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Effect of insecticide molecules on fall armyworm *Spodoptera frugiperda* (J. E. Smith) on maize under field conditions

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ABSTRACT

Observations on per cent pest infestation by counting all plants were counted per plot and oviposition were taken on 20 randomly selected plants in each treatment on weekly basis and per cent cob damage were recorded 20 randomly selected plants in each treatment. Simultaneously, the counts on natural enemies (predators, parasitized larvae and larval cadavers affected by diseases) were taken on 10 randomly selected plants in each treatment. The grain yield from individual treatment was recorded separately and expressed on hectare basis. The lowest number of egg masses were recorded in chemical treatments and the highest number of egg masses were recorded in untreated check and biopesticides at 21 and 28 days after germination. No egg masses were recorded in all treatments at 70 days after germination. The lowest percent pest infestation recorded inchemical treatments. However, the highest percent pest infestation was recorded in in untreated check and biopesticides at 21 and 28 days after germination. No pest infestation were recorded in all treatments at 70 days after germination. With respect to natural enemy activity, nimbecidine 0.03% @ 3 ml/l, *Bacillus thuringiensis var. kurstaki* 17,600 IU/mg @ 2 g/l, *Metarhiziumrileyi* 2 × 10^8 CFU @ 2 g/l and chloranitraniliprole 18.5 SC @ 0.20 ml/l treatments were as good as untreated check by safe guarding the natural enemy population. Spinetoram 11.7 SC spray @ 0.5 ml/l resulted in highest grain yield which was at par with cyantraniliprole 10 OD @ 0.3 ml/l. Lower yields were obtained from the plots which received biopesticides application.

Key words: *Oviposition, Pest infestation, Phytotoxicity, Spinetoram, Cyantraniliprole*

Introduction

Maize (*Zea mays* L.) is most important and world's leading cereal crop, widely cultivated grain that was domesticated in Central America. It is one of the most versatile emerging crops having wider adaptability. Maize belongs to the tribe Maydeae of the grass family Poaceae. '*Zea*' was derived from an old Greek name for food grass. Globally maize is known as queen of cereals because of its highest genetic yield potential (Jeyraman, 2017). Maize is the only food cereal crop that can be grown in diverse seasons, ecologies and has uses like human consumption, cattle and poultry food processing and in the extraction of starch, dextrose, corn syrup, corn oil *etc*. by various industries.

Currently, about 1147.7 million tonnes of maize is being produced together by over 170 countries with an average productivity of 5.75 t/ha (Anon., 2020). Maize production in India increased from 5101 thousand tonnes in 1971 to 31990 thousand tonnes in 2020 growing at an average annual rate of 4.67

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per cent. In India maize is cultivated in area of 9.89 m.ha with production of 31.65 MT and productivity of 3.19 t/ha. In Karnataka, maize is cultivated over an area of 1.38 m.ha with a production of 3.96 MT and productivity of 3.48 t/ha (Anon., 2020).

Under present situation, the average yields of maize are lower in India due to variety of factors. Prominent abiotic factors such as irregular rainfall, moisture stress and market price fluctuation among the biotic factors among which, the insect pests have considered as one of the most important constraints. As many as 141 insect pests cause varying degree of damage to maize crop right from sowing till harvest. Apart from these, the recent invasive pest, fall armyworm (FAW), *Spodopterafrugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) is of serious concern due to its notorious and polyphagous behaviour. It is a serious threat to agriculture and costs billions of dollars in terms of reduced production and productivity.

In its native range, FAW is known to feed on over 350 plant species (Montezano *et al.,* 2018) but considering just maize, rice, sorghum and sugarcane it has been estimated that FAW could cause crop losses up to $US 13 billion per annum across sub-Saharan Africa (Abrahams *et al.,* 2017). The pest is highly polyphagous, causing economic damage in various crops such as maize, sorghum, beans and cotton (Abrahams *et al*., 2017; Day *et al*., 2017). It can colonize over 80 different plant species of which corn is not an exception. It also attacks crops such as alfalfa, soybean, sorghum, cotton and otherdiverse pasture grasses (Virla and Murua, 2004). A total of 353 larval host plants for *S. frugiperda* have been recorded belonging to 76 plant families, predominantly from Poaceae (106), Asteraceae (31) and Fabaceae (31). It can cause a yield loss in corn as much as 70 per cent of a whole production (Ayala *et al*., 2013). From Northern Karnataka however, the pest has been reported to cause infestation ranging from 6.00 to 100 per cent on maize during *kharif* season (Mallapur *et al.,* 2019).

Materials and Methods

Field evaluation

The same treatments comprising of eight newer insecticide molecules and three bio pesticides were further evaluated under field conditions during late *kharif* of 2019 and 2020 at Main Agricultural Research Station, Dharwad. The trial was conducted in Randomized Block Design (RBD) with twelve treatments and three replications. The popular maize hybrid, NK-6240 was sown over plot size of 5 × 4m at a spacing of 60 × 20cm for each treatment. The crop was raised as per recommended packages including plant protection measures except for target pest. Application of different treatments was done two times (at 30 and 50 days of germination) using knapsack sprayer by directing the spray solution into leaf whorls. Observations on per cent pest infestation by counting all plants were counted per plot and oviposition were taken on 20 randomly selected plants in each treatment on weekly basis and per cent cob damage were recorded 20 randomly selected plants in each treatment. Simultaneously, the counts on natural enemies (predators, parasitized larvae and larval cadavers affected by diseases) were taken on 10 randomly selected plants in each treatment. The grain yield from individual treatment was recorded separately and expressed on hectare basis.

The observations on phytotoxicity (epinasty, hyponasty, yellowing, necrosis, leaf injury like tip and leaf surface, vein clearing and stunting) were recorded at 1, 3, 7 and 14 days after spray by visual observations based on 1-10 scale given below.

Visual scoring for phytotoxicity

Score	Phytotoxicity (%)
0	No Phytotoxicity
1	0-10
2	11-20
3	21-30
4	31-40
5	41-50
6	51-60
7	61-70
8	71-80
9	81-90
10	91-100

Results

Number of Egg masses per Plant

Mean Number of Egg masses per plant were recorded at 14, 21 and 28 DAG (days after germination) which found non significant difference with 4.67 to 7.83, 6.50 to 10.00 and 8.50 to 12.33 respectively. Among the treatments, T_{10} (Spinetoram 11.7 SC @ 0.50 ml/l) recorded least number of egg masses per plant of 0.50 and was found superior over other remaining treatments. Whereas, T_9 (Cyantraniliprole 10 OD @ 0.30 ml/l) was found next best treatment with 1.17 egg masses per plant. The treatment T_1 (Nimbecidine 0.03% @ 3 ml/l) with 8.33 per plant and found on par with T_3 *Metarhiziumrileyi* @ 2 g/l (8.33). The highest number of egg masses per plant was noticed in T_{12} untreated check (13.17) at 35 DAG.

At 42 DAG, least mean number of egg masses per plant was recorded in T_{10} Spinetoram 11.7 SC @ 0.50 ml/l was significantly superior over rest of the treatments 1.33. The treatments such as T_9 Cyantraniliprole 10 OD @ 0.30 ml/l (2.50) and T_7 Novaluron 5.25 percent + Emamectin benzoate 0.9 SC @ 0.2 g/l (2.33) and T_5Spinosad 45 SC @ 0.50 ml/l (3.83) were found superior over remaining treatments. However, the treatments T_9 Cyantraniliprole 10 OD @ 0.30 ml/l (2.50) and T_7 Novaluron 5.25 percent + Emamectin benzoate 0.9 SC @ 0.2 g/l (2.33) were found on par with each other. T_1 Nimbecidine 0.03% @ 3ml/l per literwas recorded 10.67 of egg masses which found to be on par with T_3 *Metarhiziumrileyi* @ 2 g/l with 11.00 mean number of egg masses per plant. Whereas, the highest 15.33 number of egg masses per plant was noticed in untreated check (T_{12}).

The lowest number of egg masses per plant 3.00 was recorded in T_{10} Spinetoram 11.7 SC @ 0.50 ml/l was found significantly superior over all the treatments. Whereas, the treatment T_7Novaluron 5.25 percent + Emamectin benzoate 0.9 SC @ 0.2 g/l (3.50) was found significantly superior over rest of the treatments except T_{10} Spinetoram 11.7 SC @ 0.50 ml/l (3.00). However, Cyantraniliprole 10 OD @ 0.30 ml/l was found to be the next best treatment with 4.50 mean number of egg masses per plant. The highest egg masses per plant of 12.50 was noticed in T_1 nimbecidine 0.03 % @ 3 ml/l per liter and T_{12} untreated check (T12) (14.00) at 49 DAG.

At 56 DAG, the treatment T_{10} (Spinetoram 11.7 SC @ 0.5 ml/l) was found superior over all the treatments with least number of egg masses per plant of 0.83. However, T_7 Novaluron 5.25 % + Emamectin benzoate 0.9 SC @ 0.2 g/l (2.00), T_5 Spinosad 45 SC @ 0.50 ml/l (2.17) and T_9 Cyantraniliprole 10 OD @ 0.30 ml/l (2.17) were found superior over rest of the treatments and found significantly at par with each other. The highest egg masses per plant was noticed in T_3 *Metarhiziumrileyi* @ 2g/l (10.50) and untreated check (T_{12}) (15.00).

Theleast mean number of egg masses per plant 1.67 was recorded in T_{10} Spinetoram 11.7 SC @ 0.50 ml/l and was found significantly superior over rest of the treatments. The treatments such as T_5 Spinosad 45 SC @ 0.50 ml/l (3.00) and T_9 Cyantraniliprole 10 OD @ 0.30 ml/l (3.33) were found superior over remaining treatments and also found significantly on par with each other. The highest egg masses per plant of 10.50, 9.50, 11.83 and 11.83 were recorded in T_1 Nimbecidine 0.03% @ 3ml/l, T_2 *Bacillus thuringiensis var. kurstaki* @ 2g/l, T_3 *Metarhiziumrileyi* @ 2g/l and T_{12} untreated check. The treatments viz., T3 *Metarhiziumrileyi* @ 2g/l and T12 untreated check were found on par with each other at 63 DAG.

Finally the observations made at 70, 77, 84, 91, 98, 105, 112 and 119 DAG revealed that none of the treatments recorded egg masses i.e., all the treatments were total recorded from egg masses.

Percent pest Infestation per Plot

Observation on mean pest Infestation per Plot was recorded at 14, 21, and 28 days after germination (DAG) which found non significant difference among treatments, 35.24 percent to 41.56 percent, 42.97 percent to 49.88 percent and 49.65 percent to 53.19 percent pest infestation per plot.

At 35 DAG,the least percent pest infestation of 49.97 percent pest infestation per plot was recorded in T_{10} Spinetoram 11.7 SC @ 0.50 ml/l whereas, T_2 *Bacillus thuringiensis var. kurstaki* @ 2 g/l was recorded 61.21 percent pest infestation per plot and was found superior over remaining treatments except T_5Spinosad 45 SC @ 0.50 ml/l (51.35 %), T_6Emamectin benzoate 5 SG @ 0.3 g/l (52.90 %), T_7Novaluron 5.25 % + Emamectin benzoate 0.9 SC @ 0.2 g/l (51.28 %), T_8Chloranitraniliprole 18.5 SC @ 0.20 ml/l (52.23 %), T_9Cyantraniliprole 10 OD @ 0.30 ml/l (49.97 %) and T_{11}Flubendiamide 480 SC @ 0.10 ml/l (54.70 %). However, high percent pest infestation per plot was noticed in untreated check (T_{12}) (80.91 %).

The minimum pest infestation of 57.15 percent per plot T_{10} Spinetoram 11.7 SC @ 0.50 ml/l was recorded in which found significantly superior over all treatments. The next best treatments such as T_9Cyantraniliprole 10 OD @ 0.30 ml/l (57.44 %), T_7 Novaluron 5.25 % + Emamectin benzoate 0.9 SC @ 0.2 g/l (57.47 %) and T_8Chloranitraniliprole 18.5 SC @ 0.20 ml/l (57.58 %) were found superior over rest of the treatments except T_{10}Spinetoram 11.7 SC @

0.50 ml/l (57.15 %). The highest percent pest infestation per plot was noticed in and T_3 *Metarhiziumrileyi*@ 2g/l (79.15 %) and untreated check (T_{12}) (85.31 %) at 42 DAG.

At 49 DAG, the least percent pest infestation of 61.90 per plot was recorded in T_{10} Spinetoram 11.7 SC @ 0.50 ml/l which found significantly superior over all treatments. The high percent pest infestation per plot was noticed in untreated check (T_{12}) (89.97 %).

Minimum percent pest infestation of 61.90 per plot was recorded in T_{10} Spinetoram 11.7 SC @ 0.50 ml/l which found significantly superior over all treatments which found significantly on par with treatments viz., T_5 Spinosad 45 SC @ 0.50 ml/l (68.63 %), T_6 Emamectin benzoate 5 SG @ 0.3 g/l (68.61 %), T_7 Novaluron 5.25 % + Emamectin benzoate 0.9 SC @ 0.2 g/l (65.95 %), T8 Chloranitraniliprole 18.5 SC @ 0.20ml/l (69.44 %), T_9Cyantraniliprole 10 OD @ 0.30 ml/l (62.02 %). The next best treatment is T_9 Cyantraniliprole 10 OD @ 0.30 ml/l (62.02 %) was found superior over rest of treatments. The high pest infestation per plot was noticed in untreated control (T_{12}) (93.16 %) at 56 DAG.

At 63 DAG, low pest infestation of 65.77 percent per plot was recorded in T_{10} Spinetoram 11.7 SC @ 0.5 ml/l which found significantly superior over all treatments and was found significantly on par with treatments viz., T_7 Novaluron 5.25 % + Emamectin benzoate 0.9 SC @ 0.2 g/l (71.12 %), T_8 Chloranitraniliprole 18.5 SC @ 0.20 ml/l (75.94 %) T_9 Cyantraniliprole 10 OD @ 0.30 ml/l (69.25 %) and T_{11} Flubendiamide 480 SC @ 0.10 ml/l (73.98 %). Whereas, T_3*Metarhiziumrileyi* @ 2g/l with 89.09 percent pest infestation was found significantly superior over T_1nimbecidine 0.03 % @ 3 ml/l (90.12 %), T_2*Bacillus thuringiensis var. kurstaki* @ 2 g/l (90.96 %) anduntreated check (T_{12}) (96.27 %) in which the treatments were found on par with each other.

The least percent pest infestation of 55.35 per plot was recorded in T_{10}Spinetoram 11.7 SC @ 0.5 ml/l. The next best treatments T9 Cyantraniliprole 10 OD @ 0.30 ml/l (69.25 %) and T_7Novaluron 5.25 % + Emamectin benzoate 0.9 SC @ 0.2 g/l (63.52 %) were found statistically superior over rest of the treatments except T_{10}Spinetoram 11.7 SC @ 0.5 ml/l (55.35 %). The high percent pest infestation per plot was recorded in untreated check (T_{12}) (90.86 %) at 70 DAG.

Lowest percent pest infestation of 48.39 percent per plot was recorded in T_{10} Spinetoram 11.7 SC @ 0.50 ml/l which found significantly superior over all treatments and was found significantly on par with treatment T_9Cyantraniliprole 10 OD @ 0.30 ml/l (51.60 %). The next treatment T_9Cyantraniliprole 10 OD @ 0.30 ml/l (51.60 %) was found significantly superior over rest of the treatments except T_{10}Spinetoram 11.7 SC @ 0.50 ml/l (48.39 %).The high percent pest infestation per plot was noticed in untreated check (T_{12}) (85.20 %) at 77 DAG.

At 84 DAG, Least percent pest infestation of 42.14 per plot was recorded in T_{10}Spinetoram 11.7 SC @ 0.50 ml/l which found significantly superior over all the treatments. The next best treatments T_9 Cyantraniliprole 10 OD @ 0.30 ml/l (45.34 %) and T_7 Novaluron 5.25 % + Emamectin benzoate 0.9 SC @ 0.2 g/l (49.63 %) were found significantly superior over rest of the treatments except T_{10} Spinetoram 11.7 SC @ 0.50 ml/l (42.14 %). The highest pest infestation per plot was noticed in the treatments such as T_1nimbecidine 0.03 % @ 3 ml/l (68.68 %), T2 *Bacillus thuringiensis var. kurstaki* @ 2g/l (71.90 %), T_3*Metarhiziumrileyi* @ 2g/l (74.76 %) and untreated check (T_{12}) (76.91 %).

Minimum percent pest infestation of 34.95 per plot was recorded in T_{10}Spinetoram 11.7 SC @ 0.50 ml/l which found significantly superior over all treatments. The next best treatments were T9 Cyantraniliprole 10 OD @ 0.30 ml/l (38.82 %) T_7 Novaluron 5.25 % + Emamectin benzoate 0.9 SC @ 0.2 g/l (42.15 %) and T_5Spinosad 45 SC @ 0.50 ml/l (45.60 %) were found statically superior over rest of the treatments except T_{10}Spinetoram 11.7 SC @ 0.50 ml/l (34.95 %). The high percent pest infestation per plot was noticed in untreated check (T_{12}) (71.23 %) at 91 DAG.

At 98 DAG, low pest infestation of 30.60 percent per plot was recorded in T_{10}Spinetoram 11.7 SC @ 0.5 ml/l which found significantly superior over all the treatments. The next best treatments were T_9Cyantraniliprole 10 OD @ 0.30 ml/l (33.70 %), T_7Novaluron 5.25 % + Emamectin benzoate 0.9 SC @ 0.2 g/l (37.63 %) and T_5Spinosad 45 SC @ 0.50 ml/l (41.18 %) were found statically superior over rest of the treatments except T_{10}Spinetoram 11.7 SC @ 0.50 ml/l (33.92 %). Whereas, the highest per cent pest infestation the treatments such as T_1 nimbecidine 0.03 % @ 3 ml/l (55.12 %), T_2 *Bacillus thuringiensis var. kurstaki* @ 2 g/l (56.69 %), T_3 *Metarhiziumrileyi* @ 2g/l (61.32 %) and untreated check (T_{12}) (67.24 %).

The minmum percent pest infestation of 16.86 per plot was recorded in T_{10}Spinetoram 11.7 SC @ 0.50

ml/l which found significantly superior over all treatments but was found at par with T_9 Cyantraniliprole 10 OD @ 0.30 ml/l (20.10 %). The next best treatments were T_5 Spinosad 45 SC @ 0.50 ml/l (23.27 %), T_9 Cyantraniliprole 10 OD @ 0.30 ml/l (20.10 %) and T_7 Novaluron 5.25 % + Emamectin benzoate 0.9 SC @ 0.2 g/l (23.43 %) and were found statically superior over rest of the treatments except T_{10} Spinetoram 11.7 SC @ 0.50 ml/l (16.86 %). Whereas, the highest per cent pest infestations were recorded in the treatments such as T_1 nimbecidine 0.03 % @ 3 ml/l (36.89 %) was found statistically superior over T_2 *Bacillus thuringiensis var. kurstaki* @ 2 g/l (39.80 %), T_3 *Metarhiziumrileyi* @ 2 g/l (41.40 %) and untreated check (T_{12}) (47.96 %) at 105 DAG.

Finally the observations made at 112 and 119 DAG revealed that none of the treatments recorded percent pest infestation i.e., all the treatments were total recorded from percent pest infestation.

Natural enemy

Pooled data

The pooled data (Table 3) indicated that nimbecidine 0.03 %, *Bacillus thuringiensis var. kurstaki, Metarhiziumrileyi* and chlorantraniliprole 18.5 SC treatments proved to be as good as untreated check at 7 and 10 DAS with the natural enemy population ranging from 0.67 to 1.25 insects/pl at 7 DAS and 0.75 to 1.40 at 10 DAS during first spray. Almost similar trend was fol-

Table 1. Pooled Mean No of Egg masses per plant

Tr. No	Treatments	7 DAG	14 DAG	21 DAG	28 DAG	35 DAG	42 DAG	49 DAG	56 DAG	63 DAG	70 DAG	77 DAG	84 DAG	91 DAG	98 DAG	105 DAG	112 DAG	119 DAG
1	Nimbecidine @ 3 ml/l	0.00 (1.00)	7.67 (2.94)a	9.17 (3.19)a	12.00 (3.60)a	8.33 (3.04)a	10.67 (3.41)a	12.50 (3.67)a	9.17 (3.17)a	10.50 (3.38)a	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)
2	*Bacillus thuringiensis var. kurstaki* @ 2 g/l	0.00 (1.00)	7.00 (2.81)b	8.83 (3.11)ab	11.50 (3.53)ab	6.83 (2.78)ab	8.67 (3.10)ab	10.50 (3.39)b	7.50 (2.90)b	9.50 (3.23)b	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)
3	*Metarhiziumrileyi* @ 2 g/l	0.00 (1.00)	6.67 (2.76)b	8.33 (3.05)b	10.67 (3.41)a	8.33 (3.05)b	11.00 (3.46)b	13.00 (3.74)c	10.50 (3.38)b	11.83 (3.58)b	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)
4	Novaluron @ 1 ml/l	0.00 (1.00)	7.50 (2.91)ab	9.83 (3.29)ab	12.33 (3.65)ab	4.50 (2.34)ab	7.33 (2.88)ab	9.17 (3.19)bc	5.33 (2.51)ab	6.83 (2.80)b	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)
5	Spinosad 45 SC @ 0.50 ml/l	0.00 (1.00)	4.67 (2.37)c	6.50 (2.72)c	8.50 (3.07)c	2.33 (1.82)c	3.83 (2.18)c	5.83 (2.61)d	2.17 (1.74)c	3.00 (1.98)c	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)
6	Emamectin benzoate 5 SG @ 0.3 g/l	0.00 (1.00)	5.50 (2.54)c	8.00 (3.00)c	10.00 (3.30)c	4.83 (2.40)c	6.83 (2.79)c	8.33 (3.05)d	4.17 (2.26)c	5.67 (2.58)c	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)
7	Novaluron 5.25 % + Emamectin benzoate 0.9 SC @ 0.2 ml/l	0.00 (1.00)	6.50 (2.72)c	6.67 (2.76)c	9.00 (3.15)c	1.83 (1.68)c	2.33 (1.82)c	3.50 (2.12)d	2.00 (1.72)c	3.83 (2.20)c	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)
8	Chloranitraniliprole 18.5 SC @ 0.20 ml/l	0.00 (1.00)	5.00 (2.44)c	6.83 (2.79)c	9.33 (3.21)c	3.17 (2.02)c	5.33 (2.50)c	6.67 (2.75)d	3.17 (2.00)c	4.83 (2.40)c	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)
9	Cyantraniliprole 10 OD @ 0.30 ml/l	0.00 (1.00)	6.17 (2.65)c	7.67 (2.94)c	10.00 (3.31)c	1.17 (1.47)c	2.50 (1.86)c	4.50 (2.33)d	2.17 (1.77)c	3.33 (2.07)c	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)
10	Spinetoram 11.7 SC @ 0.5 ml/l	0.00 (1.00)	7.83 (2.95)c	10.00 (3.31)c	11.17 (3.48)c	0.50 (1.21)c	1.50 (1.58)c	3.00 (2.00)d	0.83 (1.35)c	1.67 (1.62)c	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)
11	Flubendiamide 480 SC @ 0.10 ml/l	0.00 (1.00)	6.17 (2.67)c	8.17 (3.02)c	9.83 (3.28)c	2.00 (1.73)c	4.50 (2.34)c	7.00 (2.82)d	3.17 (2.04)c	4.17 (2.26)c	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)
12	Untreated Check	0.00 (1.00)	6.17 (2.67)c	8.50 (3.08)c	10.50 (3.38)c	13.17 (3.76)c	15.33 (4.04)c	14.00 (3.87)d	15.00 (4.00)c	11.83 (3.58)c	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)
	SEm. ±	0.00	0.18	0.17	0.16	0.14	0.14	0.14	0.17	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	CD (p=0.05)	0..00	0.56	0.52	0.51	0.43	0.42	0.43	0.51	0.50	0..00	0..00	0..00	0..00	0..00	0..00	0..00	0..00
	C.V. (%)	0.00	11.66	9.63	8.45	10.61	8.87	8.08	11.90	10.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

DAG- Days After Germination   Figures within the parenthesis indicates square root transformation

Table 2. Pooled Mean Percent Pest Infestation per Plot

Tr. No	Treatments	7 DAG	14 DAG	21 DAG	28 DAG	35 DAG	42 DAG	49 DAG	56 DAG	63 DAG	70 DAG	77 DAG	84 DAG	91 DAG	98 DAG	105 DAG	112 DAG	119 DAG
1	Nimbecidine @ 3 ml/l	0.00 (0.00)	40.48 (39.86)a	45.44 (40.65)ab	54.84 (47.76)a	61.42 (51.79)a	70.72 (57.63)a	78.77 (63.42)a	82.55 (65.70)a	90.12 (71.97)a	79.86 (63.46)a	73.19 (58.88)a	68.68 (55.98)a	61.35 (51.60)a	54.82 (47.75)a	36.89 (37.34)a	0.00 (0.00	0.00 (0.00
2	Bacillus thuringiensis var. kurstaki @ 2 g/l	0.00 (0.00)	39.40 (39.24)bc	44.42 (41.75)ab	53.55 (47.02)a	61.21 (51.47)b	72.20 (58.20)b	82.54 (65.37)b	84.85 (67.31)b	90.96 (72.80)b	82.25 (66.03)b	76.00 (60.82)b	71.90 (58.31)b	65.98 (54.41)b	56.69 (48.84)b	39.80 (39.09)b	0.00 (0.00	0.00 (0.00
3	Metarhiziumrileyi @ 2 g/l	0.00 (0.00)	39.50 (39.32)c	46.56 (42.97)b	58.10 (49.64)b	69.60 (56.64)c	79.15 (62.89)c	82.93 (65.67)b	87.06 (68.95)b	89.09 (71.22)b	85.72 (68.61)c	80.19 (64.43)b	74.76 (60.14)c	68.94 (56.14)c	61.32 (51.66)c	41.40 (40.03)b	0.00 (0.00	0.00 (0.00
4	Novaluron @ 1 ml/l	0.00 (0.00)	40.17 (40.10)b	49.88 (44.50)a	53.69 (47.10)a	58.77 (50.06)ab	67.37 (55.17)b	75.41 (60.54)b	77.14 (62.09)b	81.12 (64.39)b	75.94 (60.69)bc	67.96 (55.54)b	61.38 (51.56)b	56.62 (48.79)b	51.55 (45.87)b	30.38 (33.40)b	0.00 (0.00	0.00 (0.00
5	Spinosad 45 SC @ 0.50 ml/l	0.00 (0.00)	37.21 (38.05)	43.21 d(41.34)c	51.35 (45.76)c	51.35 (45.76)d	60.59 (51.09)d	68.63 (55.95)c	68.63 (55.95)c	77.72 (62.07)c	69.11 (56.29)d	59.80 (50.64)c	52.93 (46.66)d	45.60 (42.23)b	41.18 (39.89)d	23.27 (28.72)c	0.00 (0.00	0.00 (0.00
6	Emamectin benzoate 5 SG @ 0.3 g/l	0.00 (0.00)	35.24 (36.36)d	42.97 (41.54)c	52.90 (46.66)c	52.90 (46.66)d	61.32 (51.56)d	68.61 (55.96)c	68.61 (55.96)c	77.23 (62.04)c	72.60 (58.70)d	63.31 (52.73)c	56.34 (48.63)d	50.11 (45.05)b	46.56 (43.01)d	32.23 (34.54)c	0.00 (0.00	0.00 (0.00
7	Novaluron 5.25 % + Emamectin benzoate 0.9 SC @ 0.2 ml/l	0.00 (0.00)	38.41 (39.39)d	43.99 (43.61)c	51.28 (45.72)c	51.28 (45.72)d	57.47 (49.36)d	65.95 (54.39)c	65.95 (54.39)c	71.12 (57.88)c	63.52 (52.90)d	57.76 (49.45)c	49.63 (44.77)d	42.15 (40.45)d	37.63 (37.76)d	23.43 (28.92)c	0.00 (0.00)	0.00 (0.00)
8	Chloranitraniliprole 18.5 SC @ 0.20 ml/l	0.00 (0.00)	38.05 (38.05)d	44.06 (41.35)c	52.53 (46.44)c	52.53 (46.44)d	57.58 (49.34)d	69.44 (56.51)c	69.44 (56.51)c	75.94 (61.10)c	69.30 (56.58)d	62.08 (52.07)c	55.21 (48.10)d	49.13 (44.48)d	43.96 (41.47)d	29.62 (32.94)c	0.00 (0.00	0.00 (0.00
9	Cyantraniliprole 10 OD @ 0.30 ml/l	0.00 (0.00)	36.48 (37.58)d	44.03 (42.78)c	53.08 (46.76)c	49.97 (44.97)d	57.44 (49.26)d	62.02 (51.95)c	62.02 (51.95)c	69.25 (56.31)c	60.07 (50.83d)	51.60 (45.90)c	45.34 (42.30)d	38.82 (38.51)d	33.70 (35.45)d	20.10 (26.61)c	0.00 (0.00)	0.00 (0.00)
10	Spinetoram 11.7 SC @ 0.5 ml/l	0.00 (0.00)	39.95 (39.18)d	45.76 (42.21)c	52.42 (46.38)c	52.42 (46.38)d	57.15 (49.11)d	61.90 (51.95)c	61.90 (51.95)c	65.77 (54.28)c	55.35 (48.06)d	48.39 (44.06)c	42.14 (40.44)d	34.95 (36.20)d	30.60 (33.46)d	16.86 (24.22)c	0.00 (0.00)	0.00 (0.00)
11	Flubendiamide 480 SC @ 0.10 ml/l	0.00 (0.00)	38.65 (39.05)d	45.97 (42.81)c	54.70 (47.69)c	54.70 (47.69)d	62.28 (52.15)d	72.06 (58.09)c	72.06 (58.09)c	73.98 (59.34)css	67.82 (55.47)d	63.01 (52.52)c	56.82 (48.92)d	51.14 (45.64)d	45.31 (42.28)d	27.89 (31.80)c	0.00 (0.00)	0.00 (0.00)
12	Untreated Check	0.00 (0.00)	41.56 (40.12)d	48.01 (44.03)c	54.79 (47.74)c	80.91 (64.07)d	85.31 (68.77)d	89.97 (72.40)c	93.16 (75.71)c	96.27 (79.29)c	90.86 (72.54)d	85.20 (67.60)c	76.91 (61.39)d	71.23 (57.55)d	67.24 (55.08)d	47.96 (43.78)c	0.00 (0.00	0.00 (0.00
SEm. ±		0.00	1.81	2.19	2.25	2.89	3.06	3.19	3.00	3.47	3.19	2.53	2.64	2.55	2.14	1.78	0.00	0.00
	CD (p=0.05)	0.00	5.58	6.75	6.95	8.91	9.44	9.84	9.23	10.69	9.82	7.78	8.15	7.87	6.58	5.48	0.00	0.00
	C.V. (%)	0.00	8.07	8.93	8.30	10.06	9.73	9.32	8.59	9.33	9.33	8.02	9.05	9.46	8.50	9.21	0.00	0.00

DAG- Days After Germination

Figures within the parenthesis are arc transformed values lowed during second application as well.

Phytotoxicity

The phytotoxic effect of newer insecticide molecules and biorationals data indicated no toxic effects of the treatments on maize crop such as wilting, leaf injury, vein clearing, necrosis, epinasty and hyponasty during 2019 and 2020 (Table 4).

Cob damage

The cob damage at 75 DAG was as high as 38.33 per cent in case of untreated check which was on par with nimbecidine 0.03 % @ 3 ml/l and *Metarhiziumrileyi* 2 x 10^8 CFU @ 2 g/l treatments. The cob damage continued to increase gradually in all the treatments with the time. At 105 DAG, significantly lower cob damage (7.50 %) was observed in spinetoram 11.7 SC @ 0.5 ml/l treatment which was found at par with cyantraniliprole 10 OD @ 0.30 ml/l treatment. However, the highest (50.00 %) cob damage was recorded in the untreated check (Table 5).

Grain yield

Pooled data

The pooled data revealed significantly higher grain

Table 3. Number of Predator Population per plant

Tr.No	Treatments	Dosage	1 DBS	3 DAS	7 DAS	10 DAS
1	Nimbecidine 0.03 %	3 ml/l	0.67(1.29)a	0.83(1.35)a	0.97(1.40)a	1.40(1.44)a
2	*Bacillus thuringiensis var. kurstaki* 17,600IU/mg	2 g/l	0.55(1.24)a	0.72(1.030)b	0.90(1.37)ab	1.37(1.41)b
3	*Metarhiziumrileyi*2 × 10^8 CFU	2 g/l	0.53(1.24)a	0.45(1.20)b	0.67(1.28)b	1.28(1.31)b
4	Novaluron 10 % EC	1 ml/l	0.60(1.26)a	0.10(1.05)a	0.10(1.05)a	1.05(1.06)ab
5	Spinosad 45 SC	0.50 ml/l	0.53(1.24)b	0.32(1.14)c	0.52(1.21)c	1.21(1.20)c
6	Emamectin benzoate 5 SG	0.3 g/l	0.73(1.32)b	0.20(1.09)c	0.28(1.13)c	1.13(1.15)c
7	Novaluron 5.25 % + Emamectin benzoate 0.9 SC	0.2 ml/l	0.72(1.31)b	0.18(1.09)c	0.20(1.09)c	1.09(1.10)c
8	Chlorantraniliprole 18.5 SC	0.20 ml/l	0.63(1.28)b	0.43(1.20)c	0.62(1.27)c	1.27(1.35)c
9	Cyantraniliprole 10 OD	0.30 ml/l	0.63(1.27)b	0.13(1.06)c	0.12(1.06)c	1.06(1.10)c
10	Spinetoram 11.7 SC	0.50 ml/l	0.63(1.27)b	0.32(1.15)c	0.25(1.12)c	1.12(1.15)c
11	Flubendiamide 480 SC	0.10 ml/l	0.80(1.33)b	0.02(1.01)c	0.07(1.03)c	1.03(1.04)c
12	Untreated Check	-	0.77(1.33)b	1.15(1.45)c	1.25(1.48)c	1.48(1.53)c
	SEm. ±	0.06	0.06	0.08	0.08	
	CD (p=0.05)	0.18	0.19	0.25	0.25	
	C.V. (%)	8.11	9.08	11.84	11.19	

DAG- Days After Spray Figures within the parenthesis indicates square root transformation

Table 4. Phytooxicity (Pooled)

Tr.No	Treatments	Dosage	0 days	1 days	3 days	7 days	10 days
1	Nimbecidine 0.03 %	3 ml/l	0	0	0	0	0
2	*Bacillus thuringiensis var. kurstaki*17,600IU/mg	2 g/l	0	0	0	0	0
3	*Metarhiziumrileyi*2 × 10^8 CFU	2 g/l	0	0	0	0	0
4	Novaluron 10 % EC	1 ml/l	0	0	0	0	0
5	Spinosad 45 SC	0.50 ml/l	0	0	0	0	0
6	Emamectin benzoate 5 SG	0.3 g/l	0	0	0	0	0
7	Novaluron 5.25 % + Emamectin benzoate 0.9 SC	0.2 ml/l	0	0	0	0	0
8	Chlorantraniliprole 18.5 SC	0.20 ml/l	0	0	0	0	0
9	Cyantraniliprole 10 OD	0.30 ml/l	0	0	0	0	0
10	Spinetoram 11.7 SC	0.50 ml/l	0	0	0	0	0
11	Flubendiamide 480 SC	0.10 ml/l	0	0	0	0	0
12	Untreated Check	-	0	0	0	0	0
	SEm. ±	0	0	0	0	0	
	CD (p=0.05)	0	0	0	0	0	
	C.V. (%)	0	0	0	0	0	

yield (73.25 q/ha) in T_{10} treatment which was at par with T_9. In turn, T_9 treatment stood at par with T_5 and T_{11} treatments. Significantly lower yields (33.58 to 40.88 q/ha) were registered in T_1, T_2 and T_3 treatments and even the T_3 treatment was at par with T_{12} treatment (Table 5).

Benefit Cost Ratio

Pooled data

With highest benefit cost ratio of 2.59, T_{11} treatment was found on par with T_{10} (2.56) (Table 5).

Screening of newer insecticide molecules and biorationals against fall armyworm

Discussion

The lowest number of egg masses were recorded in chemical treatments.Whereas, the highest number of egg masses were recorded in untreated check and biopesticides at 21 and 28 days after germination. No egg masses were recorded in all treatments at 70 days after germination. The lowest percent pest infestation was recorded in chemical treatments. The highest percent pest infestation was recorded in in untreated check and biopesticides at 21 and 28 days after germination. No pest infestation were recorded in all treatments at 70 days after germination.

With respect to natural enemy activity, nimbecidine 0.03% @ 3 ml/l, *Bacillus thuringiensis var. kurstaki* 17,600 IU/mg @ 2 g/l, *Metarhiziumrileyi* 2 × 10^8 CFU @ 2 g/l and chloranitraniliprole 18.5 SC @ 0.20 ml/l treatments were as good as untreated check by safe guarding the natural enemy population. Spinetoram 11.7 SC spray @ 0.5 ml/l resulted in highest grain yield which was at par with cyantraniliprole 10 OD @ 0.3 ml/l. Lower yields

Table 5. Impact of different treatments on cob damage due to fall armyworm and grain yield in maize (Pooled data).

Tr. No.	Treatments	Dosage	Cob damage (%) 75 DAG	90 DAG	105 DAG	Mean	Grain yield (q/ha)	Benefit Cost Ratio
1	Nimbecidine 0.03 %	3 ml/l	27.50 (31.52)^{b}	32.50 (34.71)^{b}	35.83 (36.74)^{a}	31.94	40.88^{c}	1.49
2	*Bacillus thuringiensis var. kurstaki* 17,600IU/mg	2 g/l	21.67 (27.67)^{bc}	25.83 (30.50)^{cd}	28.33 (32.12)^{b}	25.28	37.41^{bc}	1.33
3	*Metarhiziumrileyi*2 × 10^8 CFU	2 g/l	25.00 (29.93)^{b}	29.17 (32.64)^{bc}	31.67 (34.22)^{b}	28.61	33.58^{ab}	1.34
4	Novaluron 10 % EC	1 ml/l	18.33 (25.33)^{cd}	20.83 (27.09)^{de}	23.33 (28.82)^{ab}	20.83	52.77^{d}	1.75
5	Spinosad 45 SC	0.50 ml/l	8.33 (16.73)^{bc}	10.00 (18.34)^{hi}	11.67 (19.94)^{c}	10.00	65.91^{g}	1.93
6	Emamectin benzoate 5 SG	0.3 g/l	15.83 (23.42)^{de}	17.50 (24.72)^{ef}	19.17 (25.91)^{c}	17.50	57.98^{de}	2.19
7	Novaluron 5.25 % + Emamectin benzoate 0.9 SC	0.2 ml/l	11.67 (19.79)^{def}	13.33 (21.28)^{fgh}	15.00 (22.73)^{c}	13.33	60.42^{ef}	2.41
8	Chlorantraniliprole 18.5 SC	0.20 ml/l	13.33 (21.39)^{efg}	15.00 (22.73)^{fg}	16.67 (23.99)^{c}	15.00	65.97^{g}	2.46
9	Cyantraniliprole 10 OD	0.30 ml/l	6.67 (14.90)^{fgh}	8.33 (16.73)^{ij}	10.00 (18.34)^{c}	8.33	68.78^{gh}	2.37
10	Spinetoram 11.7 SC	0.50 ml/l	4.17 (11.64)^{gh}	5.83 (13.91)^{j}	7.50 (15.89)^{c}	5.83	73.25^{h}	2.56
11	Flubendiamide 480 SC	0.10 ml/l	10.00 (18.34)^{hi}	11.67 (19.94)^{ghi}	13.33 (21.39)^{c}	11.67	65.54^{fg}	2.59
12	Untreated Check	-	38.33 (38.24)^{i}	45.00 (42.11)^{a}	50.00 (44.98)^{c}	44.44	29.32^{a}	1.25
	SEm. ±		1.35	1.27	1.28	-	1.79	-
	CD (p=0.05)		4.17	3.92	3.96	-	5.28	-
	C.V. (%)		10.09	8.67	8.22	-	15.81	-

DAG- Days after germination

Figures within the parenthesis are arc sine transformed values were obtained from the plots which received biopesticidesapplication (Fig.1).

Spinetoram is a fermentation product of *Saccharopolysporaspinosa*and it acts on nicotinic acetylcholine receptors and ã-aminobutyric acid receptors (GABA) existing on post synaptic membranes in insects, nervous system, causing abnormal transmission and death (Shimokawatoko*et al.*, 2012). Spinoteram is friendly to the environment and non-toxic to animals and human beings. Therefore it has been widely used in pest control and grain storage (Zhang *et al.*, 2018).

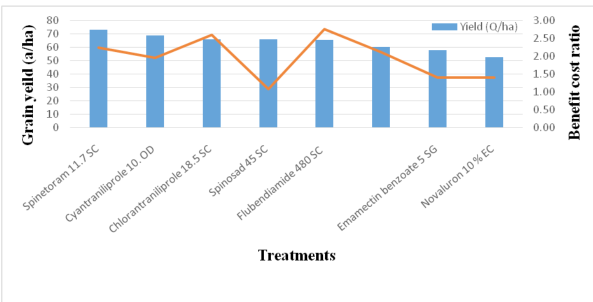

Fig. 1. Impact of different treatments on grain yield and benefit cost ratio in maize

Spinetoram 11.7 SC was also reported as effective molecule against *S. frugiperda*under laboratory and field by Mallapur*et al.* (2019). Similarly, higher effectiveness of spinetoram of FAW in maize has been reported by Tidke*et al.* (2021).Spinetoram 11.7 SC, emamectin benzoate 5 SG, chlorantraniliprole 18.5 EC, and thiodicarb 75 WP were found more effective in checking the larval population, plant and cob damage in maize which also reflected on grain and fodder yield as well (Thumar*et al.*, 2020). Emamectin benzoate was the most toxic to second instar larvae of *S. frugiperda* with LC_{50} value of 0.0051 ppm while, novaluron was the least toxic with LC_{50} value of 0.061 ppm (Deshmukh*et al.*, 2020).

Conclusion

The maximum number of egg masses were recorded in untreated check and biopesticides at 21 and 28 days after germination. None of egg masses were recorded in all treatments at 70 days after germination. The highest percent pest infestation was recorded in in untreated check and biopesticides at 21 and 28 days after germination. No pest infestation were recorded in all treatments at 70 days after germination. However, the natural enemy activity, nimbecidine 0.03% @ 3 ml/l, *Bacillus thuringiensis var. kurstaki*17,600 IU/mg @ 2 g/l, *Metarhiziumrileyi*2 × 10^8 CFU @ 2 g/l and chloranitraniliprole 18.5 SC @ 0.20 ml/l treatments were as good as untreated check by safe guarding the natural enemy population.Spinetoram 11.7 SC spray @ 0.5 ml/l resulted in highest grain yield which was at par with cyantraniliprole 10 OD @ 0.3 ml/l. Lower yields were obtained from the plots which received biopesticidesapplication.

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