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Efficacy and economics of selected insecticides and biopesticides against fall armyworm, *Spodoptera frugiperda* (J.E. Smith) on maize (*Zea mays* L.)

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Abstract
A field trial was conducted at Naini, Prayagraj during *kharif* season 2023 at central research farm, Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj, Uttar Pradesh. In Randomized Block Design with eight treatments replicated thrice times were evaluated against *Spodoptera frugiperda* i.e. Chlorantraniliprole 18.5% EC, Spinetoram 11.7% SC, Lambda cyhalothrin @ 2.5% EC, Azadirachtin (Neem oil @ 5%), *Beauveria bassiana* 5% WP, *Bacillus thuringiensis* 4% WSP, Emamectine benzoate @ 5% SG and Control. Result revealed that, among the different treatments lowest larval population of maize fall armyworm was recorded in Spinetoram @ 11.7% SC (1.19). Chlorantraniliprole @ 18.5% SC (1.49) was found to be the next best treatment followed by Emamectin benzoate @ 5% SG (1.75), Lambda cyhalothrin @ 2.5% EC (1.98), Azadirachtin (Neem oil @ 5%) (2.19). The least effective treatments were *Beauveria bassiana* 5% WP (2.39) whereas *Bacillus thuringiensis* (2.61) was found to be least effective against this pest. The plot treated with Spinetoram 11.7% SC show highest yield (45.10 q/ha) followed by Chlorantraniliprole 18.5% EC (40.34 q/ha), Emamectine benzoate @ 5% SG (36.82 q/ha), Lambda cyhalothrin @ 2.5% EC (33 q/ha), Azadirachtin (Neem oil @ 5%) (28.18 q/ha), *Beauveria bassiana* 5% WP (27 q/ha), *Bacillus thuringiensis* 4% WSP (23.12 q/ha) as compare to control plot (20.26 q/ha). Among the treatments the best and most economical treatment was Spinetoram 11.7% SC (1:2.58) followed by Chlorantraniliprole 18.5% EC (1:2.29), Emamectine benzoate @ 5% SG (1:2.23), Lambda cyhalothrin @ 2.5% EC (1:1.99), Azadirachtin (Neem oil @ 5%) (1:67), *Beauveria bassiana* 5% WP (1:1.50), *Bacillus thuringiensis* 4% WSP (1:1.39) as compare to control plot (1:1.28).

Keywords: Biopesticides, efficacy, fall armyworm, insecticides, maize, *Spodoptera frugiperda*

Introduction
Maize (*Zea mays* L.) is a member of family Poaceae. It is one of the most important cereal grains grown worldwide in a wider range of environment because of its greater adaptability (Bharadwaj *et al.*, 2020) [2]. Now days it is third major and most important cereal crop of the world after wheat and rice and is grown in tropical, subtropical and temperate regions of the world. Due to its greater genetic yield ability among all cereals, it is called as the "Queen of cereals" (Kumari *et al*., 2020) [14].

It has short growing season and is drought resistant that make it very easy to grow everywhere in different climatic conditions of the world. It is as much a significant crop in the American countries like rice and wheat in Asia. Maize is grown in more than 70 countries of the world including USA, China, Brazil, Mexico, France, Argentina, Romania, India, Italy, Indonesia and South Africa (Chouraddi *et al.*, 2017) [4].

In around 5,000 BC, the maize crop was originated in central Mexico. It is the day neutral, cross pollinated and C4 plant. Maize is an economically important cereal crop among the various cereals cultivated, which is generally cultivated in tropical as well as sub-tropical parts of the world. Leafy stalks of maize produce ears, which contains the grain and called as kernals or seeds. The kernals of maize are most commonly used as starch in cooking. The six major types of maize (corn) are dent corn, flint corn, popcorn, flour corn, and sweet corn (Porter *et al.*, 2000) [23].

Maize is India's third most important cereal crop and India is the fifth largest producer of Maize in the world contributing 3 percent of the global production.

At present, out of the total maize produced, 55% is used for food purpose, about 14% for livestock, 18% for poultry feed, 12% for starch and one percent as seed.

At present, out of the total maize produced, 55% is used for food purpose, about 14% for livestock, 18% for poultry feed, 12% for starch and one percent as seed. (Kumar *et al.*, 2017) [15]. In India, the average area under maize cultivation is 9.43 million hectares with an average production and productivity of 22.23 million tonnes and 2.5 tonnes per hectare respectively. Pakistan has sufficient advantages to grow maize crop because it is the third most important cereal after wheat and rice and is currently planted on1.026 million ha area with 2.986 million tonnes grains, and an average national yield of 2893 kg/ha (Kumar *et al*., 2017) [15].

Maize, being a C4 plant, has a greater yield potential as compared to other cereals, but attack of insect pests infesting this crop at various crop growth stages from sowing to maturity poses serious limitation in full manifestation of yield potential of maize during different seasons. Maize is affected by as many as 141 insect pests (Rakshit *et al.*, 2022) [24]. Among these, only few considered as major pests in India *viz.*, stem borers(*Chilo partellus*), shoot fly(*Atherigona soccata*), armyworm (*Mythimna separate)* and *Helicoverpa armigera* are of major importance during different seasons in India (Kumar *et al.*, 2005) [16]. However, the recent invasion of fall armyworm, *Spodoptera frugiperda* (Noctuidae: Lepidoptera) has become a great threat for maize cultivation (Mallapur *et al.*, 2019) [17].

The Fall Armyworm (*Spodoptera frugiperda*, J.E. Smith), (Lepidoptera: Noctuidae), FAW, is an insect native to tropical and subtropical regions of the Americas. FAW first reported as an invasive pest in the rainforest zones of Nigeria in 2016. Subsequently, it spread to different parts of Africa. FAW attacks 353 host plant species belonging to 76 plant families with preference to poaceae family (Varshney *et al.*, 2021) [30].

In India, it was first reported in Hassan district of Karnataka on maize which later spread to Tamil Nadu, Telangana and West Bengal (Thumar *et al.*, 2020) [28]. Thereafter, the pest has spread to most states of India and then spread to other Asian countries, including Thialand, Sri Lanka, Bangladesh, Myanmar, Vietnam, Laos, and China (Deshmukh *et al.*, 2018) [5].

Maize yield loss of 20-50% in recent estimates at Africa suggests severe impact on livelihoods of the farmers depended on Maize farming (Early *et al.*, 2018) [8]. Successive investigations have showed that the pest has been identified in 30sub Saharan African countries where it has caused extensive damage to crops especially maize fields.

Materials and Methods

The present study was conducted at Central Research Farm, SHUATS, Prayagraj, Uttar Pradesh during the *Kharif* season of 2023 for the management of fall armyworm carried out using a 'Ganga 5' variety of maize sown in plots keeping row to row and plant to plant distance of 45 × 15 cm. The field experiment was laid-out in randomized block design with eight different treatments replicated thrice. The plot had a dimension of 2×1 m^2.

All of the insecticides used in the study were sprayed as foliar application. In the experiment, eight different treatments, consisting application of T_1 Chlorantraniliprole @ 18.5% EC (0.3 ml/L), T_2 Spinetoram11.7% SC (0.1 ml/L), T_3 Lambda cyhalothrin @ 2.5% EC (0.4 ml/L), T_4 Azadirachtin (Neem oil @ 5%) (1.5 ml/L), T_5 *Beauveria bassiana* 5% WP (1.2 ml/L), T_6 *Bacillus thuringiensis* (2 g/L), T_7 Emamectin benzoate 5% SG (0.15 g/L) and T_8 untreated Control were tested to compare the efficacy against *Spodoptera frugiperda* and their influences on yield of maize. Two sprays were carried out at intervals of 14 days during the experiment to assess the effectiveness of pesticides when the *Spodoptera frugiperda* larval population reached the ETL threshold. On five randomly chosen and tagged plants in each plot, pre- and post-treatment observations on the larval population were made shortly before 24 hours and 3rd, 7th and 14th days following application, respectively.

Formulae used

The spray solution of desired concentration should be prepared by adopting the following formula:

$$V = \frac{(C \times A)}{\% \ a.i}$$

Where,

V=Volume of a formulated pesticide required. C= Concentration required.

A=Volume of total solution to be prepared.

% a.i. = Percentage of active ingredient in commercial product.

$$\text{Cost Benefit Ratio} = \frac{\text{Gross return}}{\text{Total cost of cultivation}}$$

Thuppukonda and Kumar (2022) [29].

Results and Discussion

The findings of the current investigation demonstrated that after insecticidal applications against fall armyworm, *Spodoptera frugiperda* were found significantly superior over control plot. The data on the mean (3, 7 and 14 DAS) larval population of first spray revealed that all the treatments except untreated control are effective and at par with each other. Among all the treatments lowest population was recorded in Spinetoram 11.7% SC (1.533). Chlorantraniliprole 18.5% SC (1.780) was found to be the next best treatment followed by Emamectin benzoate 5% SG (2.023), Lambda cyhalothrin @ 2.5% EC (2.243), Azadirachtin (Neem oil @ 5%) (2.420), *Beauveria bassiana* 5% WP (2.647), *Bacillus thuringiensis* (2.867) is found to be least effective but comparatively superior over the control. The data on population of *Spodoptera frugiperda* over control on second spray revealed that all the treatments were significantly superior over control. Among all treatments, Spinetoram 11.7% SC (0.847). Chlorantraniliprole 18.5% SC (1.200) was found to be the next best treatment followed by Emamectin benzoate 5% SG(1.490) recorded lowest population of Spodoptera frugiperda which was significantly superior over control followed by Lambda cyhalothrin @ 2.5% EC (1.733), Azadirachtin (Neem oil @ 5%) (1.977), *Beauveria bassiana*

5% WP (2.153), *Bacillus thuringiensis* (2.353) showed the least effectiveness among all treatments.

The yields among the different treatments were significant. All the treatments were superior over control. The highest yield was recorded in Spinetoram 11.7% SC (45.10 q/ha) followed by Chlorantraniliprole 18.5% EC (40.34 q/ha), Emamectine benzoate @ 5% SG (36.82 q/ha), Lambda cyhalothrin @ 2.5% EC (33 q/ha), Azadirachtin (Neem oil @ 5%) (28.18 q/ha), *Beauveria bassiana* 5% WP (27 q/ha), *Bacillus thuringiensis* 4% WSP (23.12 q/ha) as compare to control plot (20.26 q/ha).

When cost benefit ratio was worked out, interesting result was achieved. Among the treatments studied, the best and most economical treatment was Spinetoram 11.7% SC (1:2.53) followed by Chlorantraniliprole 18.5% EC (1:2.25), Emamectine benzoate @ 5% SG (1:2.19), Lambda cyhalothrin @ 2.5% EC (1:1.95), Azadirachtin (Neem oil @ 5%) (1:1.64), *Beauveria bassiana* 5% WP (1:1.48), *Bacillus thuringiensis* 4% WSP (1:1.36) as compare to control plot (1:1.28).

Among all the treatments lowest larval population of maize fall armyworm was recorded in Spinetoram @ 11.7% SC (1.190) similar findings were made by Bharadwaj *et al.* (2020), Dileep *et al.* (2020) [2], Thumar *et al.* (2020) [28] and Bommi and Kumar (2022) [3] who reported that Spinetoram @ 11.7% SC was most effective treatment indicating recorded lowest population of fall armyworm (*Spodoptera frugiperda*). Chlorantraniliprole @ 18.5% SC (1.490) is found to be the next best treatment which is in line with the findings of Hardke *et al.* (2011) [9], Deshmukh *et al.* (2020) [6], Jeyarajan *et al.* (2021) [11] and Suthar *et al.* (2020) [27] who reported that Chlorantraniliprole @ 18.5% SC was found to be most effective in reducing population of *Spodoptera frugiperda* as well as increasing yield. Emamectine benzoate @ 5% SG (1.755) was the next effective treatment which is line with the findings of Mallapur *et al.* (2019) [17], Badhai *et al.* (2020) [1] and Patidar *et al.* (2022) [21]. Lambda cyhalothrin @ 2.5% EC (1.985) was found to be next effective treatment which is in line with the findings of Sisay *et al.* (2019) [26], Worku and Ebabuye (2019) [31] and Kumari *et al.* (2020) [14]. Azadirachtin (Neem oil @ 5%) (2.195) was found to be the next effective treatment which is in line with the finding of Kammo *et al.* (2019) [12] and Nagesh and Tayde (2023) [19]. *Beauveria bassiana* 5% WP (2.400) was found to be next effective treatment which is in line with the findings of Montecalvo *et al.* (2021) [18], Bommi and Kumar (2022) [3] and Panigrahi and Yadav (2023) [20]. The result of *Bacillus thuringiensis* (2.610) found to be least effective but comparatively superior over the control, these findings are supported by Polanczyk *et al.* (2000) [22], Rebeca *et al.* (2020) [25], Helen *et al.* (2021) [10] and Karshanal and Kalia (2023) [13].

Table 1: Effect of insecticides and biopesticides against larval population of *Spodoptera frugiperda* on maize (1stand 2ndspray):

S. No.	Treatments	Number of larvae (*S. frugiperda*)/ five plants										Overall mean	Yield (q/ha)	C:B Ratio
		Dosage	First spray				Second spray							
			1DBS	3DAS	7DAS	14DAS	1DBS	3DAS	7DAS	14DAS				
T_1	Chlorantraniliprole 18.5% SC	0.3 ml/L	2.53	1.87	1.67	1.80	1.80	1.67	0.93	1.00		1.49	40.34	1:2.25
T_2	Spinetoram 11.7% SC	0.1 ml/L	2.47	1.60	1.47	1.53	1.53	1.27	0.60	0.67		1.19	45.10	1:2.53
T_3	Lambda cyhalothrin @ 2.5% EC	0.4 ml/L	2.80	2.33	2.13	2.27	2.27	2.07	1.53	1.60		1.98	33	1:1.95
T_4	Azadiractin (Neem Oil @ 5%)	1.5 ml/L	2.87	2.53	2.33	2.40	2.40	2.33	1.73	1.87		2.19	28.18	1:1.64
T_5	*Beauveria bassiana* 5% WP	1.2 ml/L	2.93	2.67	2.60	2.67	2.60	2.53	1.93	2.00		2.39	27	1:1.48
T_6	*Bacillus thuringiensis* 4% WSP	2 g/L	3.00	2.93	2.80	2.87	2.87	2.73	2.13	2.20		2.61	23.12	1:1.36
T_7	Emamectin benzoate 5% SG	0.15 gm/L	2.67	2.07	1.93	2.07	2.07	1.87	1.27	1.33		1.75	36.82	1:2.19
T_8	Control	….	2.67	3.07	3.13	3.20	3.20	3.27	3.33	3.40		3.23	20.26	1:1.28
	F-test		NS	S	S	S	S	S	S	S		S	…..	…..
	S.Ed (±)		-	0.18	0.21	0.09	0.09	0.15	0.13	0.15		0.19	…..	…..
	C.D.(P= 0.5)		-	0.38	0.45	0.20	0.20	0.31	0.29	0.32		0.45	…..	…..

DBS**-Day Before Spray**, DAS**-Day After Spray***

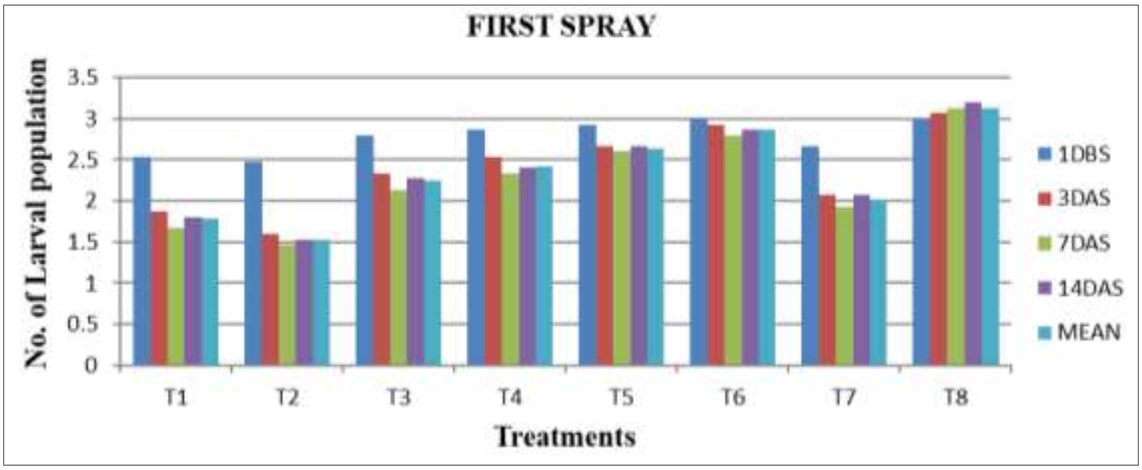

Fig 1: Larval population of fall armyworm (*Spodoptera frugiperda*) after first spray

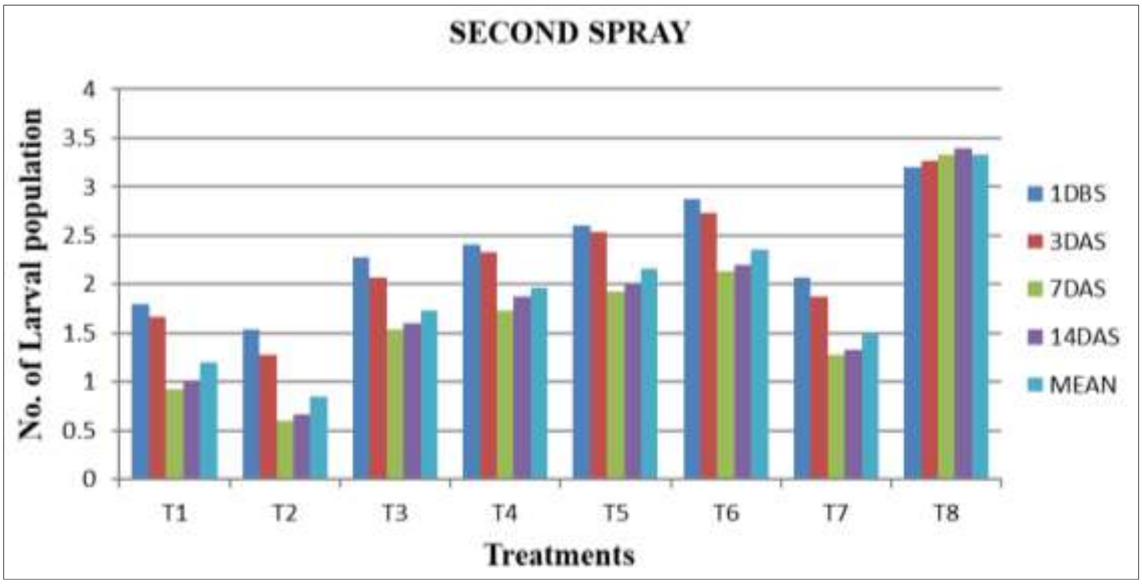

Fig 2: Larval population of fall armyworm (*Spodoptera frugiperda*) after second spray

Conclusion

From the critical analysis of the present findings, it can be concluded that Spinetoram 11.7% SC is more effective in controlling population of maize fall armyworm followed by Chlorantraniliprole 18.5% EC, Emamectine benzoate @ 5% SG, Lambda cyhalothrin @ 2.5% EC, Azadirachtin (Neem oil @ 5%), *Beauveria bassiana* 5% WP, *Bacillus thuringiensis* 4% WSP in managing *Spodoptera frugiperda.* Among the treatments studied, Spinetoram 11.7% SC gave highest cost benefit ratio (1:2.53) and marketable yield (45.10 q/ha), followed by Chlorantraniliprole 18.5% EC (1:2.25 and 40.34 q/ha), Emamectine benzoate @ 5% SG (1:2.19 and 36.82 q/ha), Lambda cyhalothrin @ 2.5% EC (1:1.95 and 33 q/ha), Azadirachtin (Neem oil @ 5%) (1:1.64 and 28.18 q/ha), *Beauveria bassiana* 5% WP (1:1.48 and 27 q/ha) and *Bacillus thuringiensis* 4% WSP (1:1.36 and 23.12 q/ha) as compare to control plot (1:1.28 and 20.26 q/ha) respectively as such more trials are required in future to validate the findings.

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