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EVALUATION OF BIORATIONALS AGAINST FALL ARMYWORM, *Spodoptera frugiperda* IN MAIZE

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ABSTRACT

Fall armyworm, *Spodoptera frugiperda* (J.E. Smith), is a major invasive pest causing substantial yield losses in maize. A field study was conducted at the Maize Research Centre, Agricultural Research Station, Vijayarai, Andhra Pradesh, India, to evaluate the efficacy of selected biorational insecticides against this pest. Seven treatments comprising *Bacillus thuringiensis* @ 2g L⁻¹, *Beauveria bassiana* @ 5g L⁻¹, *Metarhizium rileyi*, @ 2g L⁻¹ *Metarhizium anisopliae* @ 5g L⁻¹, neem oil (10,000 ppm) @ 1 L⁻¹, Agniastra, and water spray (control) were evaluated in a randomized block design with three replications. Significant differences among treatments were observed in fall armyworm infestation, cob damage, grain yield, and cost-benefit ratio. *Metarhizium rileyi* @ 5 g L⁻¹ consistently proved the most effective, recording the lowest pest infestation (28.05–33.51%), minimum cob damage (42.12–66.66%), highest grain yield (6288–7351 kg ha⁻¹), and maximum benefit ratio (1.63–1.72). *Beauveria bassiana* ranked second in efficacy, while *Bacillus thuringiensis* provided moderate control. *Metarhizium anisopliae*, neem oil, and Agniastra were comparatively less effective. The study demonstrates that *M. rileyi* is an effective, environmentally safe, and economically viable biorational option for sustainable management of fall armyworm in maize which can be included in one of the integrated pest management concepts.

Key words: *Spodoptera frugiperda*, maize, biorational insecticides, *Metarhizium rileyi*, *Beauveria bassiana*, integrated pest management

Introduction

The fall armyworm (*Spodoptera frugiperda* J.E. Smith) (*Lepidoptera: Noctuidae*) is one of the most destructive invasive insect pests of maize. Native to the tropical and subtropical regions of the Americas, it has rapidly spread across Africa, Asia, and Australia over the past decade, posing a serious threat to global maize production and food security (Day *et al.*, 2017; Tambo *et al.*, 2020a). Owing to its highly polyphagous nature, the

pest feeds on more than 350 host plant species, although maize is its preferred host. Severe infestations cause extensive foliage damage, injury to the whorl and tassel, cob damage, and substantial yield losses.

In India, *S. frugiperda* was first reported from Karnataka during May 2018 and subsequently from Andhra Pradesh during August 2018. Since then, it has become a major pest of maize during both *Kharif* and *Rabi* seasons, causing considerable economic losses to

farmers (Kalleshwaraswamy *et al.*, 2018; Sharanabasappa *et al.*, 2018). The rapid establishment and continuous occurrence of the pest have made its management a major challenge in maize-growing regions. Integrated pest management approaches involving monitoring, cultural practices, biological control and selective insecticides are therefore important for sustainable management of this invasive pest (Prasanna *et al.*, 2018).

Following the invasion of *S. frugiperda*, pest management relied largely on repeated applications of broad-spectrum chemical insecticides. The severity of infestation prompted farmers to apply insecticides frequently throughout the cropping season, often using highly toxic active ingredients (Tambo *et al.*, 2020a). Although these insecticides provide rapid suppression of the pest, their indiscriminate and continuous use has resulted in several adverse consequences, including pesticide residues in food, environmental contamination, destruction of natural enemies and pollinators, development of insecticide resistance, and increased production costs.

Biorational insecticides have emerged as promising alternatives for sustainable management of fall armyworm. These products are derived from naturally occurring organisms or substances and include microbial pesticides, botanical insecticides, and other biologically based products. They are generally target-specific, environmentally safe, biodegradable, compatible with integrated pest management (IPM) programmes, and suitable for organic farming (Prasanna *et al.*, 2018).

Among microbial biopesticides, *B. thuringiensis* (Bt)-based formulations have been widely reported to provide effective control of fall armyworm larvae (Bateman *et al.*, 2021). Botanical insecticides such as neem (*Azadirachta indica*) seed oil have also demonstrated good efficacy against *S. frugiperda* and represent cost-effective management options (Babendreier *et al.*, 2020). Entomopathogenic fungi, particularly *B. bassiana*, *M. anisopliae*, and *M. rileyi*, have shown considerable potential for biological control. These fungi are highly effective against eggs and early larval instars, reducing feeding activity and causing significant mortality, although their action is generally slower than that of conventional insecticides (Akutse *et al.*, 2019; Assefa and Ayalew, 2019; Idrees *et al.*, 2021; Idrees *et al.*, 2022a; Rajula *et al.*, 2021).

Despite the availability of several biorational products, information on their comparative field efficacy under maize-growing conditions in Andhra Pradesh is

limited. Identification of effective and economically viable biorational insecticides is therefore essential for developing sustainable management strategies against fall armyworm while minimizing dependence on synthetic insecticides.

Hence, the present investigation was undertaken to evaluate the efficacy of selected biorational insecticides against fall armyworm on maize under field conditions and to assess their influence on pest infestation, cob damage, grain yield, and economic returns.

Materials and Methods

Field experiments were conducted at the Maize Research Centre, Agricultural Research Station, Vijayarai (16.8121° N, 81.0327° E), Andhra Pradesh, India during Rabi 2018–19, Kharif 2019, and Rabi 2019–20 to evaluate the efficacy of selected biorational insecticides against fall armyworm, *S. frugiperda*, in maize. The experiments were laid out in a Randomized Block Design (RBD) with three replications. The maize hybrid recommended for the region was grown following the recommended agronomic practices. Each experimental plot measured 5 × 4.5 m (six rows), maintaining a spacing of 75 × 20 cm.

Seven treatments were evaluated:

Treatment	Dose
T1- <i>Bacillus thuringiensis</i>	2 g L ⁻¹ (400 g acre ⁻¹)
T2- <i>Beauveria bassiana</i>	5 g L ⁻¹ (1 kg acre ⁻¹)
T3- <i>Metarhizium rileyi</i>	5 g L ⁻¹ (1 kg acre ⁻¹)
T4- <i>Metarhizium anisopliae</i>	5 g L ⁻¹ (1 kg acre ⁻¹)
T5-Neem oil (10,000 ppm)	200 mL acre ⁻¹
T6-Agniastra	Recommended concentration
T7- Control	Water spray

Insecticide application

Two foliar applications of the respective treatments were made at 10–15 day intervals, commencing approximately 15 days after sowing (DAS), depending on the incidence of fall armyworm.

Observations recorded

Percent plant infestation was recorded one day before each spray (pre-treatment) and at 7 and 14 days after each spray (DAS). Plant infestation was calculated using the following formula:

$$\text{Percent plant infestation (\%)} = \frac{\text{Number of infested plants}}{\text{Total number of plants observed}} \times 100$$

The mean percent infestation for each treatment was calculated by averaging the observations recorded after the two sprays. Percent reduction over control (ROC) was also computed. At harvest, the number of damaged cobs in each plot was recorded, and percent cob damage

was calculated as:

$$\text{Percent cob damage (\%)} = \frac{\text{Number of damaged cobs}}{\text{Total number of cobs harvested}} \times 100$$

Grain yield was recorded plot-wise and converted to kg ha⁻¹. The economics of each treatment were worked out by estimating the B:C ratio based on the prevailing market price of maize and the cost of plant protection.

Statistical analysis

Percentage data on plant infestation and cob damage were subjected to arc-sine square-root transformation before analysis. The transformed data were subjected to analysis of variance (ANOVA) appropriate for a randomized block design, and treatment means were compared at the 5% level of significance ($P = 0.05$).

Results and Discussion

Effect of biorational insecticides on fall armyworm infestation, cob damage and grain yield during Rabi 2018–19

The efficacy of different biorational insecticides against fall armyworm (*S. frugiperda*) was evaluated based on percent plant infestation, cob damage and grain yield (Table 1). Pretreatment observations were non-significant, indicating uniform pest infestation before treatment application. However, significant differences among treatments were observed at 7 and 14 days after both the first and second sprays.

Among the evaluated treatments, *M. rileyi* @ 5 g L⁻¹ recorded the lowest mean fall armyworm infestation (33.51%), followed by *B. bassiana* @ 5 g L⁻¹ (47.65%) and *B. thuringiensis* @ 2 g L⁻¹ (54.30%). The highest reduction over control (53.50%) was recorded with *M. rileyi*, followed by *B. bassiana* (33.90%) and *B. thuringiensis* (24.60%). Neem oil, Agniastra and *M.*

anisopliae were comparatively less effective, recording mean infestations of 65.97, 67.19% and 61.39% respectively, while the control recorded the highest infestation (72.14%).

Cob damage differed significantly among the treatments and ranged from 66.66 to 88.68%. The lowest cob damage was recorded in *M. rileyi* (66.66%), closely followed by *B. bassiana* (67.47%). The highest cob damage was observed in the untreated control (88.68%), whereas neem oil (83.18%) and Agniastra (83.14%) also recorded comparatively higher cob damage. Grain yield ranged from 5235 to 6288 kg ha⁻¹. The highest grain yield was obtained with *M. rileyi* (6288 kg ha⁻¹), followed by *B. bassiana* (5802 kg ha⁻¹), *M. anisopliae* (5752 kg ha⁻¹) and *B. thuringiensis* (5632 kg ha⁻¹). The control produced the lowest grain yield (5235 kg ha⁻¹) (Table 1).

Effect of biorational insecticides on fall armyworm infestation, cob damage, grain yield and benefit ratio during Kharif 2019

Pretreatment observations did not differ significantly among treatments, whereas significant differences were observed at all post-treatment observations following both sprays (Table 2). Among the evaluated biorational insecticides, *M. rileyi* recorded the lowest mean fall armyworm infestation (28.05%), followed by *B. bassiana* (34.47%) and *B. thuringiensis* (38.58%). The highest reduction over control (46.95%) was obtained with *M. rileyi*, followed by *B. bassiana* (34.81%) and *B. thuringiensis* (27.04%). Agniastra and neem oil were comparatively less effective, recording mean infestations of 50.42 and 46.49%, respectively.

Cob damage ranged from 62.69 to 83.40%, with the minimum cob damage recorded in *M. rileyi* (62.69%), followed by *B. bassiana* (70.22%). The untreated control

Table 1: Effect of biorationals on percent plant infestation, cob damage and yield in maize during Rabi 2018–19.

Treatment	PPI	1 st Spray		2 nd spray		Mean of 2 sprays		CD	Y
	Pre-treatment	7 DAS	14 DAS	7 DAS	14 DAS	PI	ROC %		
T1	46.88 (43.2)	29.51 (32.8)	44.79 (42.0)	59.02 (50.2)	84.03 (66.5)	54.3	24.6	78.71 (62.7)	5632
T2	27.84 (31.8)	19.79 (26.3)	43.40 (41.2)	53.12 (47.0)	73.96 (59.5)	47.65	33.9	67.47 (55.2)	5802
T3	44.79 (42.0)	15.62 (23.3)	31.94 (34.4)	27.56 (33.2)	56.94 (49.0)	33.51	53.5	66.66 (54.8)	6288
T4	37.15 (37.3)	39.93 (39.2)	59.72 (50.6)	52.08 (52.7)	83.68 (66.2)	61.39	14.89	70.01 (56.9)	5752
T5	41.32 (40.0)	46.88 (43.2)	65.63 (54.1)	67.71 (54.1)	85.76 (67.9)	65.97	8.5	83.18 (66.0)	5474
T6	54.86 (47.8)	53.82 (47.2)	64.24 (53.3)	76.04 (55.5)	82.99 (66.9)	67.19	6.9	83.14 (65.8)	5447
T7	44.44 (41.8)	60.07 (50.9)	65.63 (54.3)	73.95 (60.5)	87.15 (69.3)	72.14	—	88.68 (70.5)	5235
F-test	NS	Sig	Sig	Sig	Sig			Sig	Sig
CD ($P = 0.05$)	—	7.74	5.26	7.72	9.20			6.35	523
CV (%)	13.93	11.58	6.27	8.60	8.13			5.79	6.2

T1: *Bacillus thuringiensis* @ 2 g/L; T2: *Beauveria bassiana* @ 5 g/L; T3: *Metarhizium rileyi* @ 5 g/L;
T4: *Metarhizium anisopliae* @ 5 g/L; T5: Neem oil @ 10,000 ppm; T6: Agniastra; T7: Control
PPI: Percent plant infestation by FAW; PI: Percent infestation by FAW; CD: Cob damage (%); Y: Yield (kg ha⁻¹)

Table 2: Effect of biorationals on percent plant infestation, cob damage and yield in maize during *Kharif* 2019.

Treat- ment	PPI	1 st Spray		2 nd spray		MI	ROC %	CD	Y	B:C ratio
	Pre-treatment	7 DAS	14 DAS	7 DAS	14 DAS					
T1	53.52 (47.01)	37.56 (37.70)	35.56 (36.55)	34.02 (36.29)	47.19 (44.36)	38.58	27.04	78.08 (62.52)	5798	1.39
T2	50.94 (45.47)	29.43 (32.81)	35.22 (36.26)	30.70 (33.54)	42.54 (40.67)	34.47	34.81	70.22 (57.12)	6314	1.50
T3	57.54 (49.49)	25.41 (30.25)	27.47 (31.48)	24.45 (29.61)	34.89 (36.16)	28.05	46.95	62.69 (52.34)	6898	1.63
T4	44.20 (41.61)	40.02 (39.22)	36.63 (37.23)	39.80 (38.98)	50.04 (45.01)	41.62	21.28	78.06 (62.61)	5800	1.40
T5	54.18 (47.53)	49.29 (44.56)	44.32 (41.67)	42.48 (40.65)	49.90 (44.93)	46.49	12.07	80.14 (64.93)	5480	1.31
T6	52.53 (46.34)	48.69 (44.23)	50.36 (45.18)	49.81 (44.87)	52.84 (46.63)	50.42	4.64	80.93 (66.32)	5562	1.35
T7	45.76 (42.73)	51.79 (46.02)	51.27 (45.72)	52.99 (46.70)	55.45 (48.14)	52.58	–	83.40 (66.42)	5024	1.24
F-test	NS	Sig	Sig	Sig	Sig	–	–	Sig	Sig	–
CD (P = 0.05)	–	6.23	8.10	7.90	6.57	–	–	8.80	1079	–
CV (%)	16.34	8.80	11.44	11.45	8.34	–	–	7.90		

T1: *Bacillus thuringiensis* @ 2 g/L; T2: *Beauveria bassiana* @ 5 g/L; T3: *Metarhizium rileyi* @ 5 g/L;
T4: *Metarhizium anisopliae* @ 5 g/L; T5: Neem oil @ 10,000 ppm; T6: Agniastra; T7: Control
PPI: Percent plant infestation by FAW; MI: Mean infestation (%); CD: Cob damage (%); Y: Yield (kg ha⁻¹)

recorded the highest cob damage (83.40%). Grain yield differed significantly among treatments and ranged from 5024 to 6898 kg ha⁻¹. The highest grain yield was recorded with *M. rileyi* (6898 kg ha⁻¹), followed by *B. bassiana* (6314 kg ha⁻¹), whereas the untreated control recorded the lowest yield (5024 kg ha⁻¹). Economic analysis revealed that *M. rileyi* recorded the highest benefit ratio (1.63), followed by *B. bassiana* (1.50), while the control recorded the lowest B:C ratio (1.24) (Table 2).

Effect of biorational insecticides on fall armyworm infestation, cob damage, grain yield and benefit ratio during *Rabi* 2019–20

Pretreatment observations indicated no significant differences among treatments, confirming a uniform distribution of fall armyworm before treatment application (Table 3). Significant differences among treatments were observed after both sprays at all observation intervals.

Among the evaluated treatments, *M. rileyi* proved to be the most effective, recording the lowest mean fall armyworm infestation (31.92%), followed by *B. bassiana* (44.08%) and *B. thuringiensis* (46.42%). The highest reduction over control (49.80%) was recorded with *M. rileyi*, followed by *B. bassiana* (30.66%) and *B. thuringiensis* (26.99%). Neem oil (59.17%), *M. anisopliae* (47.25%) and Agniastra (61.50%) were comparatively less effective, whereas the control recorded the highest infestation (63.58%).

Cob damage was significantly influenced by different biorational treatments and ranged from 42.12 to 74.30%. The lowest cob damage was recorded in *M. rileyi* (42.12%), followed by *B. bassiana* (49.70%). The untreated control recorded the highest cob damage (74.30%). Grain yield ranged from 4608 to 7351 kg ha⁻¹. The highest grain yield was obtained in *M. rileyi*-treated

plots (7351 kg ha⁻¹), followed by *B. bassiana* (7178 kg ha⁻¹), whereas the untreated control recorded the lowest yield (4608 kg ha⁻¹). The highest benefit ratio was recorded with *M. rileyi* (1.72), followed by *B. bassiana* (1.69), indicating the superior biological and economic performance of these entomopathogenic fungi (Table 3).

Comparative performance of biorational insecticides across seasons

Across the three experimental seasons, the relative efficacy of the tested biorational insecticides remained consistent. *M. rileyi* was the most effective treatment in reducing fall armyworm infestation, recording mean infestations of 33.51, 28.05 and 31.92% during *Rabi* 2018–19, *Kharif* 2019 and *Rabi* 2019–20, respectively. The treatment also consistently produced the lowest cob damage (66.66, 62.69 and 42.12%) and the highest grain yields (6288, 6898 and 7351 kg ha⁻¹). *B. bassiana* ranked second in efficacy across all seasons, whereas *B. thuringiensis* provided moderate suppression of the pest. *M. anisopliae*, Neem oil and Agniastra were comparatively less effective in reducing infestation and cob damage and consequently produced lower grain yields. These results indicate that entomopathogenic fungi, particularly *M. rileyi*, provide consistent and reliable management of fall armyworm under both *Kharif* and *Rabi* conditions.

The present investigation demonstrated significant differences in the efficacy of biorational insecticides against fall armyworm (*S. frugiperda*) under field conditions during *Rabi* 2018–19, *Kharif* 2019 and *Rabi* 2019–20. Among the evaluated treatments, *M. rileyi* consistently outperformed the other biorational insecticides by recording the lowest plant infestation and cob damage, together with the highest grain yield and benefit ratio. *B. bassiana* was the next most effective

Table 3: Effect of biorationals on percent plant infestation by fall army worm and Yield in Maize (Rabi 2019-20).

Treatment	PPI	1 st Spray		2 nd spray		Mean of 2 sprays		CD	Y	B:C Ratio
	Pre-treatment	7 DAS	14 DAS	7 DAS	14 DAS	PI	ROC %			
T1	42.33(40.50)	41.33(39.98)	45.67(42.48)	45.33(42.29)	53.33(46.9)	46.42	26.99	57.33(49.20)	6481	1.54
T2	51.67(45.97)	37.67(37.37)	50.67(45.36)	41.67(40.16)	46.33(42.87)	44.08	30.66	49.70(44.71)	7178	1.69
T3	48.00(43.83)	26.33(30.79)	33.67(35.43)	30.67(33.54)	37.00(37.44)	31.92	49.80	42.12(40.56)	7351	1.72
T4	48.67(44.21)	42.67(40.66)	52.00(46.13)	42.67(40.74)	51.67(45.97)	47.25	25.68	58.57(49.92)	6387	1.52
T5	31.33(33.99)	54.67(47.67)	59.33(50.38)	57.00(49.03)	65.67(54.22)	59.17	6.94	72.15(58.03)	5337	1.26
T6	34.33(35.84)	55.33(48.04)	63.33(52.72)	58.00(49.62)	69.33(56.47)	61.50	3.27	72.50(58.26)	5294	1.27
T7	43.33(41.12)	57.33(49.20)	63.67(52.93)	65.67(54.19)	67.67(55.39)	63.58	0.00	74.30(59.51)	4608	1.12
F-test	NS	S	S	S	S			S	S	
CD (P = 0.05)	-	6.86	6.23	5.63	8.26			6.1	825	
CV (%)	11.73	9.1	7.45	7.07	9.47			9.6	7.53	

T1: *Bacillus thuringiensis* @ 2 g/L; T2: *Beauveria bassiana* @ 5 g/L; T3: *Metarhizium rileyi* @ 5 g/L;
T4: *Metarhizium anisopliae* @ 5 g/L; T5: Neem oil @ 10,000 ppm; T6: Agniastra; T7: Control
PPI: Percent plant infestation by FAW; PI: Percent infestation by FAW; CD: Cob damage (%); Y: Yield (kg ha⁻¹)

treatment, while *Bacillus thuringiensis* provided moderate control. *M. anisopliae*, neem oil and Agniastra were comparatively less effective under field conditions.

The superior performance of *M. rileyi* may be attributed to its high virulence and host specificity against lepidopteran larvae, resulting in reduced feeding activity and effective suppression of fall armyworm populations. Similar observations were reported by Akutse *et al.*, (2019), who demonstrated the high pathogenicity of entomopathogenic fungi against eggs and early larval stages of *S. frugiperda*. Comparable results were also reported by Reddy (2021), who observed superior field performance of *M. rileyi* and *B. bassiana* in reducing fall armyworm infestation and improving maize productivity under Andhra Pradesh conditions. Furthermore, Idrees *et al.*, (2021) and Idrees *et al.*, (2022) reported that entomopathogenic fungi effectively suppress larval feeding and survival, thereby reducing crop damage.

B. bassiana consistently reduced fall armyworm infestation and cob damage and significantly improved grain yield compared with the untreated control, although its efficacy was slightly lower than that of *M. rileyi*. This difference may be due to variations in fungal virulence and the greater susceptibility of younger larval instars. Similar findings were reported by Akutse *et al.*, (2019) and Assefa and Ayalew (2019) and Harte *et al.*, (2024), who also documented the effectiveness of *B. bassiana* against fall armyworm.

The moderate efficacy of *B. thuringiensis* observed in the present study agrees with the findings of Bateman *et al.*, (2021), who reported that Bt-based biopesticides are highly effective against early larval instars but provide comparatively lower control of older larvae under field

conditions. Likewise, neem oil exhibited only moderate suppression of fall armyworm, probably because its active ingredient, azadirachtin, acts mainly as an antifeedant and insect growth regulator rather than causing rapid mortality. Similar observations were reported by Babendreier *et al.*, (2020). Agniastra was comparatively less effective, indicating that the efficacy of botanical formulations may vary depending on preparation methods, concentration, environmental conditions and pest pressure.

The reduction in fall armyworm infestation and cob damage was directly reflected in higher grain yield, confirming the close relationship between effective pest suppression and maize productivity. The higher benefit ratios recorded with *M. rileyi* and *B. bassiana* further indicate that these treatments are economically viable and environmentally safer alternatives to repeated applications of broad-spectrum insecticides. These findings are consistent with previous reports highlighting the importance of entomopathogenic fungi in sustainable fall armyworm management (Bateman *et al.*, 2021; Idrees *et al.*, 2022).

Conclusion

The present study demonstrated that *M. rileyi* @ 5 g L⁻¹ was the most effective biorational insecticide for the management of fall armyworm (*S. frugiperda*) in maize under both *Kharif* and *Rabi* seasons. It consistently reduced plant infestation and cob damage while improving grain yield and economic returns compared with the other biorational treatments. *B. bassiana* also proved effective, whereas *B. thuringiensis* provided moderate control. The consistent performance of *M. rileyi* across three cropping seasons highlights its potential as an environmentally safe and economically viable component of integrated pest

management (IPM). Therefore, *M. rileyi* @ 5 g L⁻¹ can be recommended as a sustainable biorational option for effective management of fall armyworm in maize.

Conflict of Interest: The authors declare no conflict of interest.

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