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Evaluation of Biopesticides against Fall Armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) in Maize during *Rabi*

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ABSTRACT: With the basic principle of integrated pest management (IPM) and searching for effective and sustainable alternatives for the management of *Spodoptera frugiperda* in maize different biopesticides were evaluated at Main Agricultural Research Station (MARS), UAS Raichur, Karnataka during *Rabi* 2019 cropping season. The experiment was laid in a Randomized Complete Block Design (RCBD) with three replications and seven treatments. Biopesticides such as *Metarhizium rileyi, Sf* NPV and *Bacillus thuringiensis* var. *kurstaki* were found to be the best treatments in reducing the larval population and per cent leaf damage compared to untreated control at five and seven days after two sprays. The yield and cost economics also showed that they were economically viable biopesticides.

Keywords: *Bacillus,* Biopesticides, *Metarhizium,* Rabi, SfNPV, *Spodoptera.*

INTRODUCTION

In recent years, India has invaded by a new insect pest, Fall Armyworm, *S. frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae), that has become a major threat by causing severe damage to maize. In addition to maize, it has also been reported to infest more than 300 other plant species (Anon., 2020). Among them, the most preferred host plants are maize, rice, sorghum and sugarcane (Pogue, 2002; Nagoshi *et al*., 2007; Bueno *et al*., 2010). A total of 353 *S. frugiperda* larval host plants recorded belonging to 76 plant families, principally Poaceae (106), Asteraceae (31) and Fabaceae (31) (Montezano *et al.*, 2019). The fall armyworm, *S. frugiperda* is a major pest of maize (*Zea mays*) and was previously restricted only to the Americas (Cruz *et al.*, 1999). A severe outbreak of FAW in maize was reported from African countries such as Sao Tome, Nigeria, Benin and Togo in 2016 (Goergen *et al.*, 2016). Subsequently, the pest has spread rapidly to over 44countries in sub-Saharan Africa causing significant damage to crops (Prasanna *et al*., 2018). Recently this dreaded pest has been reported from Karnataka in India on maize crop (Ganiger *et al.*, 2018; Sharanabasappa *et al*., 2018). Similarly, the occurrence of this pest in severe form was noticed in maize growing areas of Raichur.

The developing larvae eat different parts of the host plant, depending on the stage of the crop. In maize, larger larvae can cut the base of the plant. Blossomed plants suffer more due to larvae as it feeds on reproductive parts. Young larvae skeletonize the leaf lamina in a typical 'window-pane' damage at the early whorl stage. Usually, many young larvae will be present on the same plant, but normally one or two older larvae may be found on a single plant, as others will migrate and feed on neighbouring plants. Later larval instars make larger holes, causing ragged whorl leaves, and produce sawdust-like larval droppings, while fresh feeding produces big lumps. Fall armyworm can also destroy silks and developing tassels, thereby limiting fertilization of the ear. Maize plants may have the cobs attacked by larvae boring through the kernels. Damage to cobs may lead to fungal infection and aflatoxins, and loss of grain quality (Anon., 2020).

The current report of *S. frugiperda* from India is alarming because of its polyphagous nature. Therefore, the recent invasion, ensuing future spread and the possibility of the emergence of new hybrid races of *S. frugiperda* pose a significant risk to national food security. Thus, curtailing the spread and establishment of this pest in India and Indian subcontinent is a need of the hour. Insecticides pose threat to natural enemies and also ecosystem. So, the goal or ambition of the present investigation was to study the bio-efficacy of biopesticides in the field for its management.

MATERIAL AND METHODS

A field experiment was conducted at Main Agricultural Research Station, Raichur to evaluate the effect of different insecticides to manage fall armyworm during *Rabi* 2019-2020. The experiment was laid in a Randomized Block Design (RBD) with three replications and seven treatments. The whole area was divided into individual treatments of 5.4 × 3.3 m^2 and seeds of hybrid maize (Dhanvi 166) was sown in the main field with a spacing of 90 × 30 cm^2. All the management practices except the plant protection measures against fall armyworm were adopted as per the recommended package of practices. The other insect pests encountered during the study were managed using the recommended insecticides. The treatment details are given in Table 1.

Table 1: Treatment details of different biopesticides used for management of fall armyworm, *S. frugiperda.*

Tr. No.	Treatment details	Dosage	Source of procurement
T1	*Bacillus thuringiensis* var. *kurstaki* (BtG4)	2.00 ml/l	ICAR-NBAIR, Bengaluru
T2	*Sf*NPV	2.00 ml/l	ICAR-NBAIR, Bengaluru
T3	*Metarhizium rileyi*	4.00 g/l	Biocontrol unit, Dharwad
T4	*Metarhizium anisopliae* (Ma4)	4.00 g/l	Biocontrol unit, Raichur
T5	*Beauveria bassiana* (Bb5)	4.00 g/l	ICAR-NBAIR, Bengaluru
T6	*Metarhizium anisopliae* (Ma4)	2.00 ml/l	ICAR-NBAIR, Bengaluru
T7	Untreated control	--	--

Observations on fall armyworm larval population and per cent leaf damage was recorded one day before and on 3, 5, 7 and 15 days after imposition of treatments. Initiation of treatments were taken up on the appearance of fall armyworm using manually operated knack sack sprayer twice during the experimentation. Observations were made on the number of fall armyworm larvae and per cent leaf damage from five randomly tagged plants before treatment imposition. The per cent leaf damage caused by larvae of fall armyworm was estimated through visual scoring in 0-9 scale as described by Davis and Williams (1992). The per cent leaf damage caused by larvae of fall armyworm was calculated using the formula mentioned below.

$$\text{Per cent leaf damage} = \frac{\text{Number of damaged leaves}}{\text{Total number of leaves}} \times 100$$

The data obtained in the experiments in the current investigation for parameters such as the number of fall armyworm larvae were subjected to square root transformation and per cent leaf damage was subjected to arcsine transformation. Transformed values were analyzed using ANOVA for a randomized complete block design (RCBD). Reduction in pest population and leaf area damage over untreated control was calculated by using the formula mentioned below.

$$\text{Per cent reduction over control} = \frac{\text{Control - Treatment}}{\text{Control}} \times 100$$

RESULTS AND DISCUSSION

Number of larvae. A day before the first spray, the number of larvae were counted, the pest population ranged from 2.47 to 3.00 larvae per plant and found non-significant difference across the treatments. At three days after the first spray, the population ranged from 2.53 to 3.07 larvae per plant. Maximum number of larvae noticed in untreated control (3.07 larvae/plant) and minimum numbers were found in *M. rileyi* (2.53 larvae/plant). The results revealed the non-significant difference among all the treatments including untreated control. At fifth days after the first spray, the treatments showed a noticeable reduction in the number of larvae compared to earlier observations. The population ranged from 1.00 to 3.13 larvae per plant, this indicated the considerable difference among the treatments. The least number of larvae were noted in the treatment sprayed with *M. rileyi* (1.00 larva/plant) succeeded by *Sf* NPV (1.20 larvae/plant) and *B. thuringiensis* var. *kurstaki* (1.27 larvae/plant) which were significantly on par with each other. The treatments, *B. bassiana* (1.33 larvae/plant), *M. anisopliae* @ 4.00 g/l (1.67 larvae/plant) and *M. anisopliae* @ 2.00 ml/l (2.00 larvae/plant) performed better compared to untreated control (3.13 larvae/plant). The untreated control was found statistically inferior to all other treatments.

The population of FAW larvae seven days after treatment imposition was ranged from 1.07 to 3.20 larvae per plant. The number of larvae were minimal in *M. rileyi* (1.07 larvae/plant) treated plots which was found to be the superior biopesticide among all followed by *Sf* NPV (1.27 larvae/plant) and *B. thuringiensis* var. *kurstaki* (1.27 larvae/plant) which were significantly on par with each other. The treatments *B. bassiana* (1.40 larvae/plant), *M. anisopliae* @ 4.00 g/l (1.73 larvae/plant) and *M. anisopliae* @ 2.00 ml/l (2.07 larvae/plant) found to be better treatments compared to untreated control. The highest number of larvae were recorded in the control treatment (3.20 larvae/plant). At fifteen days after the first spray, a slight increase in larval numbers were noticed which ranged from 1.13 to 3.13 larvae per plant. The plots treated with *M. rileyi* (1.13 larvae/plant) was found superior with a minimum number of larvae. The plots treated with *Sf*NPV (1.33 larvae/plant) and *B. thuringiensis* var. *kurstaki* (1.33 larvae/plant) recorded the least number of larvae and were significantly on par with each other followed by *B. bassiana* (1.53 larvae/plant), *M. anisopliae* @ 4.00 g/l (1.87 larvae/plant) and *M. anisopliae* @ 2.00 ml/l (2.20 larvae/plant). The highest number of larvae were seen in the untreated control (3.13 larvae/plant).

Second spray was taken at 15 days interval looking into the pest population. Pre-treatment count was done prior to the second application, the population ranged from 1.47 to 2.80 larvae per plant and the difference was insignificant among the treatments. Even after the third day of treatment imposition, the population ranged from 1.53 to 2.87 and there was a non-significant difference among the treatments. However, the fewer number of larvae were recorded in the plot sprayed with *M. rileyi* (1.53 larvae/plant) and highest in the untreated control (2.87 larvae/plant). Five days after the second spray, the larval population ranged from 0.93 to 2.93 larvae per plant. The significant reduction in larval numbers was observed in *M. rileyi* (0.93 larva/plant) and *Sf*NPV(1.00 larva/plant) which were statistically not different from each other followed by *B. thuringiensis* var. *kurstaki* (1.07 larvae/plant). The treatments *B. bassiana*, *M. anisopliae* @ 4.00 g/l and *M. anisopliae* @ 2.00 ml/l sustained 1.20, 1.40 and 1.60 larvae per plant, respectively which were significantly different from untreated control (2.93 larvae/plant).

At seven days after the second spray, the population was ranged from 1.07 to 3.00 larvae per plant. However, the larval number increased gradually in respective treatments but were less than the control. The treatments sprayed with *M. rileyi* (1.07 larvae/plant) and *Sf*NPV (1.07 larvae/plant) were found to be the superior biopesticides and were significantly on par with each other followed by *B. thuringiensis* var. *kurstaki* (1.20 larvae/plant). The treatments *B. bassiana* (1.27 larvae/plant), *M. anisopliae* @ 4.00 g/l (1.47 larvae/plant) and *M. anisopliae* @ 2.00 ml/l (1.67 larvae/plant) found to be better over untreated control. The control plot recorded the highest population with 3.00 larvae per plant and was inferior to all other treatments. At the end of the observation period *i.e.*, on the fifteenth day after the second spray, the number of larvae per plant ranged from 0.80 to 1.40 which decreased significantly in all the treatments. The less number of larvae were recorded in *M. rileyi* (0.80 larva/plant) and more larvae were found in the untreated control (1.40 larvae/plant). However, all the treatments were statistically non-significant with one another.

The mean values of two sprays indicated larval population of 1.26 to 2.84 larave per plant. The plots treated with *M. rileyi* (1.26 larvae/plant), *Sf*NPV (1.38 larvae/plant) and *B. thuringiensis* var. *kurstaki* (1.44 larvae/plant) were the leading treatments in reducing the pest load. The treatments *B. bassiana* (1.56 larvae/plant), *M. anisopliae* @ 4.00 g/l (1.80 larvae/plant) and *M. anisopliae* @ 2.00 ml/l (2.05 larvae/plant) performed better over control in curtailing the pest population over untreated control (2.84 larvae/plant).The highest per cent reduction in larval population over control is recorded in treatment sprayed with *M. rileyi* (55.63 %), *Sf*NPV (51.41 %) and *B. thuringiensis* var. *kurstaki* (49.30 %) followed by *B. bassiana* (45.07 %), *M. anisopliae* @ 4.00 g/l (36.62 %) and *M. anisopliae* @ 2.00 ml/l (27.82 %) (Table 2).

The present findings are like the results of Firake and Behere (2020) who experienced 50 per cent larval mortality throughout the season of maize due to *M. rileyi* (Farlow) Samson and *Spfr*NPV indicating dominant mortality factors. Ginting *et al*. (2020) also reported that *M. rileyi* has occurred naturally on *S. frugiperda* larvae and caused mortality upto 79.0 per cent. The present findings are not far from the findings of Zhou *et al*. (2020) who inferred that there was no *S. frugiperda* larval survivability noticed when treated with a spore suspension of *M. rileyi* GZUIFRLS01 for seven days at 90 per cent relative humidity.

Per cent leaf damage. The per cent leaf damage ranged from 48.36 to 57.12 and all the treatments were found to be non-significant at a day before treatment imposition. On the third day after the first spray, the leaf damage was ranged from 52.37 to 60.09 per cent and there was an increase in the per cent leaf damage in respective treatments and were non-significant. However, the minimum damage was recorded in *M. anisopliae* @ 4.00 g/l (52.47 %) and the highest was found in the untreated control (60.09 %). At five days after the first spray the per cent leaf damage was ranged from 31.82 to 63.18. The least was found in the treatments that are sprayed with *M. rileyi* (31.82 %), *Sf*NPV (34.02 %) and *B. thuringiensis* var. *kurstaki* (37.29 %) which were significantly on par with each other. The treatments *B. bassiana* (40.6 %), *M. anisopliae* @ 4.00 g/l (44.38 %) and *M. anisopliae* @ 2.00 ml/l (47.45 %) achieved better results over untreated control. The highest leaf damage was noticed in the untreated control (63.18 %) plot which was statistically inferior to all the treatments (Table 3).

On the seventh day after the first spray, there was a noticeable increase in the per cent leaf damage collated to earlier observations yet it was less than the untreated control. The leaf damage across the treatments ranged from 32.55 to 65.45 per cent. The treatment sprayed with *M. rileyi* (32.55 %) and *Sf*NPV (37.44 %) recorded the least per cent leaf damage followed by *B. thuringiensis* var. *kurstaki* (40.80 %). Consequently, *B. bassiana*, *M. anisopliae* @ 4.00 g/l and *M. anisopliae* @ 2.00 ml/l found on par with one another with the leaf damage of 42.62, 47.09 and 50.09 per cent, respectively but, significantly differed from untreated control (65.45 %).At fifteen days after the first spray, the same trend was followed with leaf damage of 35.18 to 71.27 per cent. The least was observed in the treatment plots that were sprayed with *M. rileyi* (35.18 %) and *Sf*NPV (41.25 %) followed by *B. thuringiensis* var. *kurstaki* (43.98 %). The treatments *B. bassiana* (45.93 %), *M. anisopliae* @ 4.00 g/l (51.36 %) and *M. anisopliae* @ 2.00 ml/l (53.48 %) performed better over untreated control (71.27 %). The untreated control was found significantly inferior to the remaining treatments.

Second spray was taken at 15 days interval looking into the pest population. The leaf damage ranged from 42.87 to 71.30 per cent and variation was non-significant among the treatments. Observations were recorded on the third day of application, the per cent leaf damage was ranged from 46.44 to 75.11 and all the treatments were found on par with each other. After five days of the second spray, the per cent leaf damage significantly reduced in all the treatments except untreated control and it ranged from 35.94 to 78.72 per cent. The treatments sprayed with *M. rileyi* (35.94 %) recorded the least per cent of leaf damage succeeded by *Sf*NPV (39.03 %) and *B. thuringiensis* var. *kurstaki* (41.27 %) and were statistically at par with each other. The treatment plots sprayed with *M. anisopliae* @ 2.00 ml/l and *M. anisopliae* @ 4.00 g/l recorded 54.95 and 49.74 per cent leaf damage which was significantly differed with other treated plots and were statistically superior over untreated control (78.72 %).

Seven days after the second spray 38.46 to 80.45 per cent leaf damage was noticed and the same trend was followed as of five days after spray. The least per cent leaf damage was observed in the treatments sprayed with *M. rileyi* (38.46 %), SfNPV (42.64 %) and *B. thuringiensis* var. *kurstaki* (44.27 %). The treatments *B. bassiana* (46.92 %), *M. anisopliae* @ 4.00 g/l (50.28 %) and *M. anisopliae* @ 2.00 ml/l (56.54 %) performed better over untreated control. The control treatment recorded the highest per cent leaf damage (80.45 %) which was inferior to all other treatments. At the end of the observation *i.e.*, on the fifteenth day after spray, the per cent leaf damage reduced significantly in all the treatments compared to the previous observations and the range was 30.24 to 58.52 per cent. The lowest was achieved in *M. rileyi* (30.24 %) and *Sf*NPV (34.85 %) treated plots succeeded by *B. thuringiensis* var. *kurstaki* (37.78 %). Consequently, the next better treatments were *B. bassiana* (40.10 %), *M. anisopliae* @ 4.00 g/l (44.69 %) and *M. anisopliae* @ 2.00 ml/l (49.48 %). Obviously, the untreated control treatment recorded the highest per cent leaf damage (58.52 %).

The mean of per cent leaf damage after two sprays were calculated which ranged from 38.60 to 69.10. The results indicated that the *M. rileyi* (38.60 %)and *Sf*NPV(41.43 %) were performed best over other treatments and statistically on par with each other. The treatments *viz.*, *B. thuringiensis* var. *kurstaki* (43.89 %), *B. bassiana* (45.89 %), *M. anisopliae* @ 4.00 g/l (50.01 %) and *M. anisopliae* @ 2.00 ml/l (53.71 %) has given better performance over untreated control. Per cent leaf damage was highest in the untreated control (69.10 %) which was inferior to biopesticides treated plots (Table 3).The highest per cent reduction in leaf damage over control was noticed in treatments sprayed with *M. rileyi* (44.14 %), *Sf*NPV(40.04 %) and *B. thuringiensis* var. *kurstaki* (36.48 %). The treatments *B. bassiana* (33.59 %), *M. anisopliae* @ 4.00 g/l (27.63 %) and *M. anisopliae* @ 2.00 ml/l (22.27 %) achieved minimum per cent reduction over control (Table 3).

The present findings are supported by Mallapur *et al.* (2018) who evaluated *M. rileyi* on large scale in maize and achieved a 66.84 to 73.05 per cent reduction in leaf injury. Similarly, Dhobi *et al*. (2020) reported the minimum per cent plant damage in treatment sprayed with *M. rileyi* and *B. thuringiensis* var. *kurstaki*.

Grain yield. At the end of the experimentation, the crop was harvested and the grain yield per plot was recorded and further converted to q/ha and presented in Table 4. The yield was ranged from 19.92 to 36.91 q/ha, the highest was in *M. rileyi* (36.91 q/ha) treated plot which was followed by *Sf*NPV(34.47 q/ha) and *B. thuringiensis* var. *kurstaki* (33.30 %). The moderate yield was recorded from the plots treated with *B. bassiana* (29.49 %), *M. anisopliae* @ 4.00 g/l (27.17 q/ha) and *M. anisopliae* @ 2.00 ml/l (24.70 %). Certainly, the yield was lowest in the untreated control (19.92 %). The per cent yield gain over control was highest in *M. rileyi* (85.29 %) followed by *Sf*NPV (73.04 %) and *B. thuringiensis* var. *kurstaki* (67.17 %). The per cent gain over control was moderate in treatments *viz.*, *B. bassiana* (48.04 %), *M. anisopliae* @ 4.00 g/l (36.40 %) and *M. anisopliae* @ 2.00 ml/l (24.00 %).

The results on the cost and returns of fall armyworm management revealed that the highest net returns was recorded in the plot sprayed with *M. rileyi* (39982.00 ₹ ha^{-1}), *Sf*NPV (31665.27 ₹ ha^{-1}) and *B. thuringiensis* var *kurstaki* (28307.67 ₹ ha^{-1}). *B. bassiana*, *M. anisopliae* @ 4.00 g/l and *M. anisopliae* @ 2.00 ml/l recorded 25030.32, 20355.41 and 19305.33 ₹ ha^{-1} respectively. The net returns was least in untreated control (7096.30 ₹ ha^{-1}). The benefit cost ratio was highest in *M. rileyi* (2.16) and *Sf*NPV (1.84). *B. thuringiensis* var *kurstaki*, *B. bassiana*, *M. anisopliae* @ 4.00 g/l and *M. anisopliae* @ 2.00 ml/l recorded 1.73, 1.73, 1.59 and 1.57. The untreated control recorded least benefit cost ratio of 1.21.

The present findings are in line with the previous investigator who recorded the highest grain yield of 29.57 and 29.32 q/ha in treatments sprayed with *M. rileyi* and *B. thuringiensis* var. *kurstaki*, respectively (Dhobi *et al.*, 2020).

Table 2: Efficacy of different biopesticides on larval population of *S. frugiperda* in maize during *Rabi* 2019.

Tr. No.	Treatment details	Number of larvae per plant										Mean	Per cent reduction over control
		First spray					Second spray						
		DBS	3DAS	5DAS	7DAS	15DAS	DBS	3DAS	5DAS	7DAS	15DAS		
T1	*Bacillus thuringiensis* var. *kurstaki* @ 2.00 ml/l	2.67 (1.91)	2.87 (1.96)	1.27 (1.46)^{ab}	1.27 (1.46)^{ab}	1.33 (1.50)^{ab}	1.53 (1.59)	1.60 (1.61)	1.07 (1.41)^{ab}	1.20 (1.48)^{ab}	0.87 (1.36)	1.43 (1.55)^{ab}	49.30
T2	SfNPV @ 2.00 ml/l	2.53 (1.88)	2.67 (1.89)	1.20 (1.44)^{ab}	1.27 (1.46)^{ab}	1.33 (1.48)^{ab}	1.47 (1.57)	1.60 (1.58)	1.00 (1.38)^{a}	1.07 (1.44)^{a}	0.87 (1.31)	1.38 (1.54)^{ab}	51.41
T3	*Metarhizium rileyi* @ 4.00 g/l	2.47 (1.86)	2.53 (1.87)	1.00 (1.39)^{a}	1.07 (1.41)^{a}	1.13 (1.44)^{a}	1.47 (1.55)	1.53 (1.57)	0.93 (1.36)^{a}	1.07 (1.39)^{a}	0.80 (1.31)	1.26 (1.50)^{a}	55.63
T4	*Metarhizium anisopliae* @ 4.00 g/l	2.87 (1.97)	2.93 (1.98)	1.67 (1.63)^{bc}	1.73 (1.65)^{bc}	1.87 (1.69)^{bc}	2.07 (1.75)	2.20 (1.79)	1.40 (1.55)^{bc}	1.47 (1.57)^{bcd}	1.13 (1.46)	1.80 (1.67)^{cd}	36.62
T5	*Beauveria bassiana* @ 4.00 g/l	2.87 (1.97)	2.87 (1.96)	1.33 (1.53)^{ab}	1.40 (1.55)^{ab}	1.53 (1.59)^{abc}	1.8 (1.67)	1.93 (1.71)	1.20 (1.48)^{abc}	1.27 (1.51)^{abc}	0.93 (1.39)	1.56 (1.59)^{bc}	45.07
T6	*Metarhizium anisopliae* @ 2.00 ml/l	2.93 (1.98)	3.00 (2.00)	2.00 (1.73)^{c}	2.07 (1.75)^{c}	2.20 (1.79)^{c}	2.53 (1.87)	2.60 (1.90)	1.60 (1.61)^{c}	1.67 (1.63)^{cd}	1.27 (1.50)	2.05 (1.74)^{d}	27.82
T7	Untreated control	3.00 (2.00)	3.07 (2.02)	3.13 (2.03)^{d}	3.20 (2.05)^{d}	3.13 (2.03)^{d}	2.8 (1.95)	2.87 (1.97)	2.93 (1.98)^{d}	3.00 (2.00)^{d}	1.40 (1.54)	2.84 (1.96)^{e}	0.00
S. Em (±)		0.07	0.12	0.06	0.06	0.07	0.09	0.08	0.04	0.05	0.05	0.03	--
CD @ 5%		NS	NS	0.17	0.18	0.20	NS	NS	0.13	0.14	NS	0.09	--

Values in parenthesis are $\sqrt{x+0.5}$ transformed
DAS – Days after Spray, DBS – Days before Spray
Means followed by same alphabet in columns did not differ significantly (p=0.05) by DMRT

Table 3: Efficacy of different biopesticides on percent leaf damage of *S. frugiperda* in maize during *Rabi* 2019.

Tr. No.	Treatment details	Percent leaf damage per plant										Mean	Percent reduction over control
		First spray					Second spray						
		DBS	3DAS	5DAS	7DAS	15DAS	DBS	3DAS	5DAS	7DAS	15DAS		
T1	*Bacillus thuringiensis* var. *kurstaki* @ 2.00 ml/l	51.47 (45.83)	54.77 (47.73)	37.29 $(37.58)^{ab}$	40.80 $(39.66)^{abc}$	43.98 $(41.49)^{ab}$	48.24 (43.97)	50.95 (45.53)	41.27 $(39.94)^{ab}$	44.27 $(41.61)^{ab}$	37.78 $(37.87)^{ab}$	43.89 $(41.46)^{b}$	36.48
T2	SfNPV @ 2.00 ml/l	52.73 (46.58)	52.37 (46.35)	34.02 $(35.62)^{ab}$	37.44 $(37.66)^{ab}$	41.25 $(39.94)^{ab}$	46.52 (42.98)	49.83 (44.88)	39.03 $(38.63)^{ab}$	42.64 $(40.72)^{a}$	34.85 $(36.08)^{ab}$	41.43 $(40.02)^{ab}$	40.04
T3	*Metarhizium rileyi* @ 4.00 g/l	57.12 (49.15)	58.18 (49.74)	31.82 $(34.19)^{a}$	32.55 $(34.73)^{a}$	35.18 $(36.34)^{a}$	42.87 (40.85)	46.44 (42.93)	35.94 $(36.79)^{a}$	38.46 $(38.29)^{a}$	30.24 $(33.26)^{a}$	38.60 $(38.33)^{a}$	44.14
T4	*Metarhizium anisopliae* @ 4.00 g/l	50.11 (45.05)	52.47 (46.42)	44.38 $(41.75)^{ab}$	47.09 $(43.30)^{bc}$	51.36 $(45.76)^{b}$	58.94 (50.16)	60.09 (50.81)	49.74 $(44.83)^{cd}$	50.28 $(45.15)^{bc}$	44.69 $(41.92)^{c}$	50.01 $(44.99)^{cd}$	27.63
T5	*Beauveria bassiana* @ 4.00 g/l	48.36 (44.03)	50.59 (45.33)	40.60 $(39.56)^{ab}$	42.62 $(40.71)^{abc}$	45.93 $(42.63)^{ab}$	53.36 (46.95)	56.36 (48.67)	44.03 $(41.52)^{bc}$	46.92 $(43.21)^{ab}$	40.1 $(39.27)^{bc}$	45.90 $(42.62)^{bc}$	33.57
T6	*Metarhizium anisopliae*@ 2.00 ml/l	52.59 (46.49)	55.69 (48.28)	47.45 $(43.52)^{b}$	50.09 $(45.04)^{c}$	53.48 $(46.99)^{b}$	61.73 (51.88)	62.01 (52.01)	54.95 $(47.83)^{d}$	56.54 $(48.77)^{c}$	49.48 $(44.68)^{cd}$	53.71 $(47.11)^{d}$	22.27
T7	Untreated control	56.97 (49.03)	60.09 (50.92)	63.18 $(52.78)^{c}$	65.45 $(54.01)^{d}$	71.27 $(57.65)^{c}$	71.3 (57.83)	75.11 (60.11)	78.72 $(62.97)^{e}$	80.45 $(63.78)^{d}$	58.52 $(49.89)^{d}$	69.10 $(56.23)^{e}$	0.00
S. Em (±)		**3.09**	**3.32**	**2.65**	**2.05**	**2.37**	**3.20**	**1.98**	**2.58**	**2.26**	**2.05**	--	--
CD @ 5%		**NS**	**NS**	**8.18**	**6.30**	**7.30**	**NS**	**NS**	**7.95**	**6.95**	**6.32**	--	--

Values in parenthesis are arcsine transformed
DAS – Days after Spray, DBS – Days before Spray
Means followed by same alphabet in columns did not differ significantly (p=0.05) by DMRT

Table 4: Cost economics of *S. frugiperda* management through biopesticides in maize during *Rabi* 2019.

Tr. No.	Treatment details	Yield (q/ha)	Percent yield gain over control	Crop production cost (₹ ha^{-1})	Crop protection cost (₹ ha^{-1})	Total cost of cultivation (₹ ha^{-1})	Gross returns (₹ ha^{-1})	Net returns (₹ ha^{-1})	B:C
T1	*Bacillus thuringiensis* var. *kurstaki* @ 2.00 ml/l	33.30^{ab}	67.17	33043.50	5750.00	38793.50	67101.17	28307.67	1.73
T2	SfNPV @ 2.00 ml/l	34.47^{ab}	73.04	33043.50	4750.00	37793.50	69458.77	31665.27	1.84
T3	*Metarhizium rileyi* @ 4.00 g/l	36.91^{a}	85.29	33043.50	1350.00	34393.50	74375.50	39982.00	2.16
T4	*Metarhizium anisopliae* @ 4.00 g/l	27.17^{abc}	36.40	33043.50	1350.00	34393.50	54748.91	20355.41	1.59
T5	*Beauveria bassiana* @ 4.00 g/l	29.49^{abc}	48.04	33043.50	1350.00	34393.50	59423.82	25030.32	1.73
T6	*Metarhizium anisopliae* @ 2.00 ml/l	24.70^{bc}	24.00	33043.50	1050.00	34093.50	53398.83	19305.33	1.57
T7	Untreated control	19.92^{c}	0.00	33043.50	--	33043.50	40139.80	7096.30	1.21
S. Em (±)		**3.39**	--	--	--	--	--	--	--
CD @ 5%		**10.17**	--	--	--	--	--	--	--

Means followed by same alphabet in columns did not differ significantly (p=0.05) by DMRT

CONCLUSION

The pest *S. frugiperda* showed to be susceptible to isolates of *M. rileyi*, *Sf*NPV and *B. thuringiensis* var. *kurstaki* indicating potential for biological control within an integrated pest management. These biopesticides were selected to evaluate more efficient biopesticide to control fall armyworm by applying lower doses in the field, helping to overcome the economic limitations and hazardous effects caused by insecticides, and thereby enhancing ecological feasibility.

FUTURE SCOPE

Since *M. rileyi*, *Sf* NPV and *B. thuringiensis* var. *kurstaki* can be multiplied on mass scale under *in vitro* conditions; further detailed studies on augmentative biological control of FAW by using these biopesticides would give more insights on their role under field conditions.

Conflict of Interest. None.

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