*International Journal on Emerging Technologies* **16(1): 83-89(2025)**

**ISSN No. (Print): 0975-8364**
**ISSN No. (Online): 2249-3255**

# Biorational Management of Fall Armyworm, *Spodoptera frugiperda* (J.E. Smith) in Maize (*Zea mays* L.)

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*(Received 03 December 2024, Revised 15 January 2025, Accepted 10 February 2025)*
*(Published by Research Trend, Website: www.researchtrend.net)*

**DOI:** https://doi.org/10.65041/IJET.2025.16.1.11

**ABSTRACT: An experiment was conducted to study comparative efficacy of selected chemicals, botanical and biopesticides against fall armyworm in Maize. The trial was designed and evaluated in different locations Rahuri, Jhansi, Ludhiana, Dharwad & Bhubaneshwar under All India Co-ordinated Research Project on forage crops & Utilization in India. The results of field experiment concluded that, among the different treatments the lowest population of *S. frugiperda* were recorded in the treatment of emamectin benzoate 5 SG @ 5 ml/10 lit of water (16.53 % infestation of plants) which was significantly superior over rest of the treatments. Next best treatment recorded was chlorpyriphos 20 EC (26.36%) @ 20 ml/10 lit of water. The treatment *Metarhizium* (*Nomuraea*) *rileyi* 1.15% (30.73%) WP@ 75 g/10 lit of water followed by *Metarhizium anisopliae* 1.15% WP @ 75 g/ 10 lit of water (31.30%), *Beauveria bassiana* 1.15% WP (32.13%) @ 75 g/10 lit of water, *Beauveria bassiana* 1.15% WP (32.96%) and *Metarhizium* (*Nomuraea*) *rileyi* 1.15% WP (35.10%) in treated plots, respectively.**

**Keywords:** Invasive species, fall armyworm, *Spodoptera frugiperda*, biological invasions, prevention, management.

## INTRODUCTION

Zea mays, or maize, originated in central Mexico. The Poaceae family of grasses includes it. Because of its more productive growth habit and versatility, it is the most significant cereal crop grown worldwide. Among growers, it is becoming more and more popular. Worldwide, 193.7 million hectares are used to grow maize, which yields 5.75 tons per hectare. Presently, the annual production of maize kernels is about 1147.7 million tones (Anon., 2020). In addition to being widely used as fodder, both as green and silage, maize is used as food by tribal tribes in Jammu and Kashmir, Rajasthan, Gujarat, Himachal Pradesh, and Bihar. However, a number of biotic and abiotic issues currently impede maize production. About 141 insect pests can harm maize crops in different ways from planting to harvesting, but only a dozen of these are harmful enough to need management. Many biotic and abiotic issues are impeding maize productivity nowadays (Kumar *et al.*, 2015; Reddy and Trivedi 2008). Because of its infamous and polyphagous behavior, the recently introduced insect fall armyworm, *Spodoptera frugiperda*, is a major issue and has become an invasive problem worldwide. Tropical and subtropical America is home to the Fall Armyworm (FAW), which has been a nuisance in the US since 1797. Sharanabasappa *et al.* (2018) made the first reports of this new invasive pest in India. It impacts maize at every stage of development, from seedling to ear formation. By scraping and skeletonizing the top epidermis of opening leaves, FAW larvae produce papery patches and a silvery translucent membrane.

Because the FAW moth populations may migrate at a rate of 100 kilometers every night and 500 km before producing eggs, they can swiftly spread to new locations (Johnson, 1987). Depending on the weather, the pest's life cycle takes 30 to 45 days to complete. The life cycle may last up to 60–90 days in colder climates. An average of 1500 eggs are laid by the female moth and attached to the leaves. In warmer climates, the egg stage lasts only two to three days. Prior to pupation, the FAW generally goes through six larval instars, or stages. Depending on the weather, particularly temperature and humidity, the complete larval stage lasts between 14 and 30 days (Manjula *et al.*, 2019). Due to the extensive use of chemical pesticides, beneficial insects, wildlife, and human health have all suffered worldwide, and insect resistance to pesticides has spread widely. Bio-pesticides are a great substitute for conventional pesticides because they are long-lasting and do not affect animals or the environment. Considering all relevant information, the experiment was carried out to evaluate the effectiveness of several concentrations of chemical and microbial biopesticides as well as one botanical to be studied in a field condition.

## MATERIALS AND METHODS

The field trial was conducted on comparative efficacy of selected chemicals, botanical and biopesticides against Fall Armyworm, *Spodoptera frugiperda* in maize. The trial was designed and evaluated in different locations under All India Co-ordinated Research Project on forage crops & Utilization in India *i.e.*, Rahuri, Jhansi, Ludhiana, Dharwad & Bhubaneshwar during *Kharif* season (2019, 2020 and 2021). A Randomized Block Design experiment was conducted with three replications and ten treatments. African tall maize was sown, with a net area of 4.0 × 3.0 m and a 30-cm gap between two rows and a 10-cm gap inside each row. Every regular agronomical procedure was followed, with the exception of pest management methods. When the larval population reached ETL, the first application of pesticides was sprayed at the specified dosages, and the second was sprayed at a 15-day interval. For calculating the FAW % infestation, the number of infected plants per plot was counted both before and three, seven, and ten days after the spray. Prior to statistical analysis, the infestation percentage data was converted into arc sin transformation in order to determine the significance of the differences between the various treatments. The yield of green fodder was measured in each net plot and translated to q/ha. Following the proper transformation, the data were statistically analyzed to produce a valid conclusion, in accordance with Steel and Torrie (1980).

**Table 1: Treatment details.**

| Sr. No. | Treatments | Dose g/ml/L |
|---|---|---|
| T1 | Emamectin benzoate 5 SG | 0.5 |
| T2 | Chlorpyriphos 20 EC | 2 |
| T3 | *Metarhizium anisopliae* 1.15% WP ($1\times10^8$ CFU/g) | 5 |
| T4 | *Metarhizium anisopliae* 1.15% WP ($1\times10^8$ CFU/g) | 7.5 |
| T5 | *Beauveria bassiana* 1.15% WP ($1\times10^8$ CFU/g) | 5 |
| T6 | *Beauveria bassiana* 1.15% WP ($1\times10^8$ CFU/g) | 7.5 |
| T7 | *Metarhizium* (*Nomuraea*) *rileyi* 1.15% WP ($1\times10^8$ CFU/g) | 5 |
| T8 | *Metarhizium* (*Nomuraea*) *rileyi* 1.15% WP ($1\times10^8$ CFU/g) | 7.5 |
| T9 | Azadirachtin 10,000 ppm | 2 |
| T10 | Untreated Control | — |

## RESULT AND DISCUSSION

***Kharif*-2019:** The result of mean data Rahuri, Jhansi and Dharwad locations in *Kharif* 2019 revealed that the pre count (first and second spray) of fall armyworm, *Spodoptera frugiperda* was found non-significant before spray. At 3 DAS indicate that lowest percent infestation of *Spodoptera frugiperda* were recorded in the treatment of emamectin benzoate 5 SG @ 0.5 ml/lit of water (16.54 %) which was significantly superior over rest of the treatments. Next best treatment recorded was chlorpyriphos 20 EC (28.91%) @ 2 ml/lit of water followed by *Beauveria bassiana* 1.15% WP (34.52%) @ 5 g/L of water, *Metarhizium anisopliae* 1.15% @ (34.72%) WP@ 7.5 g/ lit, *Metarhizium* (*Nomuraea*) *rileyi*1.15% WP (35.26%)@ 7.5 g/L of water, *Beauveria bassiana* 1.15% WP (35.74%) @ 7.5 g/L of water, *Metarhizium anisopliae* 1.15% @ (36.28%) WP@ 5 g/ lit and *Metarhizium* (*Nomuraea*) *rileyi*1.15% WP (36.93%) @ 5 g/L of water in treated plots, respectively that differed significantly with other treatment but statistically at par with each other.

At 7 DAS, found that lowest percent infestation of *Spodoptera frugiperda* were recorded in the treatment of emamectin benzoate 5 SG (9.70 %) which was significantly superior over rest of the treatments. Next best treatment observed was chlorpyriphos 20 EC (22.55%) @ 2 ml/lit of water followed by *Metarhizium* (*Nomuraea*) *rileyi* 1.15% WP (20.95%)@ 7.5 g/L of water, *Metarhizium* (*Nomuraea*) *rileyi* 1.15% WP (21.30%) @ 5 g/L of water, *Beauveria bassiana* 1.15% WP (24.75%) @ 5 g/L of water, *Beauveria bassiana*1.15% WP (24.76%) @ 7.5 g/L of water, *Metarhizium anisopliae* 1.15% @ (26.29%) WP@ 7.5 g/lit and *Metarhizium anisopliae* 1.15% @ (26.68%) WP@ 5 g/ lit in treated plots, respectively that differed significantly with other treatment but statistically at par with each other.

At 10 DAS, it was recorded that lowest percent infestation of *Spodoptera frugiperda* were noted in the treatment of emamectin benzoate 5 SG (7.16 %) which was significantly superior over rest of the treatments. Next best treatment observed was *Metarhizium* (*Nomuraea*) *rileyi* 1.15% WP (17.22%)@ 7.5 g/L of water followed by *Metarhizium* (*Nomuraea*) *rileyi* 1.15% WP (17.24%) @ 5 g/L of water, chlorpyriphos 20 EC (19.76%) @ 2 ml/ lit of water, *Metarhizium anisopliae* 1.15% @ (20.90%) WP@ 7.5 g/10 lit, *Beauveria bassiana* 1.15% WP (21.18%) @ 5 g/L of water, *Beauveria bassiana* 1.15% WP (21.38%) @ 7.5 g/L of water and *Metarhizium anisopliae* 1.15% @ (22.58%) WP@ 5 g/10 lit in treated plots, respectively (Table 2).

**Table 2: Pooled mean three locations of insecticides and biopesticides against fall army worm on maize. during *Kharif* 2019.**

| Sr No. | Treatments | Dose g/ml/L | % plant infestation of plant | | | | GFY qt//ha | % increase over control |
|---|---|---|---|---|---|---|---|---|
| | | | Precount | 3 DAS | 7 DAS | 10 DAS | | |
| 1. | Emamectin benzoate 5 SG | 0.5 | 44.23 (41.68) | 16.54 (24.00) | 9.70 (18.14) | 7.16 (15.52) | 434.92 | 94.03 |
| 2. | Chlorpyriphos 20 EC | 2 | 45.43 (42.38) | 28.91 (32.53) | 22.55 (28.35) | 19.76 (26.39) | 324.71 | 44.86 |
| 3. | *Metarhizium anisopliae* 1.15% WP | 5 | 47.12 (43.35) | 36.28 (37.04) | 26.68 (31.10) | 22.58 (28.37) | 258.45 | 15.30 |
| 4. | *Metarhizium anisopliae* 1.15% WP | 7.5 | 43.82 (41.45) | 34.72 (36.10) | 26.29 (30.84) | 20.90 (27.20) | 281.73 | 25.69 |
| 5. | *Beauveria bassiana* 1.15% WP | 5 | 44.26 (41.71) | 34.52 (35.98) | 24.75 (29.84) | 21.18 (27.40) | 269.20 | 20.10 |
| 6. | *Beauveria bassiana* 1.15% WP | 7.5 | 45.12 (42.20) | 35.74 (36.72) | 24.76 (29.84) | 21.38 (27.54) | 283.30 | 26.39 |
| 7. | *Metarhizium* (*Nomuraea*) *rileyi* 1.15% WP | 5 | 44.96 (42.11) | 36.93 (37.42) | 21.30 (27.48) | 17.24 (24.53) | 282.98 | 26.25 |
| 8. | *Metarhizium* (*Nomuraea*) *rileyi* 1.15% WP | 7.5 | 46.30 (42.88) | 35.26 (36.43) | 20.95 (27.24) | 17.22 (24.52) | 297.52 | 32.73 |
| 9. | Azadirachtin 10,000 ppm | 2 | 47.85 (43.77) | 38.30 (38.24) | 33.12 (35.13) | 31.80 (34.32) | 263.59 | 17.59 |
| 10. | Untreated Control | — | 47.65 (43.65) | 52.03 (46.16) | 55.15 (47.96) | 53.68 (47.11) | 224.15 | 0.00 |
| SE | | | 0.88 | 2.13 | 2.32 | 2.60 | 5.74 | - |
| CD @5% | | | NS | 6.33 | 6.99 | 7.73 | 15.96 | - |
| CV% | | | 3.58 | 8.18 | 13.47 | 16.07 | 8.18 | - |

*Figures in the parenthesis are arc sin transformed values, DAS- Days After Spray, GFY- Green Fodder Yield

***Kharif*-2020:** The mean result of Rahuri, Jhansi and Ludhiana locations in *Kharif* 2020 stated that the pre count (first and second spray) of fall army worm, *Spodoptera frugiperda* was found non-significant before spray. At 3 DAS, indicate that lowest percent infestation of *Spodoptera frugiperda* were recorded in the treatment of emamectin benzoate 5 SG @ 0.5 ml/ lit of water (13.10 %) which was significant and at par with chlorpyriphos 20 EC (21.82%)@ 2 ml/ lit of water. Next treatment was *Metarhizium* (*Nomuraea*) *rileyi* 1.15% WP (25.22%)@ 7.5 g/L of water followed by *Metarhizium* (*Nomuraea*) *rileyi* 1.15% WP (26.71%) @ 5 g/L of water, *Metarhizium anisopliae* 1.15% @ (26.84%) WP@ 7.5 g/ lit, *Beauveria bassiana* 1.15% WP (27.15%) @ 7.5 g/L of water, *Metarhizium anisopliae* 1.15% @ (27.28%) WP@ 5 g/ lit, Azadirachtin 10,000 ppm (28.24) and *Beauveria bassiana*1.15% WP (28.41%) @ 5 g/L of water intreated plots, respectively.

At 7 DAS, it was found that lowest percent infestation of *Spodoptera frugiperda* recorded in the treatment of emamectin benzoate 5 SG (9.52 %) which was significant and at par with chlorpyriphos 20 EC (18.57%) @ 2ml/ lit of water followed by *Metarhizium* (*Nomuraea*) *rileyi*1.15% WP (18.99%)@ 7.5 g/L of water, *Metarhizium* (*Nomuraea*) *rileyi* 1.15% WP (20.37%) @ 5 g/L of water. Next treatment was *Metarhizium anisopliae* 1.15% @ (21.13%) WP@ 7.5 g/ lit, *Beauveria bassiana* 1.15% WP (22.62%) @ 7.5 g/L of water, *Metarhizium anisopliae* 1.15% @ (22.65%) WP@ 5 g/ lit, *Beauveria bassiana* 1.15% WP (24.23%) @ 5 g/L of water and Azadirachtin 10,000 ppm (26.28) in treated plots, respectively that differed significantly with other treatment but statistically at par with each other.

At 10 DAS, it was recorded that lowest percent infestation of *Spodoptera frugiperda* were noted in the treatment of emamectin benzoate 5 SG (6.72 %) which was significantly superior over rest of the treatments. Next best treatment observed was chlorpyriphos 20 EC (16.68%) @ 2 ml/lit of water which was at par with *Metarhizium* (*Nomuraea*) *rileyi* 1.15% WP (17.44%) @ 7.5 g/L of water followed by *Metarhizium anisopliae* 1.15% @ (18.28%) WP@ 7.5 g/lit, *Metarhizium* (*Nomuraea*) *rileyi*1.15% WP (18.54%) @ 5 g/L of water, *Beauveria bassiana*1.15% WP (20.67%) @ 7.5 g/L of water, *Metarhizium anisopliae* 1.15% @ (21.52%) WP@ 5 g/ lit and *Beauveria bassiana* 1.15% WP (28.28%) @ 5 g/L of water in treated plots, respectively that differed significantly with other treatment but statistically at par with each other.

***Kharif*-2021:** The mean result of Rahuri, Bhubanshwar and Ludhiana locations in Kharif 2021 stated that the pre count (first and second spray) of fall army worm, *Spodoptera frugiperda* was found non-significant before spray. At 3 DAS, indicate that lowest percent infestation of *Spodoptera frugiperda* were recorded in the treatment of emamectin benzoate 5 SG @ 0.5 ml/ lit of water (19.95 %) which was significant and at par with chlorpyriphos 20 EC (28.37%) @ 2 ml/ lit of water. Next treatment was *Metarhizium* (*Nomuraea*) *rileyi* 1.15% WP (31.27%)@ 7.5 g/L of water followed by *Metarhizium anisopliae* 1.15% @ (32.33%) WP@ 7.5 g/ lit, *Beauveria bassiana* 1.15% WP (33.51%) @ 7.5 g/L of water, *Metarhizium* (*Nomuraea*) *rileyi* 1.15% WP (35.56%) @ 5 g/L of water, *Metarhizium anisopliae* 1.15% @ (35.64%) WP@ 5 g/ lit, Azadirachtin 10,000 ppm (35.68) and *Beauveria bassiana*1.15% WP (35.94%) @ 5 g/L of water in treated plots, respectively.

At 7 DAS, it was found that lowest percent infestation of *Spodoptera frugiperda* recorded in the treatment of emamectin benzoate 5 SG (13.90 %) which was significantly superior over rest of the treatments. Next best treatment waschlorpyriphos 20 EC (22.61%) @ 2ml/ lit of water followed by *Metarhizium* (*Nomuraea*) *rileyi* 1.15% WP (23.39%)@ 7.5 g/L of water, *Metarhizium anisopliae* 1.15% @ (24.12%) WP@ 7.5 g/ lit, *Metarhizium* (*Nomuraea*) *rileyi* 1.15% WP (25.00%)

@ 5 g/L of water, *Beauveria bassiana* 1.15% WP (26.72%) @ 7.5 g/L of water, *Beauveria bassiana* 1.15% WP (28.13%) @ 5 g/L of water, *Metarhizium anisopliae* 1.15% @ (28.18%) WP@ 5 g/ lit and Azadirachtin 10,000 ppm (33.73) in treated plots, respectively.

At 10 DAS, recorded that lowest percent infestation of *Spodoptera frugiperda* were noted in the treatment of emamectin benzoate 5 SG (6.01 %) which was significantly superior over rest of the treatments. Next best treatment observed was chlorpyriphos 20 EC (16.18%) @ 2 ml/lit of water which was at par with *Metarhizium* (*Nomuraea*) *rileyi* 1.15% WP (14.85%) @ 7.5 g/L of water followed by *Metarhizium anisopliae* 1.15% @ (16.23%) WP@ 7.5 g/lit, *Metarhizium* (*Nomuraea*) *rileyi*1.15% WP (17.10%) @ 5 g/L of water, *Beauveria bassiana* 1.15% WP (17.99%) @ 7.5 g/L of water, *Metarhizium anisopliae* 1.15% @ (19.54%) WP@ 5 g/lit and *Beauveria bassiana* 1.15% WP (20.62%) @ 5 g/L of water in treated plots, respectively.

**Pooled data (*Kharif* 2019, 2020 and 2021):** The results of pooled data of *Kharif* 2019, 2020 and 2021 of all locations were revealed that the pre count (first and second spray) of fall army worm, *Spodoptera frugiperda* found non-significant before spray indicating uniformity of pest population in the experimental plot but after spray, it was found significantly differ in all the treatments over control. After three days of spray indicate that among all the treatments the lowest percent infestation of *Spodoptera frugiperda* were recorded in the treatment of emamectin benzoate 5 SG @ 5 ml/lit of water (16.53 %) which was significantly superior over rest of the treatments. Next best treatment found was chlorpyriphos 20 EC (26.36%) @ 2ml/lit of water. The treatment *Metarhizium* (*Nomuraea*) *rileyi* 1 1.5% WP@ 7.5 g/lit (30.73%) followed by *Metarhizium anisopliae* 1.15% WP @ 7.5 g/ 10 lit of water (31.30%), *Beauveria bassiana* 1.15% WP (32.13%) @ 75 g/10 lit of water, *Beauveria bassiana* 1.15% WP (32.96%) and *Metarhizium* (*Nomuraea*) *rileyi* 1.15% WP @ 5 g/lit (33.07%) in treated plots, respectively.

Seven days after spray it was found that lowest percent infestation of *Spodoptera frugiperda* recorded in the treatment of emamectin benzoate 5 SG (11.04 %) which was significantly superior over rest of the treatments. Next best treatment was *Metarhizium* (*Nomuraea*) *rileyi* 1.15% WP (21.11%) @ 7.5 g/L of water followed by chlorpyriphos 20 EC (21.24%) @ 2 ml/ lit of water, *Metarhizium* (*Nomuraea*) *rileyi* 1.15% WP (22.22%) @ 5 g/L of water, *Metarhizium anisopliae* 1.15% @ (23.85%) WP@ 7.5 g/ lit, *Beauveria bassiana* 1.15% WP (24.70 %) @ 7.5 g/L of water, *Beauveria bassiana* 1.15% WP (25.70%) @ 5 g/L of water and *Metarhizium anisopliae* 1.15% @ WP@ 5 g/ lit (25.84%) in treated plots, respectively that differed significantly with other treatment but statistically at par with each other. Among different treatments highest percent infestation was recorded in Azadirachtin 10,000 ppm (30.08%) followed by untreated control (50.74 %).

Ten days after spray it was observed that lowest percent infestation of *Spodoptera frugiperda* was noted in the treatment of emamectin benzoate 5 SG (6.63 %) which was significantly superior over rest of the treatments. Next best treatment observed was *Metarhizium* (*Nomuraea*) *rileyi* 1.15% WP (16.51%) @ 7.5 g/L of water which was at par with chlorpyriphos 20 EC (17.54%) @ 2 ml/lit of water followed by *Metarhizium* (*Nomuraea*) *rileyi* 1.15% WP (17.63%) @ 5 g/L of water. Thereafter the treatment *Metarhizium anisopliae* 1.15% @ (18.47%) WP@ 7.5 g/lit, *Beauveria bassiana* 1.15% WP @ 5 g/L (21.42%), *Metarhizium anisopliae* 1.15% @ (21.21%) WP@ 5 g/lit (Table 5).

The present results were in accordance with the findings of Chandan *et al*. (2023) who reported that the lowest larval population recorded in emamectin benzoate 5 SG (1.178) with highest yield 42.5 q/ha and cost benefit ratio (1:2.42) in maize. Bharadwaj *et al.* (2020) reported that emamectin benzoate 5 WG @0.002 per cent was effective in reducing the larval population of *S. frugiperda* (5.17 larvae/25 plants) during kharif 2019 in maize. Chandar and Tayde (2023) was reported that emmamectin benzoate 5 SG recorded the minimum larval population (2.24 /10 plants) during Kharif season 2021 and 2022 in maize. The present results agree with Sharanabasappa *et al*. (2020) where highest larval mortality of *S. frugiperda* was observed in treatment of emmamectin benzoate 5 SG in maize

In case of green forage yields, among the different treatments highest yield were recorded in emamectin benzoate 5SG (374.94 q/ha) which was significantly superior over rest of the treatments. Next best treatment observed was chlorpyriphos 20 EC (305.74 q/ha) which was at par with *Metarhizium anisopliae* 1.15% WP @ 7.5 g/lit of water (277.96 q/ha). Thereafter, *Metarhizium* (*Nomuraea*) *rileyi* 1.15% WP@ 5 g/lit of water (275.95 q/ha) followed by *Beauveria bassiana* 1.15% WP @ 7.5 g/lit of water (273.99 q/ha), *Metarhizium anisopliae* 1.15% WP @ 5 g/lit of water (267.24 q/ha) and *Beauveria bassiana* 1.15% WP @ 5 g/lit of water (260.40 q/ha) as compared to untreated control plot (224.16 q/ha). These findings are supported by Sangle *et al.* (2020); Suthar *et al.* (2020); Thumar *et al.* (2020) All the treatments were superior over control (Table 5). Mallapur *et al.* (2018) found that 62.50 to 66.46 per cent leaf damage and 58.91to 62.87 per cent population reduction of fall armyworm population at 15 days of *N. rileyi* spraying at vijaypur and uttar kannada district of Karnataka. The highest Green forage yield increased over control was recorded in emamectin benzoate 5 SG (67.26%) followed by chlorpyriphos 20 EC (36.40%), *Metarhizium* (*Nomuraea*) *rileyi* 1.15% WP @ 7.5g /lit (29.49), *Metarhizium anisopliae* 1.15% WP @ 7.5g/lit (24.00), *Metarhizium* (*Nomuraea*) *rileyi* 1.15% WP @ 5g /lit (23.10), *Beauveria bassiana* 1.15% WP @ 7.5g/lit (22.23), *Metarhizium anisopliae* 1.15% WP@5g/lit (19.22), (Table 5).

The present study confirmed that the treatment by emamectin benzoate reduces per cent infestation of fall armyworm, which conformity with the result of Nashwa and Aziza (2023) found that spraying of emamectin benzoate 5SG reduced 72.62 per cent infestation and also reduction of residual toxicity. Satanarayana *et al*. (2010) who found that emamectin benzoate 0.00725 % was the most effective insecticide for reducing the larval population *of Spodoptera litura.* Naram *et al.* (2022) reported that emamectin benzoate 5% SG was found

more effective in managing the population and damage in maize which also reflected on yield.

When cost benefit ratio was worked out, among the treatments studied (Table 6), the best and most economical treatment was T1 (1:1.55) followed by T2 (1:1.31), T8 (1:1.23), T7 (1:1.18), T6 (1:1.16), as compared to T10 (1:0.83). These findings are supported by Ahir *et al.* (2021) who reported that maximum incremental benefit cost ratio (1:1.87) was obtained from three spays of emamectin benzoate 5SG in maize. Tayde and Ramesh (2022) reported that emamectin benzoate was most economical treatment which recorded the benefit coat ratio of 1:1.74 in maize. Deshmukh *et al.* (2020) showed that higher efficacy with higher benefit cost ratio recorded by emamectin benzoate 5 SG against *S. frugiperda* in maize. Likwise, Metzler *et al.* (2017) reported that botanicals insecticides effective against fall armyworm and it is more cost efficient for small farmers. Sharma *et al.* (2018) also reported that safe and eco-friendly insecticide has potential to replace synthetic pesticides and provide benefit cost effective in maize agro-ecosystem.

**Table 3: Pooled mean three locations of insecticides and biopesticides against fall army worm on maize during *Kharif* 2020.**

| Sr. No. | Treatments | Dose g/ml/L | % plant infestation of plant | | | | GFY qt//ha | % increase over control |
|---|---|---|---|---|---|---|---|---|
| | | | Precount | 3 DAS | 7 DAS | 10 DAS | | |
| 1. | Emamectin benzoate 5 SG | 0.5 | 34.22 (35.80) | 13.10 (21.22) | 9.52 (17.97) | 6.72 (15.03) | 334.36 | 53.43 |
| 2. | Chlorpyriphos 20 EC | 2 | 35.00 (36.27) | 21.82 (27.85) | 18.57 (25.53) | 16.68 (24.10) | 294.00 | 34.90 |
| 3. | *Metarhizium anisopliae* 1.15% WP | 5 | 33.85 (35.58) | 27.28 (31.49) | 22.65 (28.42) | 21.52 (27.64) | 265.96 | 22.04 |
| 4. | *Metarhizium anisopliae* 1.15% WP | 7.5 | 34.20 (35.79) | 26.84 (31.20) | 21.13 (27.37) | 18.28 (25.31) | 269.98 | 23.88 |
| 5. | *Beauveria bassiana* 1.15% WP | 5 | 33.93 (35.62) | 28.41 (32.21) | 24.23 (29.49) | 22.45 (28.28) | 251.86 | 15.57 |
| 6. | *Beauveria bassiana* 1.15% WP | 7.5 | 34.68 (36.08) | 27.15 (31.40) | 22.62 (28.40) | 20.67 (27.04) | 253.47 | 16.31 |
| 7. | *Metarhizium* (*Nomuraea*) *rileyi* 1.15% WP | 5 | 33.63 (35.45) | 26.71 (31.12) | 20.37 (26.83) | 18.54 (25.50) | 272.13 | 24.87 |
| 8. | *Metarhizium* (*Nomuraea*) *rileyi* 1.15% WP | 7.5 | 32.85 (34.97) | 25.22 (30.15) | 18.99 (25.83) | 17.44 (24.69) | 280.12 | 28.54 |
| 9. | Azadirachtin 10,000 ppm | 2 | 33.58 (35.42) | 28.24 (32.10) | 26.28 (30.84) | 33.62 (35.44) | 243.48 | 11.72 |
| 10. | Untreated Control | — | 34.20 (35.79) | 42.89 (40.91) | 48.06 (43.89) | 53.45 (46.98) | 217.93 | 0.00 |
| SE | | | 2.42 | 2.77 | 3.02 | 3.02 | 14.14 | |
| CD @5% | | | 7.20 | 8.22 | 8.98 | 8.95 | 42.01 | |
| CV% | | | 13.82 | 17.08 | 18.92 | 8.92 | 9.49 | |

*****Figures in the parenthesis are arc sin transformed values, DAS- Days After Spray, GFY- Green Fodder Yield

**Table 4: Pooled mean three locations of insecticides and biopesticides against fall army worm on maize during *Kharif* 2021.**

| Sr. No. | Treatments | Dose g/ml/L | % plant infestation of plant | | | | GFY qt//ha | % increase over control |
|---|---|---|---|---|---|---|---|---|
| | | | Precount | 3 DAS | 7 DAS | 10 DAS | | |
| 1. | Emamectin benzoate 5 SG | 0.5 | 45.42 (42.37) | 19.95 (26.53) | 13.90 (21.89) | 6.01 (14.19) | 355.53 | 54.31 |
| 2. | Chlorpyriphos 20 EC | 2 | 47.17 (43.38) | 28.37 (32.18) | 22.61 (28.39) | 16.18 (23.72) | 298.53 | 29.57 |
| 3. | *Metarhizium anisopliae* 1.15% WP | 5 | 46.77 (43.15) | 35.64 (36.65) | 28.18 (32.06) | 19.54 (26.23) | 277.30 | 20.36 |
| 4. | *Metarhizium anisopliae* 1.15% WP | 7.5 | 46.39 (42.93) | 32.33 (34.65) | 24.12 (29.41) | 16.23 (23.76) | 282.17 | 22.47 |
| 5. | *Beauveria bassiana* 1.15% WP | 5 | 47.18 (43.38) | 35.94 (36.83) | 28.13 (32.03) | 20.62 (27.01) | 260.13 | 12.91 |
| 6. | *Beauveria bassiana* 1.15% WP | 7.5 | 46.79 (43.16) | 33.51 (35.37) | 26.72 (31.13) | 17.99 (25.10) | 285.20 | 23.78 |
| 7. | *Metarhizium* (*Nomuraea*) *rileyi* 1.15% WP | 5 | 45.91 (42.66) | 35.56 (36.61) | 25.00 (30.00) | 17.10 (24.43) | 272.73 | 18.37 |
| 8. | *Metarhizium* (*Nomuraea*)*rileyi* 1.15% WP | 7.5 | 46.59 (43.04) | 31.70 (34.27) | 23.39 (28.92) | 14.85 (22.67) | 293.13 | 27.23 |
| 9. | Azadirachtin 10,000 ppm | 2 | 46.42 (42.95) | 35.68 (36.68) | 30.84 (33.73) | 26.92 (31.25) | 271.70 | 17.93 |
| 10. | Untreated Control | — | 45.63 (42.49) | 48.27 (44.01) | 48.99 (44.42) | 50.40 (45.23) | 230.40 | 0.00 |
| SE | | | 0.53 | 1.92 | 2.01 | 2.26 | 14.59 | |
| CD @5% | | | NS | 5.70 | 5.98 | 6.71 | 43.35 | |
| CV% | | | 2.16 | 9.57 | 11.41 | 15.08 | 8.94 | |

*****Figures in the parenthesis are arc sin transformed values, DAS- Days After Spray, GFY- Green Fodder Yield

**Table 5: Pooled mean three locations of insecticides and biopesticides against fall army worm on maize during (*Kharif* 2021, 2022 & 2023)**

| Sr. No. | Treatments | Dose g/ml/L | % plant infestation of plant | | | | GFY qt//ha | % increase over control |
|---|---|---|---|---|---|---|---|---|
| | | | Precount | 3 DAS | 7 DAS | 10 DAS | | |
| 1. | Emamectin benzoate 5 SG | 0.5 | 41.29 (39.98) | 16.53 (23.99) | 11.04 (19.41) | 6.63 (14.92) | 374.94 | 67.26 |
| 2. | Chlorpyriphos 20 EC | 2 | 42.54 (40.71) | 26.36 (30.89) | 21.24 (27.45) | 17.54 (24.76) | 305.74 | 36.40 |
| 3. | *Metarhizium anisopliae* 1.15% WP | 5 | 42.58 (40.73) | 33.07 (35.10) | 25.84 (30.55) | 21.21 (27.42) | 267.24 | 19.22 |
| 4. | *Metarhizium anisopliae* 1.15% WP | 7.5 | 41.47 (40.09) | 31.30 (34.02) | 23.85 (29.23) | 18.47 (25.45) | 277.96 | 24.00 |
| 5. | *Beauveria bassiana* 1.15% WP | 5 | 41.79 (40.27) | 32.96 (35.03) | 25.70 (30.46) | 21.42 (27.57) | 260.40 | 16.17 |
| 6. | *Beauveria bassiana* 1.15% WP | 7.5 | 42.20 (40.51) | 32.13 (34.53) | 24.70 (29.80) | 20.01 (26.58) | 273.99 | 22.23 |
| 7. | *Metarhizium* (*Nomuraea*) *rileyi* 1.15% WP | 5 | 41.50 (40.11) | 33.07 (35.10) | 22.22 (28.13) | 17.63 (24.82) | 275.95 | 23.10 |
| 8. | *Metarhizium* (*Nomuraea*) *rileyi* 1.15% WP | 7.5 | 41.91 (40.35) | 30.73 (33.66) | 21.11 (27.35) | 16.51 (23.97) | 290.26 | 29.49 |
| 9. | Azadirachtin 10,000 ppm | 2 | 42.62 (40.75) | 34.07 (35.71) | 30.08 (33.26) | 30.78 (33.70) | 259.59 | 15.80 |
| 10. | Untreated Control | — | 42.49 (40.68) | 47.73 (43.70) | 50.74 (45.42) | 52.51 (46.44) | 224.16 | 0.00 |
| SE | | | 0.34 | 0.47 | 0.67 | 0.44 | 9.73 | |
| CD @5% | | | NS | 1.40 | 1.99 | 1.32 | 28.91 | |
| CV% | | | 1.48 | 7.40 | 8.85 | 9.79 | 6.00 | |

*****Figures in the parenthesis are arc sin transformed values, DAS- Days After Spray, GFY- Green Fodder Yield

**Table 6: Cost benefit ratio of different pesticides against FAW of Maize.**

| SN | Treatments | Maize GFY q/ha | Additional yield over control q/ha | Gross monitory return Rs/ha | Cost of treatment Rs/ha | Net monitory return Rs/ha | Additional income over control Rs/ha | BC* Ratio | ICBR** |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Emamectin benzoate 5 SG | 374.94 | 150.78 | 84361.5 | 54260 | 30102 | 29666 | 1:1.55 | 1:6.96 |
| 2 | Chlorpyriphos 20 EC | 305.74 | 81.58 | 68791.5 | 52542 | 16250 | 15814 | 1:1.31 | 1:6.22 |
| 3 | *Metarhizium anisopliae* 1.15% WP | 267.24 | 43.08 | 60129 | 52656 | 7473 | 7037 | 1:1.14 | 1:2.65 |
| 4 | *Metarhizium anisopliae* 1.15% WP | 277.96 | 53.80 | 62541 | 53156 | 9385 | 8949 | 1:1.18 | 1:2.84 |
| 5 | *Beauveria bassiana* 1.15% WP | 260.4 | 36.24 | 58590 | 52656 | 5934 | 5498 | 1:1.11 | 1:2.07 |
| 6 | *Beauveria bassiana* 1.15% WP | 273.99 | 49.83 | 61647.75 | 53156 | 8492 | 8056 | 1:1.16 | 1:2.55 |
| 7 | *Metarhizium* (*Nomuraea*) *rileyi* 1.15% WP | 275.95 | 51.79 | 62088.75 | 52656 | 9433 | 8997 | 1:1.18 | 1:3.39 |
| 8 | *Metarhizium* (*Nomuraea*) *rileyi* 1.15% WP | 290.26 | 66.10 | 65308.5 | 53156 | 12153 | 11717 | 1:1.23 | 1:3.71 |
| 9 | Azadirachtin 10,000 ppm | 259.59 | 35.43 | 58407.75 | 54354 | 4054 | 3618 | 1:1.07 | 1:0.83 |
| 10 | Untreated Control | 224.16 | 0.00 | 50436 | 50000 | 436 | -- | -- | -- |

GFY–Rs. 225/q
Chlorpyriphos 20 EC- Rs. 443/lit
Emamectin benzoate 5 SG- Rs. 521/100 g
*B:C Ratio-Benefit Cost Ratio

Azadiractin:10,000 ppm Rs. 1349/lit
*Metarhizium anisopliae* Rs. 200/kg
*Metarhizium rileyi*- Rs. 200/kg
**ICBR- Incremental Cost Benefit Ratio

No. of application = 2
*Beauveria bassiana* Rs. 200/kg
Labour cost for one spray- Rs. 827/ ha/spray @ (Rs. 331 /labour/day)

## CONCLUSIONS

On the basis of results of current investigation, it can be concluded that for management of fall armyworm, *S. frugiperda* the treatment of emamectin benzoate 5 SG @ 5 ml/10 lit of water shown most effective in reducing plant damage by fall armyworm as well as highest return on investment per rupee.

## FUTURE SCOPE

Identification of effective sustainable management practices against fall armyworm in fodder as well grain maize.

**Acknowledgements.** The authors thank the In-charge, AICRP on Forage Crops and Utilization, Mahatma Phule Krishi Vidyapeeth, Rahuri 413 722, Maharashtra for providing necessary help and guidance during the course of investigation.
**Conflict of Interest.** None.

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**How to cite this article:** S.A. Landge, K.S. Pagire and S.K. Ghodke (2025). Biorational Management of Fall Armyworm, *Spodoptera frugiperda* (J.E. Smith) in Maize (*Zea mays* L.). *International Journal on Emerging Technologies*, *16*(1): 83–89.