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Evaluation of Biopesticides for Fall Armyworm *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) Control and Predator Safety in Maize Field Condition

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Fall armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae), is a major pest of maize worldwide. The objective of present study was to evaluate the effectiveness of various biopesticides for managing *S. frugiperda* infesting maize in vegetative (whorl) and reproductive (cob) stages, their effect on the predator, and their effects on yield in Indian conditions. A field trial was conducted in 2019-20 and 2020-21 using a randomized complete block design. The effect of biopesticides against *S. frugiperda* infesting maize indicated that all the treatments were found

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effective against fall armyworm as compared to untreated control in management practices applied at the vegetative (whorl) as well as reproductive (cob) stage of maize. Among the biopesticides, spinosad 45 SC was found most effective against fall armyworm followed by *Nomuraea rileyi* 2×10^8cfu/g. Among biopesticides treatments, pongamia oil 1% was safe for lady beetles and spiders followed by *Bacillus thuringienesis* 0.5% WP, *Metarhizium anisopliae* 2×10^8cfu/ml, *Beauveria bassiana* 2×10^8cfu/ml, Azadirachtin 10000 ppm and *Nomuraea rileyi* 2×10^8cfu/g. Economics of bio-pesticides management practices revealed that Spinosad 45 SC @ 0.3 ml/l was the most economical one recording the highest yield (130.63 q/ha) and ICBR 1:36.07. It was followed by *Nomuraea rileyi* @ 4 g/l, *Beauveria bassiana* @ 5 ml/l, and *Metarhizium anisopliae* @ 3 ml/l recording ICBR of 1:12.72, 1:11.73, and 1:11.57 respectively. This study has shown the potential use of biopesticides for the management of FAW. This would offer the farmers a sustainable and affordable option for the management of FAW.

Keywords: Biocontrol, spinosad; natural enemies; Metarhizium anisopliae; Nomuraea rileyi pongamia oil; Bacillus thuringienesis; ICBR.

1. INTRODUCTION

In India, maize plays a critical role in the agricultural practices of small and marginal farmers, primarily cultivated for sustenance and fodder. It holds the position of the third most vital food grain crop, following rice and wheat, contributing significantly, with a 10% share of the total food production (Shukla et al., 2022). Notably, maize serves as a dietary cornerstone for more than 200 million individuals, forming an essential component of their food security strategies (Day et al., 2017). Because maize grows quickly and produces a lot of food in India's weather, people can grow it all year round (Joshi et al., 2005). In India, maize is grown on a huge land area of 9.86 million hectares. This results in a massive production of 31.51 million tons, and the productivity is about 31.95 quintals per hectare, (FAO, 2021). This underscores the significance of maize in India. The fall armyworm, *Spodoptera frugiperda* (J. E. Smith, 1797) (Lepidoptera: Noctuidae), is one of the most destructive pests (Goergen et al., 2016, Day et al., 2017) and, In India it was first reported Sharanabasappa et al.,2018. It's important to note that the Fall Armyworm is a polyphagous pest. This invasive pest has been observed to consume over 353 different host plants from 76 plant families around the world (Montezano et al.,2018). This pest has inflicted significant economic losses, ranging from 22 to 67% annually on a global scale (Baudron et al., 2019). The Fall Armyworm's remarkable adaptability, coupled with its migratory behaviour and rapid reproductive rate, raises the potential for this pest to invade over 70 countries worldwide (CABI, 2022) Botanicals offer a promising, eco-friendly alternative to synthetic pesticides, with substantial potential for field application due to their insecticidal, repellent, or antifeedant properties when extracted and applied externally (Dudareva et al., 2006). Various parts of these plants, such as leaves, flowers, fruits, seeds, bark, or roots, contain a diverse array of secondary metabolites that can deter or poison insect pests. Numerous biopesticides are available for managing *S. frugiperda*, and one notable example is the cost-effective neem tree (*Azadirachta indica* L.) seed oil, which has been demonstrated to be an effective control measure against *S. frugiperda*, (Babendreier et al., 2020). The 20 plant species listed were used in West Africa for their pesticidal properties, specifically in the management of arthropod pests in vegetable crops (Yarou et al., 2017) Fungi possessing entomopathogenic properties can be easily integrated into (IPM) strategies (Reddy et al., 2013, Banu Zare et al., 2001 reported that more than 750 fungi, representing over 90 species, exhibit entomopathogenic characteristics. These fungi can penetrate an insect's outer layer and infect insects at any life stage. When conditions are favorable, they can lead to outbreaks in a variety of insect groups, particularly affecting Hemiptera, Coleoptera, and Lepidoptera, Shubakov et al., 2006,*Beauveria*, *Metarhizium*, *Verticilium*, and *Nomurea* are some of the commercially accessible genera (Chhetri et al., 2019) .Microbial biopesticides, like bacteria and fungi, are utilized to biologically control insects, plant pathogens, and weeds (Chandler et al.,2011, Deravel et al.,2013). The persistent use of pesticides and the ineffectiveness of current control methods in managing pests make it essential to develop Integrated Pest Management (IPM) strategies (Pretty and Pervez, 2015). The objective of this study is to evaluate biopesticides to manage fall armyworm on field conditions in two *rabi* seasons to find the best insecticides for its management.

2. MATERIALS AND METHODS

2.1 Study Site and Climate

The field experiment was conducted at the research farm, Tetawali block–B, Central Experiment Station, Wakawali, under Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli. Tetawali block–B, Central Experiment Station, Wakawali is located 20 km away from Dapoli, at an elevation of 167 to 234 m above mean sea level with latitude of 17^0 68’ to 17^0 72’ North and longitude of 73^0 24’ to 73^0 29’ East. The Soils of the Wakawali series are well-drained, deep to very deep, and non-calcareous occurring on lower pediments of the slopes. The temperature ranges from 13^0 C to 36^0 C, and annual average rainfall is 3500 mm.

2.2 Field Studies

Seven biopesticides and the control without any treatment (Table 1) were replicated 3 times. The maize variety Sugar-75 was planted at the Tetvali block field on 18^{th} December 2019 (*Rabi* 2019-20) and 24^{th} December 2020 (*Rabi* 2020-21). The seed was sown row to row and plant to plant with spacing 60cm x 20 cm in a plot size gross plot 3 m x 3 m (9 m^2) and net plot 2.4 m x 2.8 m (6.72 m^2) All the crop-raising practices including cultural practices, fertigation, and weed management were followed to maintain healthy crops, and no insecticides other than those included in the trial were applied.

2.3 Data Collection

Three sprayings of biopesticide treatments were done, the first two sprayings at 10-day intervals during the vegetative (whorl) stage of the crop while the third application was done during the reproductive (cob) stage. Bio-pesticide treatments were applied using a knapsack sprayer with a capacity of 15 liters. After spraying different biopesticides, thoroughly clean the sprayer between applications. The observation of the number of infested plant and total number of plants was recorded 1 d before and 3, 7, and 9 days after each treatment plot; the plants in the border rows were excluded. The predator population *viz*., lady beetles and spiders were recorded at weekly intervals on randomly selected 20 plants of each treatment after the application of different bio-pesticides management practices. Treatment-wise, marketable grain yield was recorded and was pooled and expressed in kg per ha. The yield per plot of maize in the experiment plots was recorded separately at the cob maturity and ICBR was worked out.

$$\text{Per cent leaf infestation} = \frac{No.of \text{ infested } plant\ observed}{Total\ no\ of\ plant\ observed} \text{x } 100$$

2.4 Statistical Analysis

The observations recorded on the percent infestation of FAW were transformed into angular (arc sin) values by using OPSTAT software. The observations recorded on the population of natural enemies (lady beetles and spiders) were transformed intoX+0.5 values and subjected to analysis of variance by using OPSTAT software (Sheoran et al., 1998). Web-based Statistical Software Package for Agricultural Research Workers developed by Hasija Department of Mathematics Statistics, CCS HAU, Hisar which is an open source software available online at https://hau.ac.in/page/o-p-stat.

Table 1. Details of bio-pesticides used against FAW infesting maize

Sr. No	Common Name	Trade Name	Formulation	Conc (%)	Source
1	*Metarhizium anisopliae*	Kalichakra	2×10^8 ^{c}fu/ml	0.3	International Panaacea,
2.	*Beauveria bassiana*	Bassigrin	2×10^8 cfu/ml	0.5	Green Earth Agrobiotech
3.	Azadirachtin	Econeem plus	10000 ppm	0.003	Margo Biocontrols Private Limited
4.	Spinosad	Tracer	45 % SC	0.0135	Dow Agosciences India Private Limited,
5.	*Bacillus thuringienesis*	Dipole	0.5% WP	0.001	Amit boiotech,
6.	Pongamia oil	Vionic	-	1	Sadan Agro Solution, Pune
7.	*Nomuraea rileyi*	-	2×10^8 cfu/g	0.4	Institute of Organic Farming, Yettingudda
8.	Control	-	-	-	-

3. RESULTS AND DISCUSSION

3.1 Efficacy of Different Bio-Pesticides for the Management of Fall Armyworm (Pooled *Rabi* 2019-20 & 2020-21)

3.1.1 At the vegetative (whorl) stage (First and second spray)

The pooled data about the efficacy of different bio-pesticides against FAW infesting maize one day before spray and 3, 7, and 9 days after the first and second spray are presented in (Table 2). The pre-spray infestation of *S. frugiperda* ranged from 12.84 to 22.21%, showing a statistically insignificant difference between treatments. Three days after the first spray, T4-spinosad 45SC exhibited the lowest infestation (2.76%), significantly outperforming the untreated control (19.34%). Seven days post-spray, T4-spinosad 45SC maintained the lowest infestation (0.45%), statistically superior to other treatments. Nine days after the spray, all treatments were significantly better than the untreated control (23.30%), with T4-spinosad 45SC having the lowest infestation (2.30%), on par with T7- *N. rileyi* (3.25%). T1-*M. anisopliae* was the next effective treatment (6.34%), comparable to T6-Pongamia oil (7.26%), T3-Azadirachtin (8.16%), and T2-*B. bassiana* (8.17%), and T5-*B. thuringienesis* (9.47%).

Three days after the second spray, T4-spinosad 45SC demonstrated the lowest infestation (1.17%), significantly surpassing the untreated control (24.47%). T7-*N. rileyi* (3.01%) and T1-*M. anisopliae* (5.85%) followed as the next effective treatment. Seven days post-spray, T4-spinosad 45SC maintained the lowest infestation (0.50%), outperforming all other treatments, with T7-*N. rileyi* (1.83%) as the next best. Nine days after the second spray, T4-spinosad 45SC again exhibited the lowest infestation (0.33%), significantly superior to other treatments, followed by T7-*N. rileyi* (0.83%) and T1-*M. anisopliae* (3.39%). At the vegetative stage of maize, T4-spinosad 45SC had the lowest infestation (1.25%), statistically superior to other treatments, with T7-*N. rileyi* (3.86%) and T1-*M. anisopliae* (6.24%) as the next effective treatment. The untreated control had the highest infestation (23.32%).The most significant reductions in infestation compared to the untreated control were found in T4-spinosad 45SC (94.63%), and T7-*N. rileyi* (83.44%), T1-*M. anisopliae* (73.24%), T3-Azadirachtin (70.62%), T6-Pongamia oil (69.76%), T2-*B. bassiana* (67.58%), and T5-*B. thuringienesis* (59.09%).

3.1.2 At the reproductive (cob) stage (Third spray)

The two-year pooled data about the efficacy of different biopesticides against FAW infesting maize on one day before spray and 3, 7, and 9 days after spray are presented in (Table 3). The combined two-year data on *S. frugiperda* infestation one day before spraying ranged from 6.89 to 13.74%, showing statistically nonsignificant uniform distribution in treatments and replications. Three days post-spray, T4-spinosad 45SC exhibited the lowest infestation (1.58%), significantly outperforming the untreated control (13.59%). Seven days post-spray, T4-spinosad 45SC maintained the lowest infestation (0.17%), surpassing all other treatments, with T7-*N. rileyi* (1.33%) as the next best. Nine days post-spray, all treatments were significantly superior to the untreated control (9.80%), with T4-spinosad 45SC having no infestation (0.00%). At the reproductive stage of maize, T4-spinosad 45SC showed the lowest infestation (0.58%), significantly superior to other treatments, with T7-*N. rileyi* (2.72%) as the next best. The highest reduction in infestation compared to the untreated control was observed in T4-spinosad 45SC (94.66%), and T7-*N. rileyi* (74.97%), T1-*M. anisopliae* (63.93%), and T2-*B. bassiana* (63.56%).The present findings are in close agreement with the earlier research work of Bajracharya et al., 2020 reported Spinosad 45 SC @ 0.3 ml/litre found consistently superior in reducing the fall armyworm infestation in maize. (Dhobi et al., 2020) revealed that the lowest larval population, minimum plant damage, and cob damage were observed in the plot treated with *Nomuraea rileyi* 1% with the highest grain and fodder yield. (Goergen et al., 2016) recorded the lowest damaged plants to the extent of 25.00 and 28.33 percent with the highest grain yield of maize (24.20 q/ha) obtained from *Nomuraea rileyi* @ 2.5 kg/ha applied in maize whorls.

3.1.3 Effect of different biopesticides on lady beetles (*Rabi* 2019-20 & *Rabi* 2020-21)

The data about the effect of different biopesticides on the lady beetles population in maize at every seven days intervals after the first, second, and third sprays are presented in (Table 4).

3.1.4 First spray

Seven days after the first spray, the highest lady beetle population was in T8- untreated control (3.75/plant). The next best treatment was T6–pongamia oil 1% (1.08/plant), statistically similar to T3- azadirachtin 10000 ppm (0.92/plant), T5- *B. thuringienesis* 0.5% WP (0.91/plant), T1- *M. anisopliae* 2×10^8 cfu/ml (0.84/plant), T2- *B. bassiana* 2×10^8 cfu/ml (0.81/plant), and T7- *N. rileyi* 2×10^8 cfu/g (0.58/plant). The lowest lady beetle population was in T4- spinosad 45 SC (0.17 per plant). Fourteen days after the first spray, the highest lady beetle population was again in T8- untreated control (3.80/plant). The next best treatment was T6 – pongamia oil 1% (1.23/plant), statistically similar to T5- *B. thuringienesis* 0.5% WP and T1- *M. anisopliae* 2×10^8 cfu/ml (0.93/plant), T3- azadirachtin 10000 ppm (0.92/plant), and T2- *B. bassiana* 2×108 cfu/ml (0.85/plant). The lowest lady beetle population was in T4- spinosad 45 SC (0.21 per plant).

3.1.5 Second spray

Seven days after the second spray, the highest lady beetle population was in T8- untreated control (3.75/plant). The next best treatment was T6– pongamia oil 1% (1.05/plant), statistically similar to T5- *B. thuringienesis* 0.5% WP (0.69/plant), T1- *M. anisopliae* 2×10^8 cfu/ml (0.68/plant), T2- *B. bassiana* 2×10^8 cfu/ml (0.55/plant), T3- azadirachtin 10000 ppm (0.53/plant), and T7- *N. rileyi* 2×10^8 cfu/g (0.44/plant). The lowest lady beetle population was in T4- spinosad 45 SC (0.15 per plant). Fourteen days after the second spray, the highest lady beetle population was again in T8- untreated control (3.82/plant). The next best treatment was T6– pongamia oil 1% (1.20/plant), statistically similar to T5- *B. thuringienesis* 0.5% WP and T2- *B. bassiana* 2×10^8 cfu/ml (0.95/plant), T1- *M. anisopliae* 2×10^8 cfu/ml (0.86/plant), and T3- azadirachtin 10000 ppm (0.74/plant). The lowest lady beetle population was in T4- spinosad 45 SC (0.52 per plant). Twenty-one days after the second spray, the highest lady beetle population was in T8- untreated control (4.02/plant). The next best treatment was T6– pongamia oil 1% (1.34/plant), statistically similar to T5- *B. thuringienesis* 0.5% WP (1.09/plant), T2- *B. bassiana* 2×10^8 cfu/ml (1.08/plant), T1- *M. anisopliae* 2×10^8 cfu/ml (1.03/plant), T3- azadirachtin 10000 ppm (0.91/plant), and T7- *N. rileyi* 2×10^8 cfu/g (0.81/plant). The lowest lady beetle population was in T4- spinosad 45 SC (0.68 per plant). Twenty-eight days after the second spray, the highest lady beetle population was in T8- untreated control (4.30/plant). The next best treatment was T6– pongamia oil 1% (1.38/plant), statistically similar to T5- *B. thuringienesis* 0.5% WP (1.12/plant), T2- B. bassiana 2×10^8 cfu/ml (1.10/plant), T1- *M. anisopliae* 2×10^8 cfu/ml (1.06/plant), T3- azadirachtin 10000 ppm (0.95/plant), and T7- *N. rileyi* 2×10^8 cfu/g (0.83/plant). The lowest lady beetle population was in T4- spinosad 45 SC (0.69 per plant).

3.1.6 Third spray

Seven days after the third spray, the highest lady beetle population was in T8- untreated control (4.27/plant). The next best treatment was T6 – pongamia oil 1% (0.93/plant), statistically similar to T1- *M. anisopliae* 2×10^8 cfu/ml and T2- *B. bassiana* 2×10^8 cfu/ml (0.75/plant), T5- *B. thuringienesis* 0.5% WP (0.71/plant), and T3- azadirachtin 10000 ppm (0.54/plant). The lowest lady beetle population was in T4- spinosad 45 SC (0.12 per plant). Fourteen days after the third spray, the highest lady beetle population was again in T8- untreated control (3.00/plant). The next best treatment was T6 – pongamia oil 1% (1.02/plant), statistically similar to T2- *B. bassiana* 2×10^8 cfu/ml (0.86/plant), T1- *M. anisopliae* 2×10^8 cfu/ml (0.83/plant), and T5- *B. thuringienesis* 0.5% WP (0.73/plant). The lowest lady beetle population was in T4- spinosad 45 SC (0.31 per plant).

3.1.7 Effect of different biopesticides on spiders (*Rabi* 2019-20 & *Rabi* 2020-21)

The data about the effect of different bio-pesticides on the spiders population in maize at every seven days intervals after the first, second, and third sprays are presented in Table 5.

3.1.8 First spray

Seven days after the first spray, the highest spider population was in T8- untreated control (1.80/plant). The next best treatment was T1- *M.anisopliae* 2×10^8 cfu/ml (1.13/plant), statistically similar to T3- Azadirachtin 10000 ppm and T5- *B. thuringienesis* 0.5% WP (1.12/plant), T6 – pongamia oil 1% (1.02/plant), T2- *B. bassiana* 2×10^8 cfu/ml (0.97/plant), and T7- N. rileyi 2×10^8 cfu/g (0.77/plant). The lowest spider population was in T4- spinosad 45 SC (0.13/plant). Fourteen days after the first spray, the highest spider population was again in T8- untreated control (1.95/plant). The next best treatment was T5- *B. thuringienesis* 0.5% WP (1.20/plant), statistically similar to T1- *M. anisopliae* 2×108 cfu/ml and T3- azadirachtin 10000 ppm (1.18/plant), T6 – pongamia oil 1% (1.08/plant), T2- *B. bassiana* 2×10^8 cfu/ml (0.97/plant), and T7- *N. rileyi* 2×10^8 cfu/g (0.85/plant). The lowest spider population was in T4- spinosad 45 SC (0.25/plant).

Table 2. Effect of bio-pesticides against *S. frugiperda* infesting maize at the vegetative (whorl) stage (pooled)

Tr . No.	Per cent infestation of *S. frugiperda*							The overall mean of two spray	Percent reduction over untreated control
	First Spray				Second spray				
	Precount	3DAS	7DAS	9DAS	3DAS	7DAS	9DAS		
T_1	14.66 (22.41)	12.39 (20.61)	5.59 (13.58)	6.34 (14.43)	5.85 (13.97)	3.85 (11.29)	3.39 (10.60)	6.24 (14.08)	73.24
T_2	19.77 (25.75)	12.05 (20.16)	7.80 (15.85)	8.17 (16.59)	8.49 (16.91)	4.34 (11.96)	4.53 (12.25)	7.56 (15.62)	67.58
T_3	12.84 (20.97)	11.49 (19.78)	5.99 (12.93)	8.16 (16.58)	7.37 (15.75)	4.20 (11.80)	3.91 (11.33)	6.85 (14.70)	70.62
T_4	13.15 (21.16)	2.76 (9.40)	0.45 (3.11)	2.30 (8.29)	1.17 (6.04)	0.50 (4.05)	0.33 (2.70)	1.25 (5.60)	94.63
T_5	22.21 (28.01)	13.63 (21.65)	9.64 (18.08)	9.47 (17.91)	10.21 (18.63)	7.67 (16.08)	6.64 (14.93)	9.54 (17.88)	59.09
T_6	14.36 (21.97)	10.73 (19.04)	6.51 (14.73)	7.26 (15.60)	7.59 (15.98)	5.20 (13.16)	4.98 (12.88)	7.05 (15.23)	69.76
T_7	16.72 (23.88)	11.09 (19.45)	3.17 (10.09)	3.25 (10.35)	3.01 (9.95)	1.83 (7.58)	0.83 (5.13)	3.86 (10.43)	83.44
T_8	14.43 (22.33)	19.34 (25.93)	20.31 (26.78)	23.30 (28.83)	24.47 (29.60)	25.36 (30.23)	27.13 (31.38)	23.32 (28.79)	-
SE (m)	**2.56**	**1.18**	**2.12**	**1.09**	**0.83**	**0.71**	**0.79**	**1.12**	**-**
CD at 5%	**NS**	**3.59**	**6.43**	**3.31**	**2.51**	**2.14**	**2.40**	**3.40**	**-**

Figures in parenthesis are arc sin transformed values; DAS – Days After Spraying

Table 3. Effect of bio-pesticides against *S. frugiperda* infesting maize at reproductive (cob) stage (pooled)

Tr.No.	% infestation of *S. frugiperda* Third spray at reproductive (cob) stage				Mean	% the reduction over untreated control
	Precount	3DAS	7DAS	9DAS		
T_1	7.64 (15.80)	6.02 (14.16)	2.92 (9.80)	2.83 (9.66)	3.92 (11.21)	63.93
T_2	7.98 (16.25)	5.82 (13.94)	3.26 (10.37)	2.81 (9.59)	3.96 (11.30)	63.56
T_3	13.32 (20.89)	10.37 (18.76)	4.75 (12.57)	3.28 (10.41)	6.13 (13.91)	43.60
T_4	6.89 (14.80)	1.58 (7.16)	0.17 (1.35)	0.00 (0.00)	0.58 (2.84)	94.66
T_5	13.74 (20.93)	9.75 (18.13)	3.82 (11.25)	3.01 (9.94)	5.53 (13.11)	49.12
T_6	12.07 (20.22)	9.78 (18.16)	5.61 (13.65)	3.59 (10.88)	6.33 (14.23)	41.76
T_7	9.86 (18.08)	5.93 (14.03)	1.33 (5.24)	0.91 (5.39)	2.72 (8.22)	74.97
T_8	11.74 (19.98)	13.59 (21.61)	9.23 (17.65)	9.80 (18.18)	10.87 (19.15)	-
SE (m)	**2.75**	**0.86**	**1.22**	**0.69**	**0.92**	**-**
CD at 5%	**NS**	**2.61**	**3.70**	**2.10**	**2.80**	**-**

Figures in parenthesis are arc sin transformed values; DAS – Days After Spraying

Table 4. Effect of bio-pesticides on population of lady beetles in maize (pooled)

Tr.No.	Mean population of lady beetles per plant								Overall mean
	First spraying		Second spraying				Third spraying		
	7DAS	14DAS	7DAS	14DAS	21DAS	28DAS	7DAS	14DAS	
T_1	0.84 (1.16)	0.93 (1.19)	0.68 (1.08)	0.86 (1.16)	1.03 (1.23)	1.06 (1.24)	0.75 (1.12)	0.83 (1.15)	0.87 (1.17)
T_2	0.81 (1.14)	0.85 (1.16)	0.55 (1.00)	0.95 (1.20)	1.08 (1.25)	1.10 (1.26)	0.75 (1.12)	0.86 (1.16)	0.87 (1.16)
T_3	0.92 (1.17)	0.92 (1.18)	0.53 (1.02)	0.74 (1.11)	0.91 (1.17)	0.95 (1.19)	0.54 (1.02)	0.68 (1.08)	0.77 (1.12)
T_4	0.17 (0.82)	0.21 (0.84)	0.15 (0.80)	0.52 (1.01)	0.68 (1.08)	0.69 (1.09)	0.12 (0.78)	0.31 (0.89)	0.36 (0.91)
T_5	0.91 (1.19)	0.93 (1.19)	0.69 (1.09)	0.95 (1.20)	1.09 (1.26)	1.12 (1.27)	0.71 (1.10)	0.73 (1.11)	0.89 (1.18)
T_6	1.08 (1.26)	1.23 (1.31)	1.05 (1.23)	1.20 (1.30)	1.34 (1.35)	1.38 (1.37)	0.93 (1.20)	1.02 (1.23)	1.15 (1.28)
T_7	0.58 (1.04)	0.62 (1.05)	0.44 (0.97)	0.65 (1.06)	0.81 (1.12)	0.83 (1.13)	0.42 (0.96)	0.48 (0.99)	0.60 (1.04)
T_8	3.75 (2.05)	3.80 (2.06)	3.75 (2.05)	3.82 (2.07)	4.02 (2.11)	4.30 (2.18)	4.27 (2.17)	3.00 (1.87)	3.84 (2.07)
SE (m)	**0.08**	**0.07**	**0.09**	**0.08**	**0.13**	**0.12**	**0.07**	**0.04**	**0.09**
CD at 5%	**0.24**	**0.21**	**0.27**	**0.23**	**0.39**	**0.37**	**0.22**	**0.12**	**0.26**

Figures in parenthesis are X+0.5 transformed values; DAS - Days After Spraying

Table 5. Effect of bio-pesticides on the population of spiders in maize (pooled)

Tr.No.	Mean population of spiders per plant								Overall mean
	First spraying		Second spraying				Third spraying		
	7DAS	14DAS	7DAS	14DAS	21DAS	28DAS	7DAS	14DAS	
T_1	1.13 (1.28)	1.18 (1.30)	1.03 (1.24)	1.10 (1.26)	1.17 (1.29)	1.23 (1.31)	0.88 (1.17)	0.82 (1.14)	1.07 (1.24)
T_2	0.97 (1.21)	0.97 (1.21)	0.93 (1.20)	1.00 (1.22)	1.07 (1.25)	1.17 (1.29)	0.97 (1.21)	0.95 (1.20)	1.00 (1.22)
T_3	1.12 (1.27)	1.18 (1.30)	1.10 (1.26)	1.18 (1.30)	1.25 (1.32)	1.32 (1.35)	1.12 (1.27)	1.03 (1.24)	1.16 (1.28)
T_4	0.13 (0.79)	0.25 (0.85)	0.12 (0.78)	0.22 (0.84)	0.28 (0.87)	0.35 (0.91)	0.12 (0.78)	0.13 (0.79)	0.20 (0.82)
T_5	1.12 (1.27)	1.20 (1.30)	1.12 (1.27)	1.18 (1.29)	1.25 (1.32)	1.32 (1.34)	0.98 (1.22)	0.92 (1.19)	1.14 (1.27)
T_6	1.02 (1.23)	1.08 (1.26)	1.03 (1.24)	1.10 (1.26)	1.17 (1.29)	1.23 (1.31)	0.97 (1.21)	0.90 (1.18)	1.06 (1.24)
T_7	0.77 (1.10)	0.85 (1.15)	0.80 (1.13)	0.87 (1.16)	0.93 (1.19)	1.00 (1.22)	0.75 (1.11)	0.65 (1.07)	0.83 (1.14)
T_8	1.80 (1.52)	1.95 (1.57)	2.25 (1.66)	2.58 (1.76)	3.05 (1.88)	3.18 (1.92)	3.30 (1.95)	3.17 (1.91)	2.66 (1.77)
SE (m)	**0.06**	**0.06**	**0.05**	**0.06**	**0.06**	**0.06**	**0.05**	**0.04**	**0.05**
CD at 5%	**0.19**	**0.19**	**0.16**	**0.18**	**0.19**	**0.20**	**0.14**	**0.13**	**0.17**

Figures in parenthesis are X+0.5 transformed values; DAS - Days After Spraying

Table 6. Yield and incremental cost-benefit ratio of different bio-pesticide treatments (Pooled)

Tr. No.	Treatments	Qty. of bio-pesticides req./ha for three spray	Cost of treatment (Rs/ha) for three spray		Total cost (A)	Yield q/ha	Incremental yield over control (q/ha)	Value of increased yield (Rs/ha) (B)	Increment benefit (C)=(B-A) over control	ICBR (C/A)
			Bio-pesticides	Labour + Application charges						
T_1	*Metarhizium anisopliae* @ 3 ml/l	4500 ml	2250.00	2700.00	4950.00	81.37	15.56	62240.00	57290.00	1:11.57
T_2	*Beauveria bassiana* @ 5 ml/l	7500 ml	2625.00	2700.00	5325.00	82.76	16.95	68800.00	62475.00	1:11.73
T_3	Azadirachtin 10000 ppm @ 3/l	4500 ml	7200.00	2700.00	9900.00	90.96	25.15	100600.00	90700.00	1:09.16
T_4	Spinosad 45 SC @ 0.3/l	450 ml	4295.25	2700.00	6995.25	130.63	64.82	259280.00	252228.75	1:36.07
T_5	*Bacillus thuringienesis* 0.5% WP @ 2 g/l	3000 gm	6000.00	2700.00	8700.00	86.85	21.04	84160.00	75460.00	1:08.67
T_6	Pongamia oil @ 10 ml/l	15000 ml	21210.00	2700.00	23910.00	82.69	16.88	67520.00	43610.00	1:01.82
T_7	*Nomuraea rileyi* @ 4 g/l	6000 g	9000.00	2700.00	11700.00	105.96	40.15	160600.00	148900.00	1:12.72
T_8	Untreated control	-	-	-	-	65.81	-	-	-	-

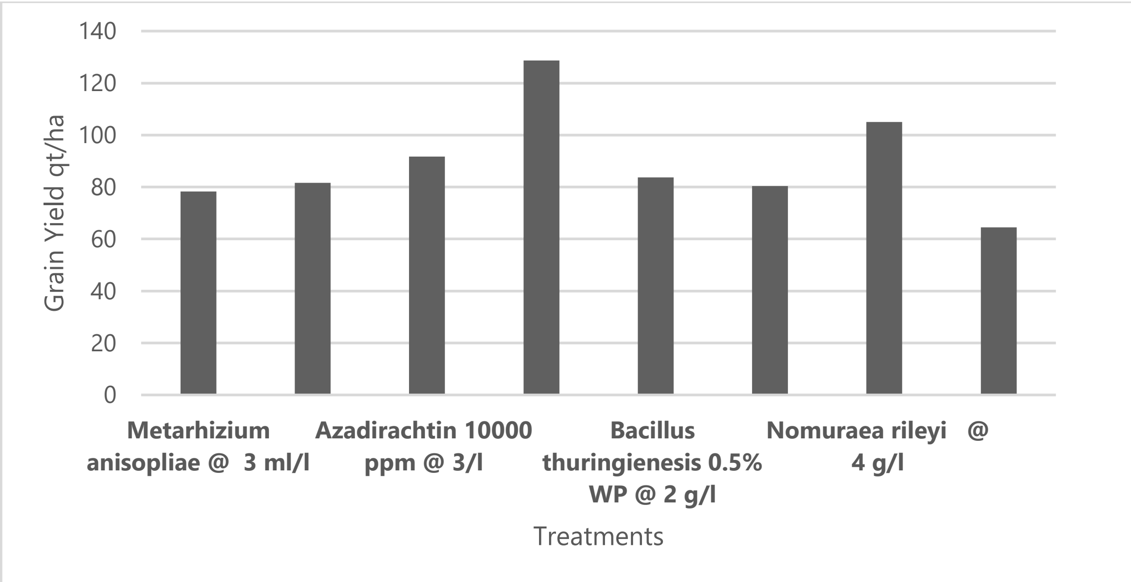

Fig. 1. Grain yield in field efficacy treatments in *rabi* 2019-20

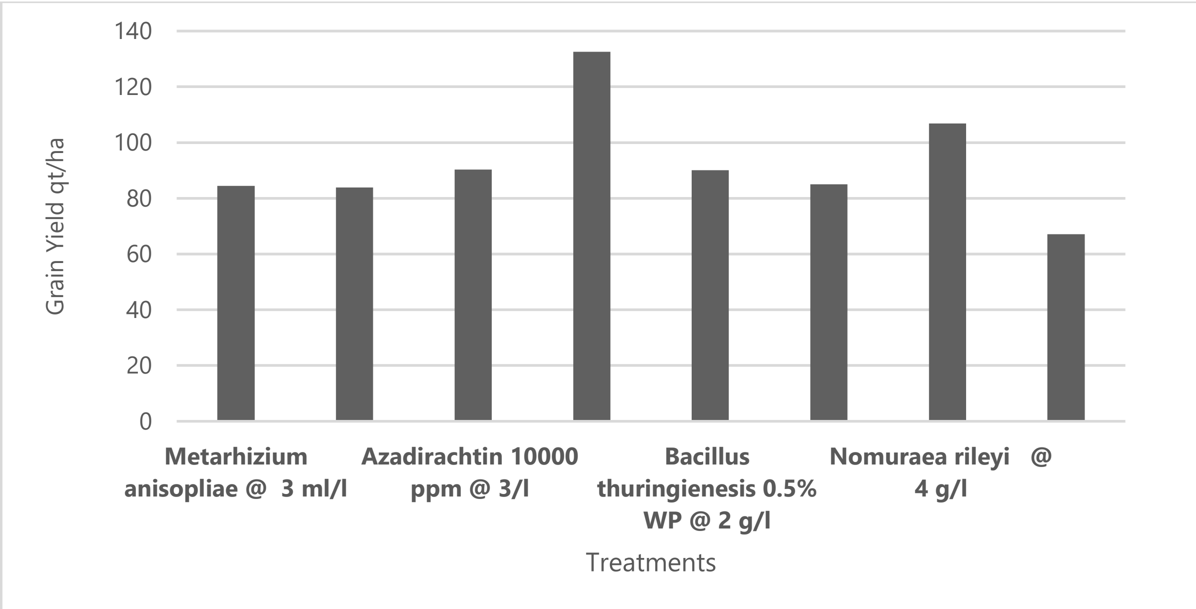

Fig. 2. Grain yield in field efficacy treatments in *rabi* 2020-21

3.1.9 Second spray

Seven days after the second spray, the highest spider population was in T8- untreated control (2.25/plant). The next best treatment was T5- *B. thuringienesis* 0.5% WP (1.12/plant), statistically similar to T3- azadirachtin 10000 ppm (1.10/plant), T1- *M. anisopliae* 2×10^8 cfu/ml and T6 – pongamia oil 1% (1.03/plant), T2- *B. bassiana* 2×10^8 cfu/ml (0.93/plant), and T7- *N. rileyi* 2×10^8 cfu/g (0.80/plant). The lowest spider population was in T4- spinosad 45 SC (0.12/plant). Fourteen days after the second spray, the highest spider population was again in T8- untreated control (2.58/plant). The next best treatment was T3- azadirachtin 10000 ppm and T5- *B. thuringienesis* 0.5% WP (1.18/plant), statistically similar to T1- *M. anisopliae* 2×10^8 cfu/ml and T6 – pongamia oil 1% (1.10/plant), T2- *B. bassiana* 2×10^8 cfu/ml (1.00/plant), and T7- *N. rileyi* 2×10^8 cfu/g (0.87/plant). The lowest spider population was in T4- spinosad 45 SC (0.22/plant). Twenty-one days after the second spray, the highest spider population was in T8- untreated control (3.05/plant). The next best treatment was T3- azadirachtin 10000 ppm and T5- *B. thuringienesis* 0.5% WP (1.25/plant), statistically similar to T1- *M. anisopliae* 2×10^8 cfu/ml and T6 – pongamia oil 1% (1.17/plant), T2- *B. bassiana* 2×10^8 cfu/ml (1.07/plant), and T7- *N. rileyi* 2×10^8 cfu/g (0.93/plant). The lowest spider population was in T4- spinosad 45 SC (0.28/plant). Twenty-eight days after the second spray, the highest spider population was in T8- untreated control (3.18/plant). The next best treatment was T3- azadirachtin 10000 ppm and T5- *B. thuringienesis* 0.5% WP (1.32/plant), statistically similar to T1- *M. anisopliae* 2×10^8 cfu/ml and T6 – pongamia oil 1% (1.23/plant), T2- *B. bassiana* 2×10^8 cfu/ml (1.17/plant), and T7- *N. rileyi* 2×10^8 cfu/g (1.00/plant). The lowest spider population was in T4- spinosad 45 SC (0.35/plant).

3.1.10 Third spray

Seven days after the third spray, the highest spider population was in T8- untreated control (3.30/plant). The next best treatment was T3- azadirachtin 10000 ppm (1.12/plant), statistically similar to T5- *B. thuringienesis* 0.5% WP (0.98/plant), T2- *B. bassiana* 2×10^8 cfu/ml and T6 – pongamia oil 1% (0.97/plant), T1- *M. anisopliae* 2×10^8 cfu/ml (0.88/plant). The lowest spider population was in T4- spinosad 45 SC (0.12/plant). Fourteen days after the third spray, the highest spider population was again in T8- untreated control (3.17/plant). The next best treatment was T3- azadirachtin 10000 ppm (1.03/plant), statistically similar to T2- *B. bassiana* 2×10^8 cfu/ml (0.95/plant), T5- *B. thuringienesis* 0.5% WP (0.92/plant), T6 – pongamia oil 1% (0.90/plant), and T1- *M. anisopliae* 2×10^8 cfu/ml (0.82/plant). The lowest spider population was in T4- spinosad 45 SC (0.13/plant). The overall mean data of the three sprays showed a significant difference among the treatments. The highest spider population was in T8- untreated control (2.66/plant). The next best treatment was T3- azadirachtin 10000 ppm (1.16/plant), statistically similar to T5- *B. thuringienesis* 0.5% WP (1.14/plant), T1- *M. anisopliae* 2×10^8 cfu/ml (1.07/plant), T6 – pongamia oil 1% (1.06/plant), T2- *B. bassiana* 2×10^8 cfu/ml (1.00/plant), and T7- *N. rileyi* 2×10^8 cfu/g (0.83/plant). The lowest spider population was in T4- Spinosad 45 SC (0.20/plant).The descending order of spider population was T8- untreated control, T3- azadirachtin 10000 ppm, T5- *B. thuringienesis* 0.5% WP, T1- *M. anisopliae* 2×10^8 cfu/ml, T6 – pongamia oil 1%, T2- *B. bassiana* 2×10^8 cfu/ml, T7- *N. rileyi* 2×10^8 cfu/g, and T4- spinosad 45 SC.

The present findings are in close agreement with earlier research workers, (Ghosh, 2013) reported botanical extract, *Polygonum hydropiper* floral part, the pathogens, *Beauveria bassiana* (Bals.) Vuillemin and *Bacillus thuringiensis* Berliner caused significantly lower killing spider (less than 30 %) on lady's fingers. (Muddasir et al.,2015). revealed that the reduction in spider population was 42.18%, 36.68%, and 33.38% with Spinosad, *A. indica* (20% conc.) and *E. globolus* (20% conc.), respectively in rice field. (Golvankar et al.,2019). revealed that *Btk* 1.5 g/lit, *HaNPV* 500 LE /ha, *Beauveria bassiana* 5 g/lit, *Metarhizium anisopliae* 5 g/lit, Azadirachtin 50000 ppm 0.8 ml/lit, was safer to lady beetles and spiders showing an equal number of population in range 1.38 to 7.00 and 0.50 to 3.75 per five plants respectively. (Singh et al., 2020 revealed that *Bacillus thuringiensis* @ 2.0 gm/liter and Neem oil (1500 ppm) @ 5.00 ml/liter were found safe against spiders population. (Gaikwad et al., 2020) revealed that among the tested biopesticides LAMIT 0.6 percent, eucalyptus oil 0.2 percent, karanj oil 0.5 percent and biomix 0.3 percent recorded the maximum population of coccinellids. It was followed by, *B. bassiana* 0.4 per cent, Neem oil 0.2 per cent, NSKE 5 per cent, *V. lecanii* 0.4 per cent, *Metarhizium* + *B. bassiana* 0.4 per cent, and dashparni ark 0.6 per cent. (Ashram and Salma,

2021) reported the highest mortality to treated *C. carnea* larvae by spinosad at 38.07% and low mortality with abamectin at 13.85%.

3.2 Effect of Different Bio-Pesticide Treatments on the Yield of Maize

During the *Rabi* 2019-20 season, superior marketable corn yield of maize was observed in T1 - spinosad 45 SC @ 0.3 ml/l (128.67 q/ha), on par with T7 - *N rileyi* @ 4 g/l (105.07 q/ha). Following closely were T3- azadirachtin 10000 ppm @ 3ml/l, T5- *B. thuringienesis* 0.5% WP @ 2 g/l, T2- *B. bassiana* @ 5 ml/l, T6- pongamia oil @ 10 ml/l, and T1- *M. anisopliae* @ 3 ml/l, recording 91.67, 83.67, 81.67, 80.33, and 78.33 q/ha marketable corn yield of maize, respectively. The lowest marketable corn yield of maize (64.48 q/ha) was noted in T8- untreated control.

In the *Rabi* 2020-21 season, T1 - spinosad 45 SC @ 0.3 ml/l (132.59 q/ha) exhibited the highest marketable corn yield of maize, on par with T7 – *N. rileyi* @ 4 g/l (106.85 q/ha). The subsequent top-performing treatments were T3- azadirachtin 10000 ppm @ 3ml/l, T5- *B. thuringienesis* 0.5% WP @ 2 gm/l, T6- pongamia oil @ 10 ml/l, T1- *M. anisopliae* @ 3 ml/l, and T2- *B. bassiana* @ 5 ml/l, recording 90.26, 90.04, 85.04, 84.41, and 83.85 q/ha marketable corn yield of maize, respectively. The lowest marketable corn yield of maize (67.15 q/ha) was recorded in T8- untreated control.

3.3 Incremental Cost Benefit Ratio (ICBR)

Considering the cost of inputs for different treatments and corresponding yield from the treatments, the incremental cost benefit ratio (ICBR) of all treatments was worked out at prevailing market rates and the data are presented in (Table 6).The data revealed that the treatment T_1- Spinosad 45 SC @ 0.3 ml/l emerged as the most economical one recording highest ICBR 1:36.07 and it was followed by T_7- *Nomuraea rileyi* @ 4 g/l, T_2- *Beauveria bassiana* @ 5 ml/l and T_1- *Metarhizium anisopliae* @ 3 ml/l recording ICBR of 1:12.72, 1:11.73 and 1:11.57 respectively. Next economic treatments were T_3- Azadirachtin 10000 ppm @ 3ml/l, T_5- *Bacillus thuringienesis* 0.5% WP @ 2 g/l and T_6- Pongamia oil @ 10 ml/l which recorded ICBR 1:09.16, 1:08.67 and 1:01.82, respectively. The findings of the present investigations are more or less similar with the findings of (Dhobi et al., 2020) reported the highest grain and fodder yield was recorded from the plot treated with *N. rileyi* 1% WP (2957 and 4069 kg/ha) and followed by *B. thuringiensis* (2932 and 4033 kg/ha). (Shinde et al., 2020) reported highest benefit cost ratio in treatment *Nomuraea rileyi* @ 2.5 kg/ha (1:7.2) followed by *Metarhizium anisopliae* @ 2.5 kg/ha (1:5.9), *Beauveria bassiana* @ 2.5 kg/ha (1:2.9). (Gouthami et al., 2020). reported ICBR ratio of (1:8.08) for Spinosad 45SC @ 0.3ml/l.

4. CONCLUSION

The present findings have demonstrated that the management practices against *S. frugiperda* infesting maize were effective as compared to untreated control in management practices applied at the vegetative (whorl) as well as reproductive (cob) stage of maize. Among the bio-pesticides, Spinosad 45 SC was found most effective against fall armyworm followed by *Nomuraea rileyi* 2×10^8 cfu/g. The effect of bio-pesticides treatments, Pongamia oil 1% was safe for lady beetles and spiders followed by *Bacillus thuringienesis* 0.5% WP, *Metarhizium anisopliae* 2×10^8 cfu/ml, *Beauveria bassiana* 2×10^8 cfu/ml, Azadirachtin 10000 ppm and *Nomuraea rileyi* 2×10^8cfu/g. In economics, Spinosad 45 SC @ 0.3 ml/l emerged as the most economical one recording the highest yield (130.63 q/ha) and ICBR 1:36.07. It was followed by *Nomuraea rileyi* @ 4 g/l, *Beauveria bassiana* @ 5 ml/l, and *Metarhizium anisopliae* @ 3 ml/l recording ICBR of 1:12.72, 1:11.73, and 1:11.57, respectively.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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