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Management of fall armyworm infesting maize by sequential application of insecticides and biopesticides

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Abstract
An experiment entitled "Efficacy of sequential application of biopesticides and insecticides against Fall armyworm, *Spodoptera frugiperda* (J. E. Smith) infesting maize**.**" was conducted at research field of Department of Agricultural Entomology, College of Agriculture, Pune during *Rabi* 2021-22. During the course of study, eight sequential applications were evaluated over untreated control against fall armyworm infesting maize. The results showed that treatment with spraying of Emamectin benzoate 5SG @ 2 g/l followed by *Nomuraea rileyi* @ 5 g/l followed by Lambda cyhalothrin 5EC @ 0.6 ml/l was found to be most effective and recorded least average survived larval population of *S. frugiperda,* also shows minimum plant damage percent. Among sequential application tested, the treatment T_6 (E. benzoate - *N. rileyi* - L. cyhalothrin) gave significantly highest grain yield of 30.44 q/ha.

Keywords: Sequential application, biopesticides, insecticides, fall armyworm, larval population, damage

1. Introduction

Maize (*Zea mays* L.), also known as corn, is a cereal grain that originated in Central America. It is now the world's third most important cereal crop and is known as the "Queen of Cereals" or "Miracle Crop." (Rautaray *et al*. 2013) [14] Maize is a leafy stalk with seeds inside its kernels. The numerous and varied uses of corn contribute for its significance. It is used as both human food and animal feed. Corn is almost entirely consumed as feed. Corn is used to make a variety of foods, including popped snack food and alkali-cooked "Mexican" items. Maize contains starch (71-72%) and protein (9-10%), making it the most important component of corn kernels used in foods and industrial products. Additionally, the starch is transformed into glucose and fructose for use as food sweetness. Ethanol made from glucose can be fermented and used as a fuel or beverage. Maize is a valuable source of nutrition for both animals and people.

On maize, more than 141 different species of insects have been identified and fall armyworm, *Spodoptera frugiperda* is serious one among them. *Spodoptera frugiperda* (J. E. Smith), often known as the fall armyworm (FAW), has been recognised as a pest of numerous agricultural crops for more than 200 years (Luginbill, 1928) [12]. It results in economic losses in a variety of pasture plants, including Bermuda grass, Johnson grass, and others, as well as in maize, paddy, jowar, peanut, alfalfa, cotton, Sudanese grass, soybean, tobacco, oat, wheat, and sugarbeet (Andrews, 1980; Capinera, 2000) [3, 4]. American-native Fall Armyworm is a polyphagous insect that causes economic loss of numerous crops, including maize, jowar, beans, and cotton, (Roger *et al*., 2017) [15]. The infestation of this pest was discovered for the first time in India on a maize crop in Karnataka in May and June 2018 (Chormule *et al*., 2018) [5]. Subsequently, it was reported in Tamil Nadu, Telangana, Maharashtra, Gujarat, and Madhya Pradesh on a variety of crops, including sorghum, cotton, sugarcane, paddy, tomato, soybean, and other millets. The agricultural crop production of India may be at risk from this ravenous pest, which has been known to destroy a one-acre field in less than a week. Due to the Indian FAW population's genetic resemblance to the South African FAW population and it predominate diet of maize, the recent incursion of this invasive pest poses a threat to India's grain-maize production (Sharanabasappa *et al*. 2018) [16]. Since insecticides have shown positive results in America and Africa (Gutierrez-Moreno *et al*. 2019) [9], the first line of defence for controlling this ravenous feeder in India is chemical control method. The use of pesticide spray and genetically modified crops (*Bt* maize) are the typical control measures for fall armyworm in its native areas of America, just similar to those used for other significant agricultural pests. However, the FAW has evolved a resistance to a number of pesticides (Abrahams *et al*., 2017; Yu *et al*., 2003) [1, 19], which points to the need for integrated management approaches to handle this invasive pest in a sustainable manner. However, there is a lack of empirical data on various IPM strategies for fall armyworm in India.

Keeping this in mind, the current experiment is conducted to evaluate the impact of both biopesticides and insecticides on larval population and prevailing predators and parasitoid i.e., natural enemies. The best management sequence was also evaluated to find the most compatible insecticide–biopesticide-insecticide combination for successful control of FAW in India. This helps to verify sequentially applying different biopesticides including *Bacillus thuringiensis* (*Bt*), *Nomuraea rileyi*, *Beauveria bassiana*, *Metarhizium anisopliae* and insecticides such as lambda cyhalothrin and emamectin benzoate to manage *Spodoptera frugiperda* (J. E. Smith) attacking maize in the field.

2. Material and Method

A field trial with eight sequential applications along with untreated control (Table 1) were carried out in Randomized Block Design with three replications, during *Rabbi* 2021-22. The seeds of maize variety 'Rajarshi' were sown during 1st fortnight of December 2021 in a plot size 5.0 m x 2.0 m. with plant spacing 60 x 20 cm. In each sequential strategy, three sprays were applied at 15 days interval by using 500 lit. of water per hector with the help of hand operated knapsack sprayer as pest population crossed ETL. The treatments are illustrated in (Table 1). In order to find out effective sequential application for control of fall armyworm in maize. The observations on fall armyworm, *S. frugiperda* larval population and damaged plants were recorded a day before spray (DBS) and 3, 7, and 14 days after each application as post-counts. The observations were recorded on randomly selected 10 plants in each plot. The grain yield from each plot was recorded and converted into quintal/ha. The percent plant damage was worked out as reported by Ahir *et al* (2021) [2]:

$$\text{Percent plant damage} = \frac{\text{Number of infested plants/plot}}{\text{Total number of plants /plot}} \times 100$$

Table 1: Treatment details

Tr. No.	Treatment name
T_1	Lambda cyhalothrin 5 EC @ 0.6 ml/l - *Metarhizium anisopliae* @ 5 g/l - Emamectin benzoate 5 SG @ 2 g/l
T_2	Lambda cyhalothrin 5 EC @ 0.6 ml/l - *Nomuraea rileyi* @ 5 g/l - Emamectin benzoate 5 SG @ 2 g/l
T_3	Lambda cyhalothrin 5 EC @ 0.6 ml/l - *Beauveria bassiana* @ 5 g/l - Emamectin benzoate 5 SG @ 2 g/l
T_4	Lambda cyhalothrin 5 EC @ 0.6 ml/l - *Bacillus thuringiensis* @ 5 g/l - Emamectin benzoate 5 SG @ 2 g/l
T_5	Emamectin benzoate 5 SG @ 2 g/l - *Metarhizium anisopliae* @ 5 g/l - Lambda cyhalothrin 5 EC @ 0.6 ml/l
T_6	Emamectin benzoate 5 SG @ 2 g/l - *Nomuraea rileyi* @ 5 g/l - Lambda cyhalothrin 5 EC @ 0.6 ml/l
T_7	Emamectin benzoate 5 SG @ 2 g/l - *Beauveria bassiana* @ 5 g/l - Lambda cyhalothrin 5 EC @ 0.6 ml/l
T_8	Emamectin benzoate 5 SG @ 2 g/l - *Bacillus thuringiensis* @ 5 g/l -Lambda cyhalothrin 5 EC @ 0.6 ml/l
T_9	Untreated control

3. Statistical analysis

The larval population and percent plant damage due to *S. frugiperda* was transformed into square root values (x + 0.5) and arc sine values respectively and subjected to analysis of variance The mean values and the data on pests, natural enemies, and yield after suitable transformation were subjected to statistical analysis to test significance as per Gomez and Gomez (1984) [10] for interpretation of the results using OPSTAT software.

4. Result and Discussion

The results obtained during the course of investigations are presented under the following heads.

4.1 Effect of sequential application of biopesticides and insecticides spray on larval population of fall armyworm on maize.

The data on larval population due to fall armyworm after first (insecticides), second (biopesticides), third (insecticides) spray are discussed here.

4.1.1 Pre count of larval population.

The pre-treatment data pertaining to larval population showed uniform distribution in all the treatments ranging between 2.93 to 3.50 larvae / plant and statistically insignificant.

4.2 First spray of insecticides in sequential application.

The data on larval population after first spray (insecticides) are presented in Table 2. In sequential application of biopesticides and insecticides against FAW, the first application of insecticides includes lambda cyhalothrin and emamectin benzoate. First spray of insecticides in sequential application revealed that the lowest surviving larval population (1.44 larvae/plant) of *S. frugiperda* was recorded in the treatment T_6 (Emamectin benzoate) and found to be superior among all other treatments and it was at par with $T_{8,}$ T_7 and T_5 each containing emamectin benzoate, due to the application of same insecticide with same dosage. The treatment T_4 (Lambda cyhalothrin) was the next best treatment recorded 2.41 survival larval population/plant and was at par with T_3, T_2 and T_1 each containing lambda cyhalothrin recorded 2.47, 2.47 and 2.52 larvae/ plant, respectively, having same dosage of lambda cyhalothrin. The untreated control recorded highest larval population (3.53 larvae / plant).

4.3 Second spray of biopesticides in sequential application.

The data concern to larval population after second spray (biopesticides) are presented in Table 3. Second spray in sequential application of biopesticides and insecticides, includes *Metarhizium anisopliae*, *Nomuraea riley*, *Beauveria bassiana*, *Bacillus thuringiensis*. After second spray, the treatment T_6 (*Nomuraea rileyi*) registered significantly lowest larval count of 0.88 surviving larva of *S. frugiperda* /plant and was at par with T_8 (*Bacillus thuringiensis*), T_4 (*Bacillus thuringiensis*) and T_2 (*Nomuraea rileyi*) which recorded 1.12, 1.20 and 1.27 larvae / plant, respectively. The next treatment in order of efficacy was T_7 (*Beauveria bassiana*) recorded 1.41larvae / plant. However, it was at par with T_5 (*Metarhizium anisopliae*), T_3 (*Beauveria bassiana*) and T_1

(*Metarhizium anisopliae*) recorded 1.60, 1.68 and 1.91 surviving larvae /plant, respectively. Maximum larval population of *S. frugiperda* per plant (3.24) was recorded in untreated control (T_9).

4.4 Third spray of insecticides in sequential application.
Larval population data after third spray (biopesticides) are presented in Table 4. In sequential application of biopesticides and insecticides against FAW, the third spray includes emamectin benzoate and lambda cyhalothrin. The third spray of sequential application revealed that the treatment T_2 (Emamectin benzoate) found to be superior among all the treatments and recorded 0.47 survival larva/plant. However, it was at par with T_6 (lambda cyhalothrin), T_4 (Emamectin benzoate) and T_8 (Lambda cyhalothrin) with 0.49, 0.54 and 0.67 larvae / plant, respectively. The next best treatments were T_3 (Emamectin benzoate), T_1 (Emamectin benzoate), T_5 (Lambda cyhalothrin) and T_7 (Lambda cyhalothrin) being on par with each other recorded 0.81, 0.88 and 1.07 and 1.07 surviving larvae/plant, respectively. Maximum larval population of *S. frugiperda* per plant (1.76) was observed in untreated control.

4.5 Pooled mean of three sprays in sequential application.
The pooled mean of larval population of fall armyworm after sequential application of three sprays are presented in Table 5. The data revealed that the lowest (0.94) mean surviving population of *S. frugiperda* larvae / plant was recorded in the treatment T_6 (E. benzoate - *N. rileyi* - L. cyhalothrin) and at par with treatment T_8 wherein, E. benzoate - *B. thuringiensis* - L. cyhalothrin applied which recorded 1.09 surviving larvae /plant. The next superior treatment in this respect of efficacy in sequential application was T_4 (L. cyhalothrin - *B. thuringiensis.* - E. benzoate) recorded 1.38 larvae /plant, which was at with T_2 (L. cyhalothrin - *N. rileyi* - E. benzoate), T_7 (E. benzoate- *B. bassiana*- L. cyhalothrin), T_5 (E. benzoate - *M. anisopliae* - L. cyhalothrin), T_3 (L. cyhalothrin- *B. bassiana* - E. benzoate) and T_1 (L. cyhalothrin - *M. anisopliae* - E. benzoate) recorded 1.40, 1.41, 1.47, 1.65 and 1.77 larvae /plant, respectively. Highest mean surviving larval population of *S. frugiperda* / plant was recorded in untreated control plot i.e., 2.87 larvae /plant.

4.6 Effect of sequential application of biopesticides and insecticides on plant damage by fall armyworm on maize.
4.6.1 Pre count of percent plant damage
The pre-treatment data related to damaged plant percent due to fall armyworm observed uniform distribution in all the treatments fluctuated between 56.67 to 66.67 percent with no significance differences.

4.6.2 Plant damage after first spray in sequential application (Insecticides).
First spray of insecticides in sequential application consists lambda cyhalothrin and emamectin benzoate. The data concern to damage percent after first spray (insecticide) are presented in Table 2. The minimal damage percent recorded in T_6 (Emamectin benzoate) and T_8 (Emamectin benzoate) recorded 25.56 percent in each treatment, however, which were at par with treatment T_7 (Emamectin benzoate) and T_5 (Emamectin benzoate) with 34.44 and 35.56 percent damaged plants. The next best treatments were T_4 (Lambda cyhalothrin), T_2 (Lambda cyhalothrin), T_3 (Lambda cyhalothrin) and T_1 (Lambda cyhalothrin) being on par each other showing 44.44, 45.56, 47.78 and 52.22 percent damage, respectively. The highest damage percent was noticed in untreated control (78.89%).

Table 2: Effectiveness of insecticides spray in sequential application of biopesticides and insecticides on plant damage by larvae of fall armyworm (First Spray)

Tr. No.	Treatment	No. of larvae/plant				Mean	Plant damage (%)				Mean
		Pre-Count	3 DAS	7DAS	14 DAS		Pre-count	3 DAS	7 DAS	14 DAS	
T_1	L. cyhalothrin - *M. anisopliae* - E. benzoate	3.17 (1.92) *	2.60 (1.76)	2.27 (1.66)	2.70 (1.79)	2.52 (1.74)	63.33 (52.75) **	53.33 (46.90)	46.67 (43.06)	56.67 (48.83)	52.22 (46.26)
T_2	L. cyhalothrin - *N. rileyi* - E. benzoate	3.10 (1.90)	2.57 (1.75)	2.23 (1.65)	2.60 (1.76)	2.47 (1.72)	60.00 (50.83)	50.00 (44.98)	40.00 (39.13)	46.67 (43.06)	45.56 (42.41)
T_3	L. cyhalothrin - *B. bassiana* - E. benzoate	3.07 (1.75)	2.53 (1.74)	2.20 (1.64)	2.67 (1.78)	2.47 (1.72)	60.00 (50.83)	50.00 (44.98)	43.33 (41.14)	50.00 (44.98)	47.78 (43.70)
T_4	L. cyhalothrin-*B. thuringiensis* - E. benzoate	2.93 (1.71)	2.43 (1.71)	2.17 (1.63)	2.63 (1.77)	2.41 (1.71)	56.67 (48.83)	46.67 (43.06)	40.00 (39.13)	46.67 (43.06)	44.44 (41.77)
T_5	E. benzoate - *M. anisopliae* - L. cyhalothrin	3.40 (1.73)	1.83 (1.53)	1.60 (1.45)	1.83 (1.53)	1.75 (1.50)	66.67 (54.76)	36.67 (37.21)	30.00 (33.20)	40.00 (39.22)	35.56 (36.59)
T_6	E. benzoate - *N. rileyi* - L. cyhalothrin	2.93 (1.71)	1.50 (1.41)	1.30 (1.34)	1.53 (1.43)	1.44 (1.39)	56.67 (48.83)	30.00 (33.20)	20.00 (26.55)	26.67 (30.98)	25.56 (30.34)
T_7	E. benzoate - *B. bassiana* - L. cyhalothrin	3.50 (1.77)	1.80 (1.52)	1.57 (1.44)	1.90 (1.55)	1.76 (1.50)	66.67 (54.76)	40.00 (39.13)	26.67 (30.98)	36.67 (37.21)	34.44 (35.89)
T_8	E. benzoate -*B. thuringiensis*-L. cyhalothrin	3.03 (1.74)	1.53 (1.43)	1.33 (1.35)	1.57 (1.44)	1.48 (1.41)	60.00 (50.83)	33.33 (35.20)	16.67 (23.85)	26.67 (30.98)	25.56 (30.28)
T_9	Untreated control	3.13 (1.77)	3.53 (2.01)	3.63 (2.03)	3.80 (2.07)	3.65 (2.04)	63.33 (52.75)	73.33 (58.98)	80.00 (63.90)	83.33 (66.12)	78.89 (62.85)
	SE±	0.19	0.09	0.09	0.08	0.08	2.54	2.40	2.72	2.32	2.17
	C.D. at 5%	N/S	0.26	0.24	0.27	0.24	N/S	7.26	8.22	7.02	6.56
	C.V.	10.5	6.61	6.78	6.49	6.20	8.50	9.75	12.43	9.41	9.14

*Figures in parentheses are ($\sqrt{x}$+0.5) transformations; **Figures in parentheses are arc sin transformations; NS= non-significant

4.6.3 Plant damage after second spray in sequential application. (Biopesticides)

The data related to damage percent after second spray (biopesticides) are presented in Table 3. Second spray in sequential application consists of biopesticides *viz. Metarhizium anisopliae, Nomuraea riley*, *Beauveria bassiana*, *Bacillus thuringiensis.* The observations regarding damaged plant percent after second spray revealed that all the treatment were found effective over untreated control. The most effective treatment was T_6 wherein application of *Nomuraea rileyi* which listed minimum damaged plants to the extent of 16.67 percent. However, it was at par with T_8 (*Bacillus thuringiensis*), T_2 (*Nomuraea riley*) and T_4 (*Bacillus thuringiensis*) with 20.00, 25.56 and 25.56 percent damage, respectively. The next potent treatments were T_7 (*Beauveria bassiana*), T_5 (*Metarhizium anisopliae*), T_3 (*Beauveria bassiana*) and T_1 (*Metarhizium anisopliae*) being at par with each other these treatments scored 31.11, 31.11, 38.89 and 45.56 percent damage, respectively. The untreated control noted highest damaged plants among all treatments (70.00%).

4.6.4 Plant damage after third spray in sequential application. (Insecticides)

Next third spray in sequential application includes emamectin benzoate and lambda cyhalothrin. The observations regarding damage percent after third spray are presented in Table 4. and revealed that all the insecticides applications were found to be significantly superior over untreated control in reducing larvae. The treatment T_2 (Emamectin benzoate) recorded minimum plant damage to the extent of 14.44 percent which was at par with treatments T_6 (Lambda cyhalothrin), T_8 (Lambda cyhalothrin) and T_4 (Emamectin benzoate) with 14.44, 16.67 and 16.67 percent damage, respectively. The next effective treatments were T_1 (Emamectin benzoate), T3 (Emamectin benzoate), T_7 (Lambda cyhalothrin) and T_5 (Lambda cyhalothrin) being at par with each other, these were recorded 25.56, 25.56, 28.89, and 28.89 percent damage, respectively. The untreated control recorded maximum plant damage among all treatments (47.78%).

4.6.5 Pooled mean of plant damage after three sprays in sequential application

The pooled mean of damage percent after sequential application of three sprays are presented in Table 5. After sequential application of three sprays, the pooled mean of damage percent (18.89%) by fall armyworm after sequential application indicated that T_6 (E. benzoate - *N. rileyi* - L. cyhalothrin) was found to be most superior to reduce the number of damaged plants and was on par with T_8 (E. benzoate - *B. thuringiensis* - L. cyhalothrin) scoring plant damage up to 20.74 percent. The next effective treatment was T_2 (L. cyhalothrin - *N. rileyi* - E. benzoate) with 28.52 percent and at par with treatment T_4 (L. cyhalothrin - *B. thuringiensis.* - E. benzoate), T_7 (E. benzoate- *B. bassiana*- L. cyhalothrin) and T_5 (E. benzoate - *M. anisopliae* - L. cyhalothrin) with 28.89, 31.48 and 31.85 percent, respectively. Among all sequential applications least effective treatments were T_3 (L. cyhalothrin -*B. bassiana* - E. benzoate) and T_1 (L. cyhalothrin - *M. anisopliae* - E. benzoate), wherein damage was 37.41 and 41.11 percent, respectively. Untreated control recorded maximum percent plant damage (65.56%). It was also revealed that all the treatments depicted a steady decrease in damaged plants after each application**.**

The findings in respect of larval population management with insecticides was concurrent with Deshmukh *et al*., (2020) [6] who concluded that the most effective insecticides were chlorantraniliprole 18.5 SC followed by emamectin benzoate 5 SG, spinetoram 11.7 SC, flubendiamide 480 SC, indoxacarb 14.5 SC, lambda cyhalothrin 5 EC and novaluron 10 EC against FAW in maize. Present result on sequential application of insecticides and biopesticides against fall armyworm as evidenced in the present study cannot be discussed due to lack of literature. Results in respect of chemical insecticides are in corroboration with Mastan Shareef *et al*., (2020) [13] who evaluated ten pesticides against *S. frugiperda* for third instar larvae. Among the all treatments emamectin benzoate was found to be extremely harmful and the most effective insecticide to *S. frugiperda*, followed by spinetoram, chlorantraniliprole, novaluron + emamectin benzoate, novaluron, novaluron + indoxacarb, flubendiamide, indoxacarb, lambda cyhalothrin, and chlorpyriphos. Similar observations have been made by Shinde *et al*., (2020) [17] who observed that spinetoram 11.7% SC with minimum larval population of FAW. It was followed by emamectin benzoate 5% SG, chlorantraniliprole 18.5% SC, flubendiamide 39.35% SC, thiamethoxam 12.6% + lambda-cyhalothrin 9.5% ZC, and spinosad 45% SC and followed the same sequence for efficacy of insecticides in case of plant damage. Additionally, it was observed that all treatments decreased the number of damaged plants after each spraying.

In the present studies, the treatment with *Nomuraea rileyi* proved to be the most potent biopesticides against FAW in maize. Similar results were reported by Shinde *et al.*, (2020) [17] who found that fall armyworm was most successfully countered by *Nomuraea rileyi* applications in whorls. It was followed in order of effectiveness by poison bait, *Metarhizium anisopliae*, carbofuran, *Beauveria bassiana*, sand + lime, and EPN. Additionally, it was noticed that after each spraying, all treatments lowered the number of damaged plants. These findings are also in agreement with Dhobi *et al.*, (2020) evaluated results with *N. rileyi* 1% WP (1.81 larvae /10 plants). However, it was at par with *B. thuringiensis* 1% WG (2.03 larvae /10 plants) these results in respect of *B. thuringiensis* in present experiment are in similar line. The remaining biopesticides *B. bassiana* and *M. anisopliae* perform equally effective against fall armyworm in maize.

Table 4: Effectiveness of insecticides spray in sequential application of biopesticides and insecticides on plant damage by larvae of fall armyworm (Third spray)

Tr. No.	Treatment	No. of larvae/plant			Mean	Plant damage %			Mean
		3 DAS	7 DAS	14 DAS		3 DAS	7 DAS	14 DAS	
T_1	L.cyhalothrin - *M. anisopliae* - E. benzoate	1.03 (1.24) *	0.73 (1.11)	0.87 (1.17)	0.88 (1.17)	26.67 (30.98) **	23.33 (28.77)	26.67 (30.98)	25.56 (30.28)
T_2	L. cyhalothrin - *N. rileyi* - E. benzoate	0.57 (1.03)	0.37 (0.93)	0.47 (0.98)	0.47 (0.98)	13.33 (21.14)	13.33 (21.14)	16.67 (23.85)	14.44 (22.20)
T_3	L. cyhalothrin - *B. bassiana* - E. benzoate	0.93 (1.20)	0.67 (1.08)	0.83 (1.15)	0.81 (1.14)	26.67 (30.98)	23.33 (28.77)	26.67 (30.98)	25.56 (30.34)
T_4	L.cyhalothrin - *B. thuringiensis* - E. benzoate	0.67 (1.08)	0.43 (0.97)	0.53 (1.02)	0.54 (1.07)	16.67 (23.85)	13.33 (21.14)	20.00 (26.55)	16.67 (24.09)
T_5	E. benzoate - *M. anisopliae* - L. cyhalothrin	1.17 (1.29)	0.90 (1.18)	1.13 (1.28)	1.07 (1.25)	30.00 (33.20)	26.67 (30.98)	30.00 (33.20)	28.89 (32.49)
T_6	E. benzoate - *N. rileyi* - L. cyhalothrin	0.57 (1.03)	0.43 (0.97)	0.47 (0.98)	0.49 (0.99)	13.33 (21.14)	13.33 (21.14)	16.67 (23.85)	14.44 (22.30)
T_7	E. benzoate - *B. bassiana* - L. cyhalothrin	1.00 (1.18)	0.97 (1.21)	1.23 (1.32)	1.07 (1.25)	30.00 (33.20)	23.33 (28.77)	33.33 (35.20)	28.89 (32.47)
T_8	E. benzoate - *B. thuringiensis*- L. cyhalothrin	0.80 (1.14)	0.60 (1.05)	0.60 (1.05)	0.67 (1.08)	13.33 (21.14)	16.67 (23.85)	20.00 (26.55)	16.67 (24.02)
T_9	Untreated control	2.07 (1.60)	1.90 (1.55)	1.33 (1.35)	1.76 (1.50)	53.33 (46.20)	46.67 (43.06)	43.33 (41.14)	47.78 (43.71)
	SE±	0.06	0.05	0.06	0.05	2.76	1.38	1.99	1.35
	C.D at 5%	0.18	0.16	0.18	0.14	8.34	4.16	6.03	4.08
	C.V.	10.37	11.93	12.44	9.41	16.36	8.66	11.42	8.04

*Figures in parentheses are ($\sqrt{x}$+0.5) transformations; **Figures in parentheses are arc sin transformation

These findings are corroboratory with present findings. Both *B. bassiana* 5% WP and azadirachtin 1500 ppm were equally effective treatments for the pest, coming in at 22.74 percent and 23.46 percent plant damage, respectively. Studies further revealed that *Metarhizium anisopliae*, *Beauveria bassiana* was nest effective treatments in order of efficacy. The findings are in confirmation with Harika *et al.*, (2020) [11] who investigated effectiveness of microbial bioinsecticides against fall armyworm with three fungal biopesticides (*Metarhizium anisopliae*, *Beauveria bassiana*, and *Metarhizium rileyi*) and untreated control. All of the microbial bioinsecticides that were tested had a significant impact in controlling the pest. Among all treatment *M. rileyi* demonstrated the highest mortality rates, followed by *M. anisopliae* (2.41) *B. Bassiana* (2.43), which was statistically at par and followed by *Bt* product Dipel (2.77) over the untreated control with the least foliar damage, Similar results were reported by earlier workers in respect of biopesticides by Dileep kumar, (2020) [8].

4.7 Effect of different sequential applications on grain yield of maize

The data on effect of various sequential applications of biopesticides and insecticides on grain yield of maize are presented in Table 5. Grain yield of maize from all sequential applications were recorded significantly higher grain yield of maize over the untreated control. The grain yield from different sequential treatments were ranged between 30.44 to 13.18 q/ha. The significantly highest grain yield of maize (30.44 q/ha) was observed in the treatment T_6 (E. benzoate - *N. rileyi* - L. cyhalothrin) which was at par with treatment T_8 (E. benzoate - *B. thuringeinsis* - L. cyhalothrin) wherein maize yield recorded was 28.78 qt/ha. It was followed by treatment T_4 (L. cyhalothrin - *B. thurngiensis* - E. benzoate), T_2 (L. cyhalothrin - *N. rileyi.* - E. benzoate), T_7 (E. benzoate - *B. bassiana* - L. cyhalothrin), T_5 (E. benzoate - *M. anisopliae* - L. cyhalothrin.) and T_3 (L. cyhalothrin- *B. bassiana* - E. benzoate). The lowest grain yield was recorded from the treatment T_1 (L. cyhalothrin - *M. anisopliae* - E. benzoate), had yield of 19.83 qt/ha. The untreated plot recorded minimum grain yield (13.18 q/ha) amongst all treatments.

The yield impact by sequential application was similarly supported by Dhobi *et al.*, (2020) who observed the plot treated with *N. rileyi* 1% WP yielded the highest grain and fodder yield, followed by *B. thuringiensis*. The plot treated with *N. rileyi* 1% WP had the least larval population, the lowest amount of plant damage and cob damage and it was at par with *Bacillus thuringiensis var. kurstaki* 1% WG., Shinde *et al.*, (2020) [17] assessed various whorl applications for managing *Spodoptera frugiperda*, the fall armyworm on maize.

Table 5: Effectiveness of sequential application of biopesticides and insecticides on plant damage by larvae of fall armyworm, *S. frugiperda* in maize. (Pooled mean)

Tr. No.	Treatment name	No. of larvae /plant				Pooled Mean	Plant damage %				Pooled Mean
		Pre-count	I Spray	II Spray	III Spray		Pre-count	I Spray	II Spray	III Spray	
T_1	L.cyhalothrin - *M. anisopliae*- E. benzoate	3.17 (1.91) *	2.52 (1.74)	1.91 (1.55)	0.88 (1.17)	1.77 (1.51)	63.33 (52.75)**	52.22 (46.26)	45.56 (42.43)	25.56 (30.28)	41.11 (39.86)
T_2	L. cyhalothrin -*N. rileyi*- E. benzoate	3.10 (1.90)	2.47 (1.72)	1.27 (1.33)	0.47 (0.98)	1.40 (1.38)	60.00 (50.83)	45.56 (42.41)	25.56 (30.28)	14.44 (22.20)	28.52 (32.19)
T_3	L. cyhalothrin -*B. bassiana*- E. benzoate	3.07 (1.89)	2.47 (1.72)	1.68 (1.48)	0.81 (1.14)	1.65 (1.47)	60.00 (50.83)	47.78 (43.70)	38.89 (38.53)	25.56 (30.34)	37.41 (37.66)
T_4	L.cyhalothrin-*B. thuringiensis* - E. benzoate	2.93 (1.85)	2.41 (1.71)	1.20 (1.30)	0.54 (1.02)	1.38 (1.37)	56.67 (48.83)	44.44 (41.77)	25.56 (30.28)	16.67 (24.09)	28.89 (32.48)
T_5	E. benzoate -*M. anisopliae*- L. cyhalothrin	3.40 (1.97)	1.75 (1.50)	1.60 (1.45)	1.07 (1.25)	1.47 (1.40)	66.67 (54.76)	35.56 (36.59)	31.11 (33.88)	28.89 (32.47)	31.85 (34.34)
T_6	E. benzoate - *N. rileyi*- L. cyhalothrin	2.93 (1.85)	1.44 (1.39)	0.88 (1.17)	0.49 (0.99)	0.94 (1.20)	56.67 (48.83)	25.56 (30.34)	16.67 (24.02)	14.44 (22.30)	18.89 (25.73)
T_7	E. benzoate - *B. bassiana*- L. cyhalothrin	3.50 (2.00)	1.76 (1.50)	1.41 (1.38)	1.07 (1.25)	1.41 (1.38)	66.67 (54.76)	34.44 (35.89)	31.11 (33.86)	28.89 (32.47)	31.48 (34.10)
T_8	E. benzoate -*B. thuringiensis*-L. cyhalothrin	3.03 (1.88)	1.48 (1.41)	1.12 (1.27)	0.67 (1.08)	1.09 (1.26)	60.00 (50.83)	25.56 (30.28)	20.00 (26.50)	16.67 (24.02)	20.74 (27.06)
T_9	Untreated control	3.13 (1.91)	3.65 (2.04)	3.19 (1.92)	1.76 (1.50)	2.87 (1.84)	63.33 (52.75)	78.89 (62.85)	70.00 (56.98)	47.78 (43.71)	65.56 (54.12)
	SE±	0.19	0.08	0.06	0.05	0.05	2.54	3.13	2.77	2.31	2.20
	C.D. at 5 %	N/S	0.24	0.17	0.14	0.16	N/S	6.69	5.91	4.94	4.69
	C.V.	10.5	6.20	6.06	9.41	5.99	8.50	9.44	9.63	9.47	7.62

*Figures in parentheses are ($\sqrt{x}$+0.5) transformations; **Figures in parentheses are arc sin transformations

The plots with whorl application of *Nomuraea rileyi* had the maximum grain yield of maize (24.20 q/ha), followed by whorl applications with *Metarhizium anisopliae* (23.00 q/ha), Poison bait (22.50 q/ha), *Beauveria bassiana* (21.50 q/ha), Carbofuran (19.70 q/ha), EPN (18.60 q/ha) and Sand + Lime. Ash-treated plots had the minimum grain yield of all the insecticidal treatments. Out of all the treatments, the untreated plots had the lowest grain production (15.10 q/ha).

Deshmukh *et al.*, (2020) [6] concluded that the results of field efficacy testing for two planting dates (June and September sown crop 2018) showed that the most effective insecticides were chlorantraniliprole 18.5 SC followed by emamectin benzoate 5 SG, spinetoram 11.7 SC, flubendiamide 480 SC, indoxacarb 14.5 SC, lambda cyhalothrin 5 EC and novaluron 10 EC. In comparison to the control, better efficacy was also associated with higher grain yield. Shinde *et al.* (2020) [17] found that the spinetoram 11.7% SC had the best yield of maize grain, followed by the spraying of emamectin benzoate 5% SG, chlorantraniliprole 18.5% SC, flubendiamide 39.35% SC, thiamethoxam 12.6% + lambda - cyhalothrin 9.5% ZC, and spinosad 45 SC. However, plots treated with the insecticide Lambda-cyhalothrin 5% EC, recorded the lowest grain yield of maize., Dileep Kumar *et al.* (2020) [8] revealed result that maximum yield (33.48 q/ha) was recorded in a spinetoram 11.7 SC treated plot. Following spinetoram, plots treated with novaluron, chlorantraniliprole, spinosad, thiodicarb, emamectin benzoate, indoxacarb, *Bacillus thuringiensis* toxin, lambda cyhalothrin, chlorpyrifos, and azadirachtin 1% are next one.

Table 5: Effect of sequential application on maize grain yield (qt/ha)

Tr. No.	Treatment	Yield (q/ha)
T_1	L. cyhalothrin - *M. anisopliae* - E. benzoate	19.83
T_2	L. cyhalothrin - *N. rileyi* - E. benzoate	25.22
T_3	L. cyhalothrin - *B. bassiana* - E. benzoate	21.41
T_4	L. cyhalothrin - *B. thuringiensis* - E. benzoate	25.90
T_5	E. benzoate - *M. anisopliae* - L. cyhalothrin	23.17
T_6	E. benzoate - *N. rileyi* - L. cyhalothrin	30.44
T_7	E. benzoate - *B. bassiana* - L. cyhalothrin	23.72
T_8	E. benzoate - *B. thuringiensis* - L. cyhalothrin	28.78
T_9	Untreated control	13.18
	SE±	1.33
	C.D. at 5%	4.03
	C.V.	9.81

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