B. bassiana* (4.75) and *L. lecanii* (4.75) are ordinary in their performance (Table No. 3).

The mean data obtained by pooling all the observations after respective treatment application exhibited the most effective among all bio-pesticides treatments as *B.t var. kurstaki* recording a mean of 1.65 larvae/plant and 71.15% reduction of larval population over control ($F = 23.16$; $df = 5, 24$; $p < 0.001$). *M. anisopliae* (2.21) and Azadirachtin (2.73) are the next best performing with a 63.16 and 52.27 percent reduction over control. An overall lowest level of control was reported in both treatments *B. bassiana* (4.33) and *L. lecanii* (4.48) which are on par with each other. The control plot population was significantly highest of all the bio-pesticide treated plots concluding all the bio-pesticide treatments are superior to the control (Fig No. 1).

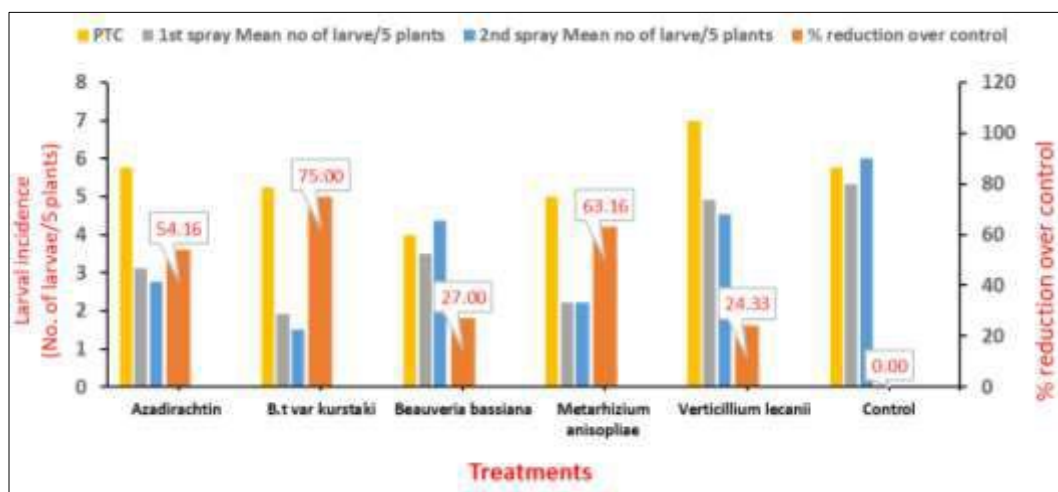


Fig 1: Efficacy of different Bio-pesticides in controlling fall armyworm larval population in maize – Rabi 2022-23

Table 2: The larval population of maize fall armyworm, as influenced by various bio-pesticide treatments (First spray)

S. No.	Treatment details	Dosage (g/ml per liter)	*No. of larva (e) per 5 plants at indicated sprays and days								% reduction over control
			PTC	1	3	5	7	10	14	Mean	
1	Azadirachtin 1500 ppm	5	5.75 (2.4)	4.5 (2.2)	1.75a (1.5)	2.75b (1.8)	2.25ab (1.6)	3.5c (2.0)	4.00bcd (2.12)	3.13b (1.90)	41.27
2	<i>Bacillus thuringiensis var. kurstaki</i> 1% WG	3	5.25 (2.4)	4 (2.1)	1.75a (1.5)	1a (1.2)	1a (1.2)	1.25a (1.3)	2.50a (1.72)	1.92a (1.55)	63.95
3	<i>Beauveria bassiana</i> 1.15% 1×10^7 CFU	10	4 (2.2)	4.25 (2.2)	3.5bc (2.0)	2.75b (1.8)	3bc (1.9)	3.75cd (2.1)	3.75abc (2.05)	3.50b (2.00)	29.64
4	<i>Metarhizium anisopliae</i> 2% 1×10^7 CFU	10	5 (2.4)	3.5 (2.0)	2ab (1.5)	1.25a (1.3)	1.5ab (1.4)	2.25b (1.6)	2.75ab (1.79)	2.21a (1.65)	58.53
5	<i>Lecanicillium lecanii</i> 1.15% 1×10^7 CFU	10	7 (2.6)	5 (2.3)	5.5d (2.4)	4.25bc (2.2)	4.75cd (2.3)	4.75cd (2.3)	5.25cd (2.40)	4.92c (2.33)	7.69
6	Control	--	5.75 (2.4)	5.25 (2.3)	5cd (2.3)	5c (2.3)	6d (2.5)	5.25d (2.4)	5.50d (2.44)	5.33c (2.42)	--
	SE (d)		0.09	0.31	0.25	0.22	0.26	0.17	0.17	0.10	
	CD ($p < 0.01\%$)		0.21	0.93	0.75	0.65	0.77	0.52	0.52	0.29	

PTC- Pre-treatment count

*Mean of four replications; DAS – Days After Spraying

Means were analysed after square root transformation (values inside the parentheses)

Means followed by the same letter(s) are not statistically different by Tukey's test ($p < 0.01\%$)

Percent leaf damage

The leaf damage of maize crop due to FAW was uniform on all the treatment plots before the application of respective bio-pesticide treatments ranging from 40.88% to 33.40%. The observations taken after applying treatments after a day ($F = 2.27$; $df = 5, 15$; $P = 0.09$) and 3 ($F = 0.87$; $df = 5, 15$; $P = 0.52$) show no significant difference among the treatments.

The comparative lowest leaf damage was recorded in *M. anisopliae* (22.58%) at 5 DAT and it was followed by *B.t var. kurstaki* with 28.49% leaf damage ($F = 1.70$; $df = 5, 15$; $p < 0.19$). An average control of leaf damage was noted from *B. bassiana* (31.93%), Azadirachtin (35.96%) and *L. lecanii* (41.61%) treatments are with quite high leaf damage which is on par with the control plot. At 7 DAT, the leaf damage of maize in *Metarhizium anisopliae* (26.70%) was significantly low followed by *B.t var. kurstaki* (28.90%) and Azadirachtin (29.79%) recording similar levels of leaf damage ($F = 9.89$; $df = 5, 15$; $p < 0.01$). *B. bassiana* (39.30%) and *L. lecanii* (37.41%) are poor performers in reducing the leaf damage. With a slight change from previous observation, all three treatments *M. anisopliae* (20.65%), *B.t var. kurstaki* (22.89%) and Azadirachtin (22.62%) recorded an equally effective range of leaf damage at 10 DAT, which are on par with each other ($F = 19.51$; $df = 5, 15$; $p < 0.001$). A similar trend of previous observations recorded at 10 DAT showing the highest leaf damage in plots treated with *B. bassiana* (36.02%) and *L. lecanii* (40.60%). The final observation of the initial treatment application was taken at 14 DAT, which recorded the significantly lowest level of leaf damage in *M. anisopliae* (20.37%) and *B.t var. kurstaki* (22.89%) treated plots ($F = 5.70$; $df = 5, 15$; $p < 0.001$). The leaf damage in Azadirachtin (26.92%) was median in its effectiveness. The highest percentage of leaf damage was in *B. bassiana* (35.8%) and *L. lecanii* (34.96%) continued to be poor performing treatments. The Untreated control reported 45.53% leaf damage which is significantly the highest of all the treatments (Table No. 4).

The mean data of percent leaf damage after the first spray has shown the best effective treatment among all bio-pesticide treatments applied is *M. anisopliae* with 25.54% mean leaf damage and 43.9% reduction of damage over control ($F = 12.52$; $df = 5, 24$; $p < 0.001$). The second-best treatment for effective reduction of leaf damage in maize due to FAW was *B.t var. kurstaki* with 27.57 mean leaf damage and 39.44% reduction of damage over control. A mediocre result of damage control was recorded from Azadirachtin (32.49%) and *B. bassiana* (34.7%) was reported. Although *B. bassiana* (34.7%) and *L. lecanii* (34.96%) is almost on par in control the leaf damage was comparatively high in *L. lecanii* with a 15.3% damage reduction over control (Fig No. 2).

The observations taken a day after the application of respective treatments showed almost homogenous leaf damage ranging from 22.39% to 30.07% which are at par with each other. The leaf damage from the control plot was 49.81% significantly the highest in comparison to all treatment plots. At 3 DAT, the significantly lowest level of leaf damage was reported from *B.t var. kurstaki* (17.55%) and *M. anisopliae* (19.93%) which are on par with each other ($F = 12.64$; $df = 5, 15$; $p < 0.001$). Azadirachtin (22.85%) and *B. bassiana* (32.05%) are next performing respectively in reducing leaf damage. *L. lecanii* (42.62%) was reported at par with the control plot. The leaf damage recorded 5 DAT reported the lowest leaf damage in *B.t var. kurstaki* (18.84%) treatment however, the leaf damage of treatments *M. anisopliae* (19.87%) and Azadirachtin (26.85%) were on par with it ($F = 32.85$; $df = 5, 15$; $p < 0.001$). Average leaf damage of 27.83% was recorded from *B. bassiana*. A similar trend of highest leaf damage was continued in *L. lecanii* (38.59%). With a slight deviation from the previous observation, a reduction in the leaf damage was observed in all treatments at 7 DAT with the significantly lowest level of leaf damage from *B.t var. kurstaki* (14.07%) again. *M. anisopliae* (17.58%) and Azadirachtin (21.04%) were at par with each other showing the next best lower levels of leaf damage, respectively ($F = 10.08$; $df = 5, 15$; $p < 0.01$). Though the damage from previous observation was less, the leaf damage from *B. bassiana* (25.59%) and *L. lecanii* (28.92%) was comparatively highest among the treatments. After 10 DAT ($F = 13.63$; $df = 5, 15$; $p < 0.001$) and 14 DAT ($F = 5.82$; $df = 5, 15$; $p < 0.001$) the treatments *B.t var. kurstaki* (19.34% and 21.99%) and *M. anisopliae* (21.35% and 20.50%) proved to be performing well reporting lowest leaf damages. *B. bassiana* and Azadirachtin were on par with each other with satisfying levels of damage reductions. *L. lecanii* continued to record the highest leaf damage among all treatments which is almost equal to control plot leaf damage (Table No. 5).

The mean percentage of leaf damage after the second round of treatment application revealed the best treatment among the respective bio-pesticide treatments was *B.t var. kurstaki* (19.03%) having 61.18% damage reduction over the control plot ($F = 17.40$; $df = 5, 24$; $p < 0.001$). The next best treatment *M. anisopliae* (21.16%) and Azadirachtin (24.17%) are on par with each other showing 58.22% and 50.70% leaf damage reduction over control. Mediocre leaf damage was observed in the case of *B. bassiana* (28.01%) with 42.87% damage reduction over control. Among all the treatments *L. lecanii* (35.42%) was the least effective to control the leaf damage with a 27.75% reduction over control (Fig No. 2).

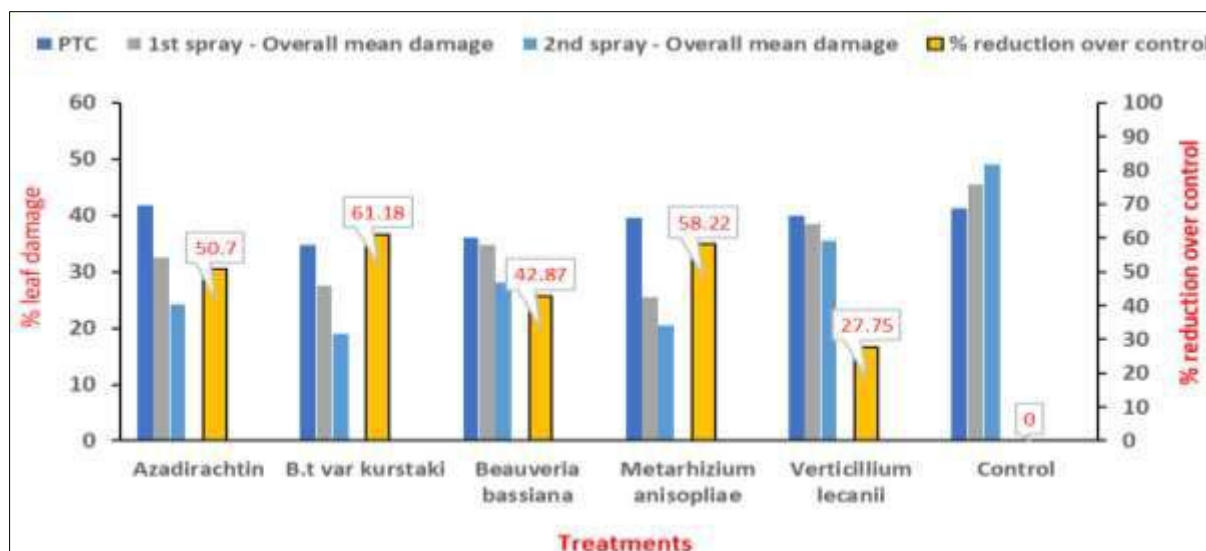


Fig 2: Efficacy of different biopesticides in reducing the leaf damage of maize due to fall armyworm – Rabi 2022-23

Table 3: The larval population of maize fall armyworm, as influenced by various bio-pesticide treatments (Second spray)

S. No	Treatment details	Dosage (g/ml per liter)	*No. of larva (e) per 5 plants at indicated sprays and days								% reduction over control
			PTC	1	3	5	7	10	14	Mean	
1	Azadirachtin 1500 ppm	5	4.00bcd (2.12)	3.25ab (1.93)	2.25ab (1.60)	1.5ab (1.4)	2.25b (1.64)	3.50bc (1.98)	3.75b (2.05)	2.75b (1.73)	54.16
2	<i>Bacillus thuringiensis</i> var. <i>kurstaki</i> 1% WG	3	2.50a (1.72)	2.25a (1.65)	1.50a (1.39)	0.75a (1.1)	1.25a (1.31)	1.50a (1.39)	1.75a (1.49)	1.50a (1.47)	75.00
3	<i>Beauveria bassiana</i> 1.15% 1×10 ⁷ CFU	10	3.75abc (2.05)	4.50bc (2.23)	3.75bc (2.05)	3.25b (1.9)	5.50c (2.45)	4.50cd (2.24)	4.75b (2.29)	4.38c (2.22)	27.00
4	<i>Metarhizium anisopliae</i> 2% 1×10 ⁷ CFU	10	2.75ab (1.79)	2.75a (1.80)	1.75a (1.47)	1.5ab (1.4)	2.50b (1.70)	2.50ab (1.72)	2.25a (1.64)	2.21b (1.69)	63.16
5	<i>Lecanicillium lecanii</i> 1.15% 1×10 ⁷ CFU	10	5.25cd (2.40)	4.25bc (2.18)	4.00c (2.12)	5.25c (2.4)	4.75c (2.28)	4.25bc (2.14)	4.75b (2.28)	4.54c (2.23)	24.33
6	Control	--	5.50d (2.44)	5.25c (2.37)	5.25c (2.39)	6.00c (2.5)	6.5c (2.64)	6.50d (2.64)	6.50c (2.64)	6.00d (2.49)	--
	SE (d)		0.17	0.17	0.27	0.21	0.17	0.22	0.14	0.12	
	CD (<i>p</i> <0.01%)		0.52	0.50	0.80	0.61	0.52	0.66	0.43	0.33	

PTC- Pre-treatment count

*Mean of four replications; DAS – Days After Spraying

Means were analysed after square root transformation (values inside the parentheses)

Means followed by the same letter(s) are not statistically different by Tukey's test ($p < 0.01\%$)

Table 4: The leaf damage of maize due to fall armyworm, as influenced by various bio-pesticide treatments (First spray)

S. No.	Treatment details	Dosage (g/ml per liter)	*No. of damaged leaves/ 5 plants at indicated sprays and days								% reduction over control
			PTC	1	3	5	7	10	14	Mean	
1	Azadirachtin 1500 ppm	5	41.89	40.88 (39.65)	38.76 (38.45)	35.96bc (36.82)	29.79abc (33.06)	22.62a (28.34)	26.92ab (31.16)	32.49bc (34.75)	28.64
2	<i>Bacillus thuringiensis</i> var. <i>kurstaki</i> 1% WG	3	34.71	34.34 (35.68)	29.23 (32.7)	28.49ab (32.26)	28.90ab (32.51)	21.57a (27.59)	22.89a (28.54)	27.57ab (31.67)	39.44
3	<i>Beauveria bassiana</i> 1.15% 1×10^7 CFU	10	35.98	33.40 (35.26)	31.9 (34.34)	31.93b (34.26)	39.30c (38.79)	36.02b (36.86)	35.80bc (36.72)	34.73cd (36.11)	23.72
4	<i>Metarhizium anisopliae</i> 2% 1×10^7 CFU	10	39.50	35.64 (36.63)	27.27 (31.46)	22.58a (28.32)	26.70a (30.9)	20.65a (27.02)	20.37a (26.49)	25.54a (30.35)	43.90
5	<i>Lecanicillium lecanii</i> 1.15% 1×10^7 CFU	10	39.91	40.48 (39.5)	36.18 (36.8)	41.61c (40.15)	37.41bc (37.56)	40.60b (39.56)	34.96bc (36.16)	38.54d (38.38)	15.35
6	Control	--	41.33	40.32 (39.36)	39.28 (38.76)	43.95c (41.52)	50.38d (45.24)	55.15c (48.08)	44.10c (41.51)	45.53e (42.44)	--
	SE (d)		1.60	2.97	3.29	2.23	2.77	2.70	3.35	1.78	
	CD ($p < 0.01\%$)		4.73	8.76	9.71	6.57	8.17	7.97	9.89	4.78	

PTC- Pre-treatment count

*Mean of three replications; DAS – Days After Spraying

Means were analysed after arc sin transformation (values inside the parentheses)

Means followed by the same letter(s) are not statistically different by Tukey's test ($p < 0.01\%$)

Table 5: The leaf damage of maize due to fall armyworm, as influenced by various bio-pesticide treatments (Second spray)

S. No	Treatment details	Dosage (g/ml per liter)	*No. of damaged leaves/ 5 plants at indicated sprays and days								% reduction over control
			PTC	1	3	5	7	10	14	Mean	
1	Azadirachtin 1500 ppm	5	26.92ab (31.16)	28.22a (32.04)	26.34b (30.81)	22.85ab (28.45)	21.04ab (27.02)	21.41a (27.39)	25.18ab (30.10)	24.17ab (29.42)	50.70
2	<i>Bacillus thuringiensis</i> var. <i>kurstaki</i> 1% WG	3	22.89a (28.54)	22.39a (28.22)	17.55a (24.76)	18.84a (25.70)	14.07a (21.81)	19.34a (26.02)	21.99a (27.96)	19.03a (25.86)	61.18
3	<i>Beauveria bassiana</i> 1.15% 1×10^7 CFU	10	35.80bc (36.72)	28.49a (32.2)	32.05b (34.47)	27.83b (31.77)	25.59b (30.22)	25.40ab (30.03)	28.68ab (32.06)	28.01b (31.95)	42.87
4	<i>Metarhizium anisopliae</i> 2% 1×10^7 CFU	10	20.37a (26.49)	23.66a (29.07)	19.93a (26.33)	19.87ab (26.27)	17.58ab (24.77)	21.35a (27.36)	20.50a (26.90)	20.48ab (26.89)	58.22
5	<i>Lecanicillium lecanii</i> 1.15% 1×10^7 CFU	10	34.96bc (36.16)	35.16b (36.36)	42.62c (40.71)	38.59c (38.38)	28.92b (32.23)	33.99b (35.39)	33.24bc (35.11)	35.42c (36.49)	27.75
6	Control	--	44.10c (41.51)	49.81c (44.89)	49.36c (44.63)	49.49d (44.71)	49.17c (44.54)	51.94c (46.11)	44.42c (41.75)	49.03d (44.45)	--
	SE (d)		3.35	1.75	1.94	2.59	3.56	2.93	3.12	1.01	
	CD ($p < 0.01\%$)		9.89	5.16	5.74	7.63	10.49	8.64	9.19	2.82	

PTC- Pre-treatment count

*Mean of three replications; DAS – Days After Spraying

Means were analysed after arc sin transformation (values inside the parentheses)

Means followed by the same letter(s) are not statistically different by Tukey's test ($p < 0.01\%$)

The effect of bio-pesticides on the cob damage and yield of maize

The bio-pesticide treatments evaluated significantly reduced the cob damage when compared to the control plot ($F = 55.25$; $df = 5, 15$; $p < 0.0001$). The extent of cob damage ranged from 21.67% for the application of *B.t. var. kurstaki* to 46.88% in the control. *B.t. var. kurstaki* resulted in the lowest cob damage at 21.67% and the highest percent reduction over control (53.78%) whereas the highest cob damage was observed in *L. lecanii* (40.84%) treatment. A closely trailing reduction over control of 53.33% was observed with the use of *M. anisopliae*. In contrast, the least

reduction in cob damage, at a mere 12.88% over control, was observed in the *L. lecanii* (Table No. 6 & Fig No. 3).

Regarding yield, the highest yield of 1942 kg/ha was achieved in plots treated with *B.t. var. kurstaki*, a result comparable to the yield of 1930 kg/ha obtained from *M. anisopliae* ($F = 8.11$; $df = 5, 23$; $p < 0.01$). Additionally, the yield of 1750 kg/ha was obtained from the application of Azadirachtin, which was statistically similar to the yield of 1773 kg/ha from *B. bassiana*. The untreated control plot recorded a lowest yield of 1350 kg/ha (Table No. 6 & Fig No. 3).

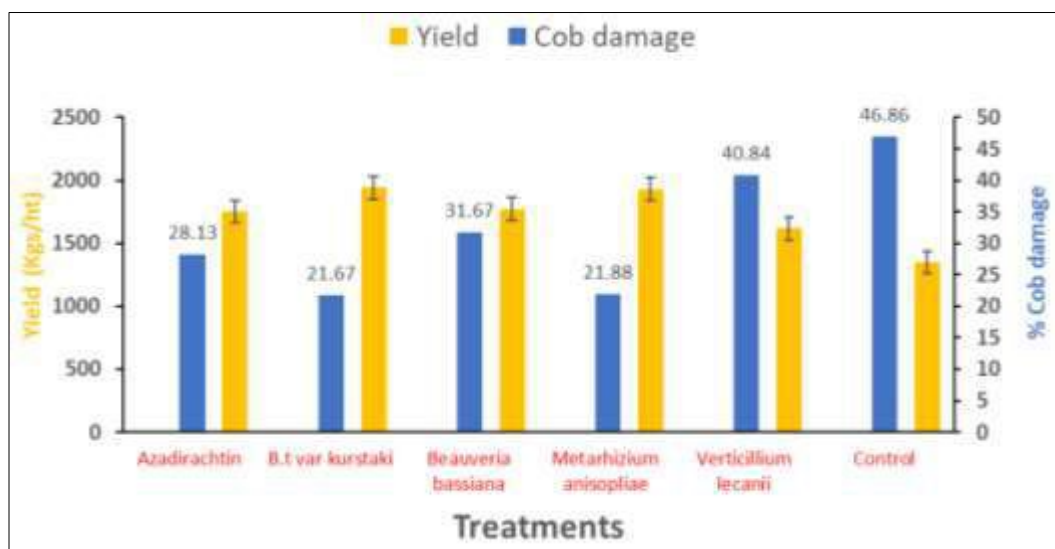
**Fig 3:** Cob damage and yield of maize influenced by different Bio-pesticide treatments – Rabi 2022-23

Table 6: Effect of different bio-pesticides on cob damage and yield of maize

S. No.	Treatment details	Dosage (g/ml/liter water)	Mean of four replications		
			*% Cob damage	% reduction over control	**Yield (kg/ha)
1	Azadirachtin 1500 ppm	5	28.13b (32.02)	40.00	1750ab
2	<i>Bacillus thuringiensis</i> var. <i>kurstaki</i> 1% WG	3	21.67a (27.73)	53.78	1942a
3	<i>Beauveria bassiana</i> 1.15% 1×10^7 CFU	10	31.67b (34.20)	32.44	1773ab
4	<i>Metarhizium anisopliae</i> 2% 1×10^7 CFU	10	21.88a (27.87)	53.33	1930a
5	<i>Lecanicillium lecanii</i> 1.15% 1×10^7 CFU	10	40.84c (39.69)	12.88	1616b
6	Control	--	46.88d (43.20)		1350c
SE (d)			1.19		0.02
CD ($p < 0.01\%$)			3.52		0.08

*Means were analysed after arc sin transformation (values inside the parentheses)

**Means were analysed after log transformation (values inside the parentheses)

Means followed by the same letter(s) are not statistically different by Tukey's test ($p < 0.01\%$)

Discussion

The field trial aimed to assess the efficacy of various native bio-pesticides against the fall armyworm in maize. The results of the trial demonstrated that all tested bio-pesticide formulations outperformed the control plot in terms of reducing fall armyworm larval populations and minimizing maize damage. The field trial identified *B.t* var *kurstaki* 1% WG as the most effective treatment against fall armyworm in terms of reducing larval populations and minimizing leaf damage in maize. *M. anisopliae* 2% also demonstrated notable efficacy as a native EPF formulation newly evaluated against fall armyworm. Montecalvo *et al.*, 2021^[10] also tested *M. anisopliae* against FAW reporting effective control in early stage larvae. Azadirachtin 1500 ppm and *B. bassiana* 1.15% showed moderate efficacy, while *L. lecanii* 1.15% exhibited the least effectiveness among all bio-pesticides evaluated. In Indian conditions studies related to the evaluation of native entomopathogenic fungi are very limited however, EPF like *M. anisopliae*, *B. bassiana* and another bio-pesticide *B.t* var *kurstaki* used for controlling the *Spodoptera* spp are tested against FAW, reported to cause mortality in early instars (Dhobi *et al.*, 2020)^[5]. The virulence of most of the EPF were analysed in native and African countries where the efficacy was quite attractive (Idrees *et al.*, 2022)^[6]. India, with its diverse ecological conditions, offers great potential for the availability of native biocontrol strains. Similar to the previously evaluated biocontrol agents, there is a need to assess different native strains in both laboratory and field conditions, especially in countries that are invaded by FAW, such as India. This presents ample opportunities for further commercialization.

Conclusion

Overall, the present field trial to evaluate different biopesticides in controlling FAW in maize concluded the commercial formulation *B.t. var kurstaki* was the most effective. Among the three native EPF strains evaluated, the *M. anisopliae* was superior to the remaining. Azadirachtin was effective in controlling the early stages of larvae. *L. lecanii* 1.15% treatment was poor performer in all the conditions.

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