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Efficacy of different insecticides against fall armyworm, *S. frugiperda* in maize

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Abstract
To evaluate the efficacy of different insecticides against fall armyworm *S. frugiperda*, the experiment was carried out at Agronomy Instructional Farm, C. P. College of Agriculture, S. D. Agricultural University, Sardarkrushinagar, during *kharif*, 2020. Different nine insecticides were evaluated against fall armyworm in maize. Results revealed that application of emamectin benzoate 5 SG @ 0.0025%, spinosad 45 SC @ 0.014% and chlorantraniliprole 18.5 SC @ 0.0055% were found more effective in checking the larval population and plant damage in maize which also reflected on grain yield as well.

Keywords: Maize, spodoptera frugiperda, emamectin benzoate, spinosad, and chlorantraniliprole

Introduction
Maize, *Zea mays* L. is a member of the family, Poaceae also known as corn, is one of the most flexible growing crop with greater adaptability to different agro-climatic conditions. Due to higher genetic yield potential amongst the cereals, this crop is globally popular as the "Queen of cereals" (Jeyaraman, 2017) [1]. In around 5,000 BC, the maize crop was originated in Central Mexico. It is a day neutral, cross pollinated and C_4 plant. It is an economically important cereal crop among the various cereals cultivated, which is generally cultivated in tropical as well as in sub-tropical parts of the world. Leafy stalks of maize produce ears, which contains the grain are called as kernels or seeds. The kernels of maize are most commonly used as starch in cooking. The six major types of maize (corn) are dent corn, pod corn, flint corn, popcorn, flour corn and sweet corn (Atwal and Dhaliwal, 2002) [2].

The fall armyworm *Spodoptera frugiperda* (J. E. Smith) is one of the most serious pest on maize globally. The fall armyworm is native to the tropical and subtropical areas of the Americas. It has a broad host range, disperses rapidly and has now invaded nearly 100 countries around the world by quickly establishing in the novel ecologies (Babu *et al*., 2019) [3]. The larvae feed on the leaves, stems and reproductive parts of more than 100 plants species, causing major damage to economically important cultivated cereals such as maize, rice, sorghum, millets, sugarcane and pasture grasses as well as other crops including cabbage, beet, peanut, soybean, alfalfa, onion, cotton, tomato and potato. *S. frugiperda* larvae feed inside the whorls of maize plants, causing distinctive holes that are visible in the leaves, which increase drastically in size as the larvae ages.

The fall armyworm, *S. frugiperda* is the new invasive pest observed in maize growing regions of the world including India. It is considerably spreading very fast across the continent and getting as the status of globally invasive pest. In India recently fall armyworm has been reported in the state of Karnataka, Andhra Pradesh, Madhya Pradesh, Maharashtra, Tamil Nadu, Telangana, Gujarat and Chhattisgarh (Babu *et al*., 2019) [3]. It is notorious pestiferous insect with high dispersal ability, wide host range and high fecundity (Chaudhari *et al.*, 2019) [4].

Material and Methods
Detail of experiment

Location	:	Agronomy Instructional farm, C. P. College of Agriculture, S. D. Agricultural University, Sardarkrushinagar
Crop and Variety	:	Maize, GAYMH 1
Design	:	Randomized Block Design (RBD)
Replications	:	3 (Three)
Treatments	:	10 (Ten)
Plot size	:	Gross: 3.60 m x 3.00 m Net: 2.40 m x 2.60 m
Spacing	:	60 cm x 20 cm
Season and Year	:	*Kharif*, 2020
Fertilizer dose	:	120-60-00 (N: P: K) kg/ ha

Table 1: Detail of insecticides used against fall army worm in maize

Sr. No.	Treatments	Concentration (%)	Dose (g or ml/10 lit. of water)
1.	Flubendiamide 48 SC	0.015	3
2.	Emamectin benzoate 5 SG	0.0025	5
3.	Novaluron 5.25% + Emamectin benzoate 0.9% SC	0.0030	5
4.	Chlorantraniliprole 18.5 SC	0.0055	3
5.	Spinosad 45 SC	0.014	3
6.	Chlorpyriphos 20 EC	0.04	20
7.	Chlorantraniliprole 10% + Lambda cyhalothrin 5% ZC	0.015	10
8.	Profenophos 40% + Cypermethrin 4% EC	0.088	20
9.	Thiomethoxam 12.6% + Lambda cyhalothrin 9.5% ZC	0.011	5
10.	Untreated control	-	-

Methodology
All the standard agronomical practices were followed. The first application of insecticide was imposed at initiation of pest. The second spray was applied after 15 days after the first spray. The spray volume for treatment applications was calibrated by spraying control treatment with plain water. Spraying was done using a knapsack sprayer fitted with a hollow cone nozzle.

Observations recorded
For recording the FAW population and its damage, 25 plants were selected randomly from each net plot. The number of larva and damaged plants were counted from randomly selected plants before as well as 3, 7, 10 and 14 days after each application.

Grain yield
At harvest, the grain yield was recorded separately from each net plot. On the basis of yield, the economics was calculated. Avoidable losses and increases in yield over control were calculated applying the formula suggested by Khoshla (1977) [5].

$$\text{Increase in yield over control (\%)} = \frac{\text{Yield in treatment} - \text{Yield in control}}{\text{Yield in control}} \times 100$$

$$\text{Avoidable loss (\%)} = \frac{\text{Highest yield in treated plot} - \text{Yield in treatment}}{\text{Highest yield in treated plot}} \times 100$$

Economics
In order to know the economics of different treatments evaluated against *S. frugiperda* pest infesting maize, Protection Cost Benefit Ratio (PCBR) was worked out. For this purpose, the total cost of insecticidal treatment per hectare was calculated for each treatment based on prevailing market price. The increased yield over control was calculated by subtracting the yield obtained in control treatment from the yield obtained in each insecticidal treatment. Then, gross realization (₹ /ha) was worked out for each treatment based on yield (kg/ha). The net realization (₹ /ha) for each treatment was computed by deducting the income of the control treatment from the income of each insecticidal treatment. The net gain (₹ /ha) was worked out by deducting the cost of insecticidal treatment from the net realization. The PCBR was calculated by dividing net gain by the cost of treatment.

Results and Discussion
Efficacy of different insecticides against fall armyworm, *S. frugiperda* in maize
Based on pooled data of first spray indicates that the plot treated with emamectin benzoate 5 SG @ 0.0025% (0.36 larva/plant) recorded the lowest larval population per plant which was at par with spinosad 45 SC @ 0.014% (0.48 larva/plant) and chlorantraniliprole 18.5 SC @ 0.0055% (0.55 larva/plant). These three treatments found significantly superior to untreated control. Next effective treatment was flubendiamide 48 SC @ 0.015 (1.13 larvae/plant), chlorantraniliprole 10% + lambda cyhalothrin 5% ZC @ 0.015% (1.18 larvae/plant) and novaluron 5.25% + emamectin benzoate 0.9% SC @ 0.0030 (1.27 larvae/plant), All these three treatments were found statistically at par with each other, profenophos 40% + cypermethrin 4% EC @ 0.088 (2.03 larvae/plant), after that these three treatments, thiomethoxam 12.6% + lambda cyhalothrin 9.5% ZC @ 0.011% (2.10 larvae/plant) and chlorpyriphos 20 EC @ 0.04% (2.19 larvae/plant) were also found statistically at par with each other and the highest larval population was recorded in untreated control (3.06 larvae/plant).

Based on pooled data of second spray the plot treated with emamectin benzoate 5 SG @ 0.0025% (0.24 larva/plant) recorded the lowest larval population per plant which was at par with spinosad 45 SC @ 0.014% (0.39 larva/plant) and chlorantraniliprole 18.5 SC @ 0.0055% (0.48 larva/plant). These three treatments found significantly superior to untreated control. Next effective treatment was flubendiamide 48 SC @ 0.015 (1.11 larvae/plant), chlorantraniliprole 10% + lambda cyhalothrin 5% ZC @ 0.015% (1.20 larvae/plant) and novaluron 5.25% + emamectin benzoate 0.9% SC @ 0.0030 (1.35 larvae/plant), all these three treatments were found statistically at par with each other. After these three treatments, profenophos 40% + cypermethrin 4% EC @ 0.088 (2.05 larvae/plant), thiomethoxam 12.6% + lambda cyhalothrin 9.5% ZC @ 0.011% (2.27 larvae/plant) and chlorpyriphos 20 EC @ 0.04% (2.38 larvae/plant) were also found statistically at par with each other and the highest larval population was recorded in untreated control (3.54 larvae/plant).

Based on data of pooled over spray indicates in Table 2 and Fig 1 that, most effective treatment was emamectin benzoate 5 SG @ 0.0025% with minimum larval population (0.30

larva/plant) and it was at par with spinosad 45 SC @ 0.014% (0.44 larva/plant) and chlorantraniliprole 18.5 SC @ 0.0055% (0.51 larva/plant). These three treatments found significantly superior to untreated control. Next effective treatment was flubendiamide 48 SC @ 0.015 (1.12 larvae/plant), chlorantraniliprole 10% + lambda cyhalothrin 5% ZC @ 0.015% (1.19 larvae/plant) and novaluron 5.25% + emamectin benzoate 0.9% SC @ 0.0030 (1.31 larvae/plant), all these three treatments were found statistically at par with each other. Whereas, profenophos 40% + cypermethrin 4% EC @ 0.088 (2.04 larvae/plant), thiomethoxam 12.6% + lambda cyhalothrin 9.5% ZC @ 0.011% (2.18 larvae/plant) and chlorpyriphos 20 EC @ 0.04% (2.28 larvae/plant). All the above treatments are superior to control. The highest larval population was recorded in untreated control (3.3 larvae/plant).

Plant damage (%)

Based on pooled data of first spray the plot treated with emamectin benzoate 5 SG @ 0.0025% (14.46%) recorded the lowest plant damage which was at par with spinosad 45 SC @ 0.014% (16.12%) and chlorantraniliprole 18.5 SC @ 0.0055% (18.29%). These three treatments found significantly superior to rest of the insecticides. Next effective treatment was flubendiamide 48 SC @ 0.015 (21.96%) followed by chlorantraniliprole 10% + lambda cyhalothrin 5% ZC @ 0.015% (25.16%) and novaluron 5.25% + emamectin benzoate 0.9% SC @ 0.0030 (27.41%), profenophos 40% + cypermethrin 4% EC @ 0.088 (30.70%), thiomethoxam 12.6% + lambda cyhalothrin 9.5% ZC @ 0.011% (31.22%) and Chlorpyriphos 20 EC @ 0.04% (32.47%). The highest plant damage was recorded in untreated control (47.49%).

Based on pooled data of second spray the plot treated with emamectin benzoate 5 SG @ 0.0025% (4.45%) recorded the lowest plant damage which was at par with spinosad 45 SC @ 0.014% (5.66%) and chlorantraniliprole 18.5 SC @ 0.0055% (7.69%). These three doses found significantly superior to untreated control. Next effective treatment was fubendiamide 48 SC @ 0.015 (18.30%)% followed by chlorantraniliprole 10% + lambda cyhalothrin 5% ZC @ 0.015 C (21.02%) and novaluron 5.25% + emamectin benzoate 0.9% SC @ 0.0030 (23.19%), profenophos 40% + cypermethrin 4% EC @ 0.088 (28.12%), thiomethoxam 12.6% + lambda cyhalothrin 9.5% ZC @ 0.011% (29.17%) and chlorpyriphos 20 EC% 0.04% (30.07%). The highest plant damage was recorded in untreated control (61.91%).

Based on data of pooled over spray indicates in Table 3 and Fig 2 that all the treatments were significantly superior over untreated control. Among them, most effective treatment was emamectin benzoate 5 SG @ 0.0025% with minimum plant damage (8.80%) and it was at par with spinosad 45 SC @ 0.014% (10.30%) and chlorantraniliprole 18.5 SC @ 0.0055% (12.51%) these three treatments found significantly superior to rest of the insecticides. Next effective treatment was flubendiamide 48 SC @ 0.015 (20.10%), chlorantraniliprole 10% + lambda cyhalothrin 5% ZC @ 0.015% (23.60%) and novaluron 5.25% + emamectin benzoate 0.9% SC @ 0.0030 (25.27%), All these three treatments were found statistically at par with each other. Whereas, profenophos 40% + cypermethrin% EC @ 0.088 (29.23%), thiomethoxam 12.6% + lambda cyhalothrin 9.5% ZC @ 0.011% (30.19%) and chlorpyriphos 20 EC @ 0.04% (31.40%). All the above treatments are superior to control. The highest number of plant damage was recorded in untreated control (54.75%).

According to Thumar *et al*. (2020) [7] Anand, emamectin benzoate 5 SG, 0.0025%, chlorantraniliprole 18.5 EC, 0.006% and thiodicarb 75 WP, 0.11% were found more effective in checking the larval population and plant damage in maize which also reflected on grain yield. According to Deshmukh *et al.* (2020) [6], emamectin benzoate 5 SG showed the highest acute toxicity value, followed by chlorantraniliprole 18.5 SC and spinetoram 11.7 SC. Our present investigation results showed that emamectin benzoate 5 SG @ 0.0025% recorded the lowest number of larvae per plant and plant damage which was at par with spinosad 45 SC @ 0.014% and chlorantraniliprole 18.5 SC @ 0.0055% which is similar with the results of Thumar *et al.* (2020) and Deshmukh *et al*. (2020) [7].

Grain yield

The insecticidal treated plots produced significantly higher yield than the control (Table 4). The highest (30.5 q/ha) grain yield was obtained in the plot treated with emamectin benzoate 5 SG @ 0.0025% and it was statistically at par with application of spinosad 45 SC @ 0.014% (28.40 q/ha) and chlorantraniliprole 18.5 SC @ 0.0055% (28.00 q/ha). Minimum (16.70 q/ha) grain yield was obtained in the untreated plot. Whereas 22.70 q/ha, 22.00 q/ha and 20.40 q/ha maize grain yield were recorded from the treatment of profenophos 40% + cypermethrin 4% EC @ 0.088, thiomethoxam 12.6% + lambda cyhalothrin 9.5% ZC @ 0.011% and chlorpyriphos 20 EC @ 0.04% respectively. Present results is all most similar with the results revealed by Thumar *et al.* 2020 [7] recorded the highest (2914 kg/ha) grain yield in the treatment of spinetoram 11.7 SC which was at par emamectin benzoate 5 SG (2792 kg/ha) and chlorantraniliprole 18.5 SC (2732 kg/ha).

Increased in yield over control (%)

Increase in yield over control ranged from 22.16 to 82.63% (Table 4) in various insecticidal treatments. Maximum increase in grain yield (82.63%) was recorded from the plots treated with emamectin benzoate 5 SG @ 0.0025% followed Spinosad 45 SC @ 0.014% (70.06%) and chlorantraniliprole 18.5 SC @ 0.0055% (67.66%). Whereas, lowest increase in yield over control was recorded in seed treated plot with clorpyriphos 20 EC @ 0.04% (20.40%) followed by thiomethoxam 12.6% + lambda cyhalothrin 9.5% ZC @ 0.011% recorded 22.00%.

Avoidable losses

So far avoidable losses in yield of maize are concerned, it varied from 6.89 to 45.25% in different treatments (Table 4) in comparison to emamectin benzoate 5 SG @ 0.0025% the most effective treatment. Lowest (6.89%) avoidable loss in yield was recorded in the treatment of spinosad 45 SC @ 0.014% followed by chlorantraniliprole 18.5 SC @ 0.0055% (8.20%). The avoidable loss in yield was the maximum (33.11%) in the chlorpyriphos 20 EC @ 0.04% followed by thiomethoxam 12.6% + lambda cyhalothrin 9.5% ZC @ 0.011% (27.87%).

Economics

Economics of various treatments was worked out considering prevailing market price of maize and cost of insecticidal treatments including labour charges. The total income, net realization, net gain and Protection Cost Benefit Ratio (PCBR) were also worked out for all the treatments and presented in Table 5. The total cost of treatment was minimum (₹ 1866.00/ha) in chlorpyriphos 20 EC @ 0.04% followed by novaluron 5.25% + emamectin benzoate 0.9% SC @ 0.0030 (₹ 1937.56/ha), however chlorantraniliprole 10% + lambda cyhalothrin 5% ZC @ 0.015% was costliest (₹ 9790.00/ha) treatment.

The gross realization was highest (₹ 56425/ha) in emamectin benzoate 5 SG @ 0.0025% followed by spinosad 45 SC @ 0.014% (₹ 52540/ha) and chlorantraniliprole 18.5 SC @ 0.0055% (₹ 51800/ha) however, it was lowest in untreated plot (₹ 30895/ha). The economics of various insecticides (Table 5) revealed that the highest (₹ 25530/ha) net realization was obtained in treatment of emamectin benzoate 5 SG @ 0.0025% followed by spinosad 45 SC @ 0.014% (₹ 21645/ha) and chlorantraniliprole 18.5 SC @ 0.0055% (₹ 20905/ha). The remaining insecticidal treatments showed the net realization (₹ 6845 to 18685/ha).

The economics of various insecticides (Table 5) revealed that the highest (₹ 21990/ha) net gain was obtained in treatment of emamectin benzoate 5 SG @ 0.0025% followed by chlorantraniliprole 18.5 SC @ 0.0055% (₹ 15947/ha) and spinosad 45 SC @ 0.014% (₹ 14146/ha). The remaining insecticidal treatments showed the net gain (₹ 5915 to 13787/ha).

The highest PCBR was obtained in the treatments of plots treated with novaluron 5.25% + emamectin benzoate 0.9% SC @ 0.0030 (1:7.12) followed by, emamectin benzoate 5 SG @ 0.0025% (1: 6.21). The PCBR was 1: 1.14 to 1: 3.22 in rest of the insecticidal treatments. The lowest PCBR (1: 0.76) was calculated in the treatment chlorantraniliprole 10% + lambda cyhalothrin 5% ZC @ 0.015%.

Table 2: Efficacy of different insecticides against larval population of fall armyworm, *S. frugiperda* in maize

Sr. No.	Treatment	Conc. (%)	No. of larvae/plant days after spray											
			Before Spray	1st Spray					2nd Spray					Pooled over sprays
				3	7	10	14	Pooled	3	7	10	14	Pooled	
1	Flubendiamide 48 SC	0.015	1.51^{a} (1.78)	1.29^{b} (1.17)	1.24^{bc} (1.04)	1.19^{bc} (0.93)	1.37^{b} (1.38)	1.28^{b} (1.13)	1.31^{bc} (1.23)	1.25^{bc} (1.06)	1.22^{b} (1.00)	1.29^{b} (1.17)	1.27^{b} (1.11)	1.27^{b} (1.12)
2	Emamectin benzoate 5 SG	0.0025	1.53^{a} (1.85)	0.97^{a} (0.44)	0.91^{a} (0.33)	0.86^{a} (0.24)	0.96^{a} (0.42)	0.93^{a} (0.36)	0.91^{a} (0.33)	0.87^{a} (0.25)	0.81^{a} (0.15)	0.86^{a} (0.24)	0.86^{a} (0.24)	0.89^{a} (0.30)
3	Novaluron 5.25% + Emamectin benzoate 0.9% SC	0.0030	1.65^{a} (2.24)	1.32^{c} (1.25)	1.30^{c} (1.20)	1.27^{c} (1.11)	1.43^{bc} (1.54)	1.33^{b} (1.27)	1.39^{cd} (1.44)	1.34^{cd} (1.30)	1.33^{bc} (1.26)	1.38^{bc} (1.42)	1.36^{b} (1.35)	1.35^{b} (1.31)
4	Chlorantraniliprole 18.5 SC	0.0055	1.59^{a} (2.03)	1.04^{ab} (0.58)	1.01^{ab} (0.52)	0.96^{ab} (0.42)	1.09^{a} (0.69)	1.02^{a} (0.55)	1.05^{ab} (0.60)	0.98^{ab} (0.45)	0.93^{a} (0.36)	1.00^{a} (0.51)	0.99^{a} (0.48)	1.01^{a} (0.51)
5	Spinosad 45 SC	0.014	1.55^{a} (1.91)	1.01^{a} (0.53)	0.97^{a} (0.45)	0.93^{a} (0.36)	1.05^{a} (0.60)	0.99^{a} (0.48)	1.00^{a} (0.51)	0.93^{a} (0.36)	0.89^{a} (0.30)	0.96^{a} (0.42)	0.95^{a} (0.39)	0.97^{a} (0.44)
6	Chlorpyriphos 20 EC	0.04	1.64^{a} (2.18)	1.63^{de} (2.16)	1.61^{d} (2.10)	1.59^{d} (2.02)	1.73^{de} (2.49)	1.64^{c} (2.19)	1.71^{e} (2.44)	1.67^{ef} (2.30)	1.68^{d} (2.34)	1.72^{d} (2.45)	1.70^{c} (2.38)	1.67^{c} (2.28)
7	Chlorantraniliprole 10% + Lambda cyhalothrin 5% ZC	0.015	1.52^{a} (1.80)	1.30^{b} (1.19)	1.27^{c} (1.11)	1.22^{c} (0.99)	1.40^{b} (1.46)	1.30^{b} (1.18)	1.34^{c} (1.29)	1.26^{bc} (1.10)	1.27^{b} (1.11)	1.34^{bc} (1.29)	1.30^{b} (1.20)	1.30^{b} (1.19)
8	Profenophos 40% + Cypermethrin 4% EC	0.088	1.59^{a} (2.04)	1.60^{d} (2.07)	1.56^{d} (1.95)	1.52^{d} (1.82)	1.67^{cd} (2.30)	1.59^{c} (2.03)	1.63^{de} (2.15)	1.58^{de} (2.01)	1.57^{cd} (1.97)	1.61^{cd} (2.09)	1.60^{c} (2.05)	1.60^{c} (2.04)
9	Thiomethoxam 12.6% + Lambda cyhalothrin 9.5% ZC	0.011	1.62^{a} (2.12)	1.62^{de} (2.11)	1.59^{d} (2.02)	1.55^{d} (1.90)	1.70^{de} (2.39)	1.61^{c} (2.10)	1.67^{de} (2.30)	1.65^{de} (2.23)	1.66^{d} (2.25)	1.67^{d} (2.29)	1.66^{c} (2.27)	1.64^{c} (2.18)
10	Untreated control	-	1.69^{a} (2.37)	1.88^{e} (3.02)	1.87^{e} (2.99)	1.85^{e} (2.91)	1.96^{e} (3.35)	1.89^{d} (3.06)	1.97^{f} (3.37)	2.02^{f} (3.57)	2.01^{e} (3.53)	2.05^{e} (3.69)	2.01^{d} (3.54)	1.95^{d} (3.30)
	S. Em.±		0.10	0.09	0.08	0.08	0.09	0.08	0.28	0.10	0.09	0.09	0.09	0.09
	C.V.%		11.09	11.06	10.82	10.78	11.11	11.08	11.80	13.42	11.87	11.65	11.40	11.42

Note: Figures in parenthesis are retransformed values of $\sqrt{x+0.5}$ transformation

Treatment means with the letter(s) in common are not significant by DNMRT at 5% level of significance

Table 3: Efficacy of different insecticides against plant damage due to fall armyworm, *S. frugiperda* in maize

Sr. No.	Treatment	Conc. (%)	Plant damage (%) days after spray											
			Before Spray	1st Spray					2nd Spray					Pooled over sprays
				3	7	10	14	Pooled	3	7	10	14	Pooled	
1	Flubendiamide 48 SC	0.015	34.09^{a} (31.42)	29.84^{bcd} (25.42)	27.16^{bc} (20.83)	24.72^{b} (17.49)	30.06^{bc} (25.10)	27.95^{c} (21.96)	26.55^{b} (19.98)	25.09^{b} (17.99)	23.32^{b} (15.68)	26.33^{b} (19.68)	25.33^{c} (18.30)	26.64^{cd} (20.10)
2	Emamectin benzoate 5 SG	0.0025	34.82^{a} (32.60)	25.03^{a} (17.90)	22.39^{a} (14.51)	16.95^{a} (8.50)	25.02^{a} (17.89)	22.35^{a} (14.46)	16.19^{a} (7.78)	11.85^{a} (4.22)	9.05^{a} (2.48)	11.58^{a} (4.03)	12.17^{a} (4.45)	7.26^{a} (8.80)
3	Novaluron 5.25% + Emamectin benzoate 0.9% SC	0.0030	34.90^{a} (32.74)	32.80^{de} (29.47)	29.97^{cd} (24.96)	28.24^{bc} (22.38)	35.21^{de} (33.24)	31.57^{ed} (27.41)	30.30^{bcd} (25.45)	29.06^{bc} (23.59)	27.03^{b} (20.65)	28.76^{bc} (23.15)	28.78^{d} (23.19)	30.18^{de} (25.27)
4	Chlorantraniliprole 18.5 SC	0.0055	35.48^{a} (33.68)	27.91^{abc} (21.92)	25.26^{ab} (18.21)	20.24^{a} (11.97)	27.88^{ab} (21.87)	25.32^{b} (18.29)	19.80^{a} (11.48)	16.30^{a} (7.87)	12.84^{a} (4.94)	15.45^{a} (7.10)	16.10^{b} (7.69)	20.71^{bc} (12.51)
5	Spinosad 45 SC	0.014	34.56^{a}	26.38^{ab}	23.77^{ab}	18.67^{a}	25.87^{ab}	23.67^{ab}	17.39^{a}	14.66^{a}	10.08^{a}	12.94^{a}	13.77^{a}	18.72^{b}

			(32.17)	(19.74)	(16.25)	(10.25)	(19.03)	(16.12)	(8.93)	(6.40)	(3.06)	(5.01)	(5.66)	(10.30)
6	Chlorpyriphos 20 EC	0.04	34.01 ^{a} (31.29)	35.29^{e} (33.37)	33.25^{d} (30.06)	33.14^{d} (29.89)	37.95^{e} (37.82)	34.91^{f} (32.75)	33.81^{cd} (30.97)	33.24^{c} (30.04)	32.56^{c} (28.97)	33.40^{d} (30.31)	33.25^{e} (30.07)	34.08^{e} (31.40)
7	Chlorantraniliprole 10% + Lambda cyhalothrin 5% ZC	0.015	34.91 ^{a} (32.75)	31.73^{cde} (27.65)	29.30^{cd} (23.95)	26.54^{bc} (19.96)	32.88^{cd} (29.47)	30.11^{d} (25.16)	29.26^{bc} (23.81)	27.41^{b} (21.19)	25.24^{b} (18.18)	27.26^{b} (20.98)	27.29^{cd} (21.02)	28.70^{de} (23.06)
8	Profenophos 40% + Cypermethrin 4% EC	0.088	35.46 ^{a} (33.65)	34.56^{e} (32.18)	31.65^{d} (27.53)	30.41^{cd} (25.62)	36.42^{de} (35.24)	33.26^{ef} (30.07)	33.08^{cd} (29.80)	32.38^{c} (28.68)	31.32 ^{c} (27.03)	32.03^{cd} (28.12)	32.20^{e} (28.40)	32.73^{de} (29.23)
9	Thiomethoxam 12.6%+ Lambda cyhalothrin 9.5% ZC	0.011	34.77 ^{a} (32.52)	35.02^{e} (32.94)	32.17^{d} (28.35)	31.21^{d} (26.85)	37.47^{de} (37.01)	33.97^{f} (31.22)	33.52^{d} (30.49)	32.73^{c} (29.24)	31.66^{c} (27.55)	32.84^{d} (29.41)	32.69^{e} (29.17)	33.33^{e} (30.19)
10	Untreated control	-	33.68^{a} (30.75)	40.04^{f} (41.39)	42.43^{e} (45.53)	44.67^{e} (49.43)	47.09^{f} (53.64)	43.56^{g} (47.49)	49.41^{e} (57.67)	51.84^{d} (61.82)	52.83^{d} (63.50)	53.49^{e} (64.60)	51.89^{f} (61.91)	47.73^{f} (54.75)
S. Em.±		-	1.74	1.56	1.33	1.34	1.63	0.73	1.57	1.67	1.28	1.35	0.73	2.29
C.V.%		-	8.70	4.65	7.77	8.46	8.40	8.31	9.37	10.54	8.69	8.56	9.35	11.02

Note: Figures in parenthesis are retransformed values of arc sin transformation
Treatment means with the letter(s) in common are not significant by DNMRT at 5% level of significance

Table 4: Impact of insecticides on yield, increase in yield over control and avoidable losses due to fall armyworm, *S. frugiperda* in maize

Sr. No.	Treatments	Yield (q/ha)	Increased in yield over control (%)	Avoidable loss (%)
1	Flubendiamide 48 SC	26.80	60.48	12.13
2	Emamectin benzoate 5 SG	30.50	82.63	0.00
3	Novaluron 5.25% + Emamectin benzoate 0.9% SC	25.20	50.90	17.38
4	Chlorantraniliprole 18.5 SC	28.00	67.66	8.20
5	Spinosad 45 SC	28.40	70.06	6.89
6	Chlorpyriphos 20 EC	20.40	22.16	33.11
7	Chlorantraniliprole 10% + Lambda cyhalothrin 5% ZC	26.00	55.69	14.75
8	Profenophos 40% + Cypermethrin 4% EC	22.70	35.93	25.57
9	Thiomethoxam 12.6%+ Lambda cyhalothrin 9.5% ZC	22.00	31.74	27.87
10	Untreated control	16.70	0.00	45.25
S.Em.±		1.46	-	-
C.D at 5%		4.78		
C.V.%		10.82		

Table 5: Economics of different insecticides evaluated against fall armyworm, *S. frugiperda* in maize

Sr. No	Treatments	Quantity of insecticides (kg or l) 2 spray	Cost of material (₹ /ha)	Labour charges (₹ /ha)	Cost of Treatment (₹ /ha)	Yield (q/ha)	Gross realization (₹ /ha)	Net realization (₹ /ha)	Net gain (₹ /ha)	PCBR
1	Flubendiamide 48 SC	0.310	5618.75	1040	6658.75	26.80	49580	18685	12026	1:1.81
2	Emamectin benzoate 5 SG	0.500	2500.00	1040	3540.00	30.50	56425	25530	21990	1:6.21
3	Novaluron 5.25% + Emamectin benzoate 0.9% SC	0.490	897.60	1040	1937.56	25.20	46620	15725	13787	1:7.12
4	Chlorantraniliprole 18.5 SC	0.300	3917.18	1040	4957.18	28.00	51800	20905	15947	1:3.22
5	Spinosad 45 SC	0.310	6458.70	1040	7498.66	28.40	52540	21645	14146	1:1.89
6	Chlorpyriphos 20 EC	2.000	826.00	1040	1866.00	20.40	37740	6845	4979	1:2.67
7	Chlorantraniliprole 10% + Lambda cyhalothrin 5% ZC	1.000	8750.00	1040	9790.00	26.00	48100	17205	7415	1:0.76
8	Profenophos 40% + Cypermethrin 4% EC	4.400	4144.80	1040	5184.80	22.70	41995	11100	5915	1:1.14
9	Thiomethoxam 12.6% + Lambda cyhalothrin 9.5% ZC	0.500	1455.90	1040	2495.88	22.00	40700	9805	7309	1:2.93
10	Untreated Control	-	-	-	-	16.70	30895	-	-	-

Note: Price of maize: ₹ 18.5/kg, Cost of labour: ₹ 260/day for spraying (Required labour for spraying: 2 labour/ha), flubendiamide 48 SC 17980/lit, emamectin benzoate 5 SG ₹ 5000/kg, novaluron 5.25% + emamectin benzoate 0.9% SC ₹ 1840/lit, chlorantraniliprole 18.5 SC ₹ 13176/lit, spinosad 45 SC ₹ 20760/lit, chlorpyriphos 20 EC ₹ 413/lit, chlorantraniliprole 10% + lambda cyhalothrin 5% ZC ₹ 8750/lit, profenophos 40% + cypermethrin 4% EC ₹ 942/lit, thiomethoxam 12.6% + lambda cyhalothrin 9.5% ZC ₹ 2925/lit

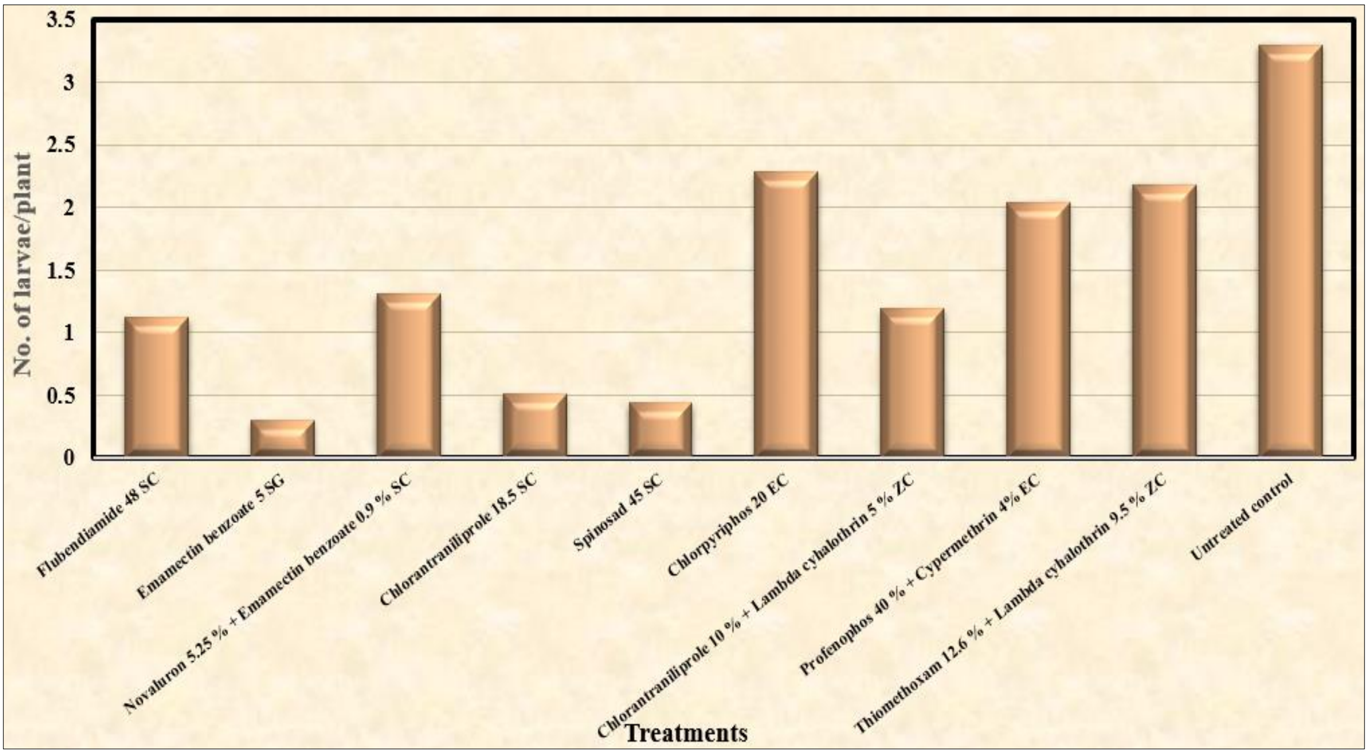

Fig 1: Efficacy of different insecticides against larval population of fall armyworm, *S. frugiperda* in maize

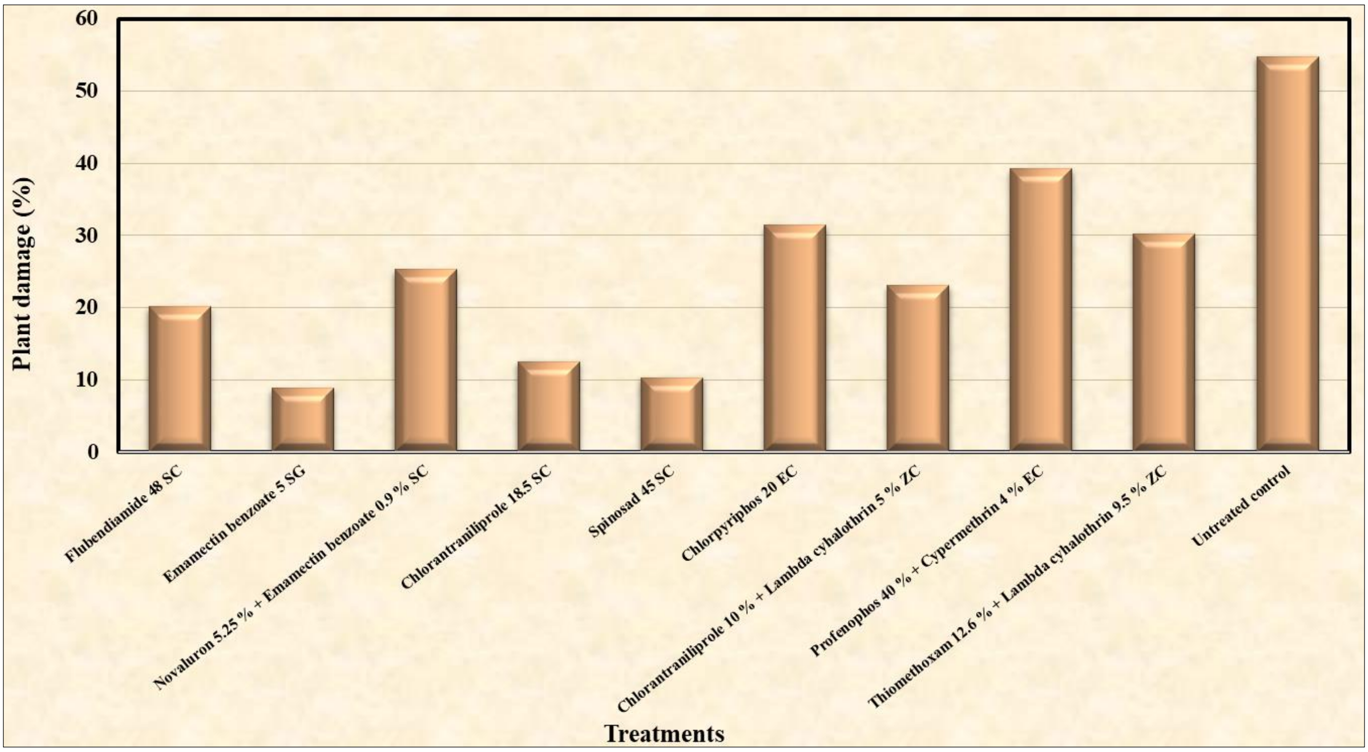

Fig 2: Efficacy of different insecticides against plant damage due to fall armyworm, *S. frugiperda* in maize

Conclusion

Present study was implied to know the effectiveness of certain selected insecticides under field conditions against the invasive pest fall armyworm. The result revealed that the emamectin benzoate 5 SG @ 0.0025% recorded the lowest number of larvae per plant and plant damage which was at par with spinosad 45 SC @ 0.014% and chlorantraniliprole 18.5 SC @ 0.0055% while, thiomethoxam 12.6% + lambda cyhalothrin 9.5% ZC @ 0.011% and chlorpyriphos 20 EC @ 0.04% were least effective.

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