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Field efficacy of selected insecticides against invasive pest, fall armyworm *Spodoptera frugiperda* (j. E. Smith) on maize crop

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Abstract
Fall armyworm, *Spodoptera frugiperda* (J. E. Smith), is an exotic and most destructive pest causing potential damage to maize crop in India. The experiment was carried out at MRC, Vijayari during *rabi*, 2018-19 and *Kharif*, 2019 to find out the field efficacy of chlorantraniliprole at different doses against fall army worm in maize. Chlorantraniliprole at 100ml, 150ml, 200ml and 250ml/ha along with two commercial standards (lambda-cyhalothrin + thiamethoxam@ 125ml/ha and Carbofuran 3G@ 33kg/ha) were evaluated along with untreated control in the present study. The results of two years of field trial against fall armyworm infestation in maize showed that chlorantraniliprole reduced the number of infested whorls (percent plant infestation) below that in the untreated control and lambda-cyhalothrin+ thiamethoxam and carbofuran at 7 & 14 days after spraying. Highest reduction in percent of mean plant infestation (% ROC) of 84.52 & 83.24 over control was recorded in chlorantraniliprole @ 250 ml and 200 ml/ha after 2nd spraying respectively. Foliar damage was recorded from plants in single middle row at 7 & 14 days after spraying based on mean whorl feeding injury in terms of visual score on 0-9 scale given by Davis and Williams 1992. Mean foliar damage was significantly lower with a scores of 1.4 and 1.2 at higher doses of chlorantraniliprole @ 250 ml and 200 ml/ha treated plots compared to other treatments *viz*., thiamethoxam 12.6% + lambda-cyhalothrin 9.5% ZC and carbofuran 3% CG including untreated control, resulted in significantly higher yields. These results indicate that chlorantraniliprole @ 200ml and 250ml/ha are significantly effective against fall armyworm than other insecticides tested without showing phytotoxicity.

Keywords: Bio-efficacy, chlorantraniliprole, fall army worm, maize, *Spodoptera frugiperda*

Introduction
Maize is cultivated nearly in 150 m ha in about 160 countries having wider diversity of soil, climate, biodiversity and management practices that contributes 36% (782 m t) in the global grain production. In India, maize area has reached to 9.2 million ha in 2018-19 with a production of 27.8million metric tons and productivity of 2965 kg/ha. Andhra Pradesh is having highest state productivity and few districts like Krishna, West Godavari etc. records as high as 12 t/ha productivity. In India, about 15 million farmers are engaged in maize cultivation and it generates employment for more than 650 million person-days at farming and its related business ecosystem levels (FICCI, 2018) [9]. In India, maize is cultivated throughout the year as grain, feed, fodder, green cobs, sweet corn, baby corn, pop corn and industrial products. These unique characteristics of maize make the crop a suitable crop candidate for enhancing farmer's income and livelihoods in India.

Fall armyworm, *Spodoptera frugiperda* (J. E. Smith), is an exotic and one of the most destructive pests causing potential damage to maize in India. The incursion of fall armyworm as an invasive pest into Asia was first reported in India on maize crop during May 2018 (Sharanabasappa *et al*., 2018a) [19]. Since then, it has spread to different states of India on maize (Mahadevaswamy *et al*., 2018; Sharanabasappa *et al*., 2018b) [15, 20]. Though it is major pest of maize, it also attacks more than 80 species of different crops such as rice, millets, cotton (FAO, 2020) [8] due to its polyphagous nature.

In the year of its introduction 2018 in India, farmers lacking suitable and immediate management practices to contain the pest below economic threshold levels (ETLs). Since the occurrence of fall army worm in India, farmers have been widely used synthetic insecticides as an emergency response to arrest the rapid spread of the pest and to minimize damage to maize fields.

The fall armyworm larva feeds in the whorls of maize, thus reducing its contact with insecticides. Farmers have resorted to 4-5 sprays of different insecticides at high doses without the knowledge of their efficacy and opined that the currently used synthetic insecticides at recommended doses are not effective against fall army worm. Multiple sprays of insecticides may lead to the quick development of resistance has occurred in other areas (Gutierrez-Moreno *et al*. 2019) [10] and also causing accumulation of pesticides in the environment.

At present, the Central Insecticide Board and Registration Committee (CIBRC) recommends the spraying of chlorantraniliprole 18.5 SC, thiamethoxam 12.6% + lambda cyhalothrin 9.5% ZC, and spinetoram 11.7 SC. (as adhoc recommendations) for use against fall armyworm in addition to other IPM practices. (DPPQS 2019) [7]. The Registration committee also suggested application of carbofuran 3% CG and phorate 10% CG for management of *S. frugiperda* in maize (Anonymous, 2018) [1].

Insecticide application is the commonest and widely used method in IPM of fall army worm in Africa (Prasanna *et al*., 2018) [17] and in all over the world. Synthetic insecticides with novel mode of action have been developed for management of lepidopteran pests, to which the fall army worm in India has yet to be exposed. One of such group of insecticides is the diamides which includes chlorantraniliprole. The mode of action of diamides differs greatly from that of products currently used by farmers for control of fall armyworm in various crops. The dose of insecticide used can influence the mechanism of evolved resistance to the pesticide, with high doses favoring target site resistance and low doses favoring other mechanisms. To overcome resistance problems, right doses of insecticides with selective mode of action and persistence against target pest have to be selected. The main aim of this study is to evaluate selected synthetic insecticides to manage fall armyworm under natural field infestation in two cropping seasons to find the best insecticide at right dose for its effective management.

At present, reports on efficacy of chlorantraniliprole and other traditional insecticides against fall armyworm in Indian conditions are not available because it is a recent invader. Hence, an experiment has been carried out to evaluate the bio-efficacy of chlorantraniliprole 18.5 SC at different doses as foliar spray against fall army worm besides its phytotoxicity, and grain yield during *Rabi*, 2018-19 and *Kharif*, 2019.

Materials and Methods

The trials was carried out for two years during *rabi*, 2018 -19 and *kharif*, 2019 at Maize Research Centre, ARS, Vijayarai in a randomized block design with a spacing of 75 cm X 20 cm. The experiment was carried out with seven treatments *viz*., chlorantraniliprole 18.5 SC@ 100 ml ha-1, chlorantraniliprole 18.5 SC @ 150 ml ha-1, chlorantraniliprole18.5 SC EC @ 200 ml ha-1, chlorantraniliprole18.5 SC @ 250 ml ha-1, Thiamethoxam 12.6% + Lambda-Cyhalothrin 9.5% ZC@ 125 ml ha-1, Carbofuran 3%CG @ 33 kg ha-1, were evaluated against fall armyworm (Table No:1) including untreated control.

Three treatments were evaluated for phytotoxicity (Table No.2). All the agronomic practices were followed as per the recommended package of practices. Two sprays were given for all treatments when the crop is at 20-25 days old except untreated check. During spraying, insecticides were directed specifically at the whorl region where as carbofuran 3% CG was applied in whorls of maize plants.

The observations on per cent plant infestation (%) and leaf damage (damage severity) were recorded. The pretreatment observations at 24 hours before spraying and post treatment observations at 7 and 14 days after each spraying were recorded.

$$\text{Per cent plant infestation} = \frac{\text{Number of plants showing infested symptoms}}{\text{Total number of plants in each treatment}} \times 100$$

The data pertaining to per cent plant infestation was subjected to arcsine transformation. Later, transformed values were analysed using ANOVA.

Reduction in pest population over untreated control (% ROC) was calculated by using the formula suggested by Henderson & Tilton (1955) [13]. Similarly, the FAW damage severity was recorded on single middle row in each plot at seven-day intervals at 7 and 14 days after spraying based on a rating scale described by Davis and Williams 1992 [5]; 0 = no visible leaf damage, 1 = only pin-hole damage to the leaves, 2 = pin-hole and shot-hole damage to leaves, 3 = small elongated lesions (5–10 mm) on 1–3 leaves, 4 = mid sized lesions (10–30 mm) on 4–7 leaves, 5 = large elongated lesions (>30 mm) or small portions eaten on 3–5 leaves, 6 = elongated lesions (>30 mm) and large portions eaten on 3–5 leaves, 7 = elongated lesions (>30 cm) and 50% of leaf eaten, 8 = elongated lesions (30 cm) and large portions eaten on 70% of leaves, 9 = most leaves have long lesions and complete defoliation is observed. Yield was arrived by leaving two border rows in all treatments and expressed as kg/ha.

The data thus obtained pertaining to leaf damage and yield from field experiments in a randomized block design were analyzed statistically by ANOVA.

Table 1: Treatment details for evaluation of bio – efficacy of different insecticides

Treatment Number	Treatments	DOSAGE	
		a.i (g)/ha	Formulation (ml/g)/ha
T1	Chlorantraniliprole 18.5% SC	20	100
T2	Chlorantraniliprole 18.5% SC	30	150
T3	Chlorantraniliprole 18.5% SC	40	200
T4	Chlorantraniliprole 18.5% SC	50	250
T5	Carbofuran 3% CG	1000	33300
T6	Thiamethoxam 12.6% + Lambda cyhalothrin 9.5% ZC	27.5	125
T7	T7: Untreated Control		

Table 2: Treatment Details for Evaluation of Phytotoxicity

Treatment Number	Treatments	DOSAGE	
		a.i (g)/ha	Formulation (ml/g)/ha
T_1	Chlorantraniliprole 18.5% SC	40	200
T_2	Chlorantraniliprole 18.5% SC	80	400
T_3	Untreated control	-	

Phytotoxicity was assessed by visual observations. Ten plants in each treatment replicated thrice were observed critically at 0, 1, 3, 5, 7, 10 and 14 days after spraying in T1: Chlorantraniliprole 18.5% SC @ 40 g.a.i./ha, T2: Chlorantraniliprole 18.5% SC @ 80 g.a.i./ha, and T3: Untreated Control for chlorosis & vein clearing, wilting & necrosis, stunting & leaf injury, epinasty and hyponasty and were graded on 0-10 point phytotoxicity scale.

Results and Discussion

Chlorantraniliprole at different doses along with other insecticide molecules were assessed in the maize field against the *S. frugiperda*. Data for two consecutive seasons were pooled. One day before treatment imposition, mean percent plant infestation by fall army worm was statistically on par among the treatments and ranged from 29.07 to 44.07 indicating uniformity of pest infestation under natural conditions in the experimental plots. At all the intervals of observation, significantly higher percent plant infestation by fall army worm was recorded in untreated plots as compared to insecticide applied ones. During the first spray, the mean percent plant infestation ranged from 9.84 to 47.68 and 10.80 to 45.02 at 7 days and 14 days after spraying was recorded in the plots treated with insecticides compared to untreated control with 55.95 and 54.70% plant infestation at 7 days and 14 days after spraying respectively. The results suggested that the all the insecticides were effective in reducing mean percent plant infestation in the experimental field. At 7 days after first spraying, chlorantraniliprole@ 250 ml and 200 ml /ha was found significantly superior in reducing the percent plant infestation of 9.84 and 13.45 respectively as compared to other treatments. At 14 days after spraying, lowest plant infestation was recorded in chlorantraniliprole @250ml/ha (10.80%) followed by chlorantraniliprole @ 200 ml/ha (14.43%) and both were at par each other and are significantly different from other treatments. Overall mean after 1st spray of 2years study indicates that, chlorantraniliprole @ 250 ml and chlorantraniliprole @ 200ml/ha recorded lowest percent plant infestation of 10.32 and 13.94 with 81.35 and 74.80 percent reduction over control (% ROC) respectively.

Second spray at 14 days after the 1st spray resulted in further reduction in percent plant infestation by fall army worm. The mean percent plant infestation was ranged from 6.83 to 57.82 at 7 days after 2nd spray. The lowest percent plant infestation (6.83) was noticed in chlorantraniliprole@250ml/ha and it was at par with chlorantraniliprole@200 ml/ha (7.60) and both were significantly different from other treatments. Similar trend was followed even after 14 days of second spray. The lowest percent plant infestation (11.60) was noticed in chlorantraniliprole@250ml/ha followed by chlorantraniliprole @200ml/ha (12.35), with highest percent reduction (% ROC) of 84.52 and 83.24 respectively over control after 2nd spray. (Table No 3). The present findings are closely corroborated with the results of Hardke *et al*., 2011 [11] who reported that chlorantraniliprole is highly effective (10%) than other insecticides tested and significantly reduced fall armyworm infested whorls compared to the non-treated control plots (50.0%) at 3 days after treatment and reduced fall armyworm infestations by 2.5-fold below that in the non-treated control at 7 days after treatment. Similarly, Smith (2009) [23] evaluated efficacy of insecticide against fall armyworm in maize and reported that coragen and diamond were found most effective in reducing the fall armyworm larval population at 15 days after treatment. In Ethiopia, fall armyworm was effectively controlled by using insecticides *viz*., spinetoram, chlorantraniliprole, spinosad and lambda cyhalothrin (Sisay *et al*., 2019) [22]. Further, Bajracharya *et al*., 2020 also found chlorantraniliprole was most effective in reducing percent plant infestation and foliar damage with damage score by fall army worm in maize fields in Nepal. Our results revealed that thiamethoxam 12.6 + lambda cyhalothrin 9.5 ZC and carbofuran 3% CG were less effective in reducing the percent plant infestation. These results are in accordance with the Mallapur *et al*., 2019 who concluded that thiamethoxam 0.25% WG was least effective in controlling fall army worm at seven days after treatment in maize. Sangle *et al*., 2020 [18] proved that chlorantraniliprole was highly effective with minimum infestation whereas thiamethoxam 12.6 + lambda cyhalothrin 9.5 ZC was moderately effective against fall armyworm in maize. Hardke *et al*., 2014 [12] observed higher mortality of fall army worm with new insecticides like Cholarantraniliprole, flubendiamide, and spinetoram compared to traditional ones like lambda-cyhalothrin when applied in laboratory. Bharadwaj *et al*., 2020 [3] studied the efficacy of selected synthetic insecticides against fall army worm and revealed that efficacy of chlorantraniliprole was superior than Thiamethaxam 12.6 + Lambda cyhalothrin 9.5 ZC and untreated control.

Leaf damage: Impact of insecticide on leaf damage caused by fall army worm was recorded seven-day intervals after spraying. Results of Pooled data of 2 years showed that significant reduction of leaf damage was recorded in all the treatments over untreated control on 7th and 14 days after 1st and 2nd sprayings. Results of pooled data of first sprayings showed that the lowest leaf damage was recorded in plots treated with chlorantraniliprole@ 250 ml/ha (1.24) followed by chlorantraniliprole @ 200 ml/ha (1.56) and both were at par with each other at 7 days after 1st spraying. The next best treatments were chlorantraniliprole @ 150 ml/ha (2.46), followed by Lambda cyhalothrin + Thiamethoxam @ 125.ml/ha (4.08), chlorantraniliprole @ 100ml/ha (5.29) and carbofuran 3G @33kg/ha(4.85).The highest damage was found in untreated control with damage score of 6.97 at 7 days after 1st spraying. At 14 days after 1st spraying, the lowest leaf damage score of 2.17 was recorded in chlorantraniliprole @ 250 ml/ha, which is at par with chlorantraniliprole @200ml/ha (2.50). The mean of 7 &14 days after the first spray reveals that lowest mean leaf damage of 3.39 and 3.47 was recorded in chlorantraniliprole @ 250 ml/ha and 200 ml/ha respectively with percent reduction over control (% ROC) of 51.22 and 50.07 respectively. Similar trend was noticed even after 2nd spraying also. Second spraying of insecticides, further reduced the mean leaf

damage. Lowest mean leaf damage score of 1.04 and 1.19 (at 7 and 14 days) was recorded in chlorantraniliprole @ 250 ml/ha followed by chlorantraniliprole @ 200ml/ha with a score of 1.39 and 1.42 at 7 and 14 days respectively, after 2nd spraying and both treatments were at par each other and are significantly different from other treatments. Highest leaf damage score of 7.81 and 8.08 was recorded in untreated control at 7 and 14 days respectively, after 2nd spraying. Pooled mean leaf damage score after 2nd spraying ranged from 1.12 to 7.94. The results indicated that lowest leaf damage score of 1.12 and 1.40 with percent reduction of 85.94 & 82.34 (% ROC) leaf damage in chlorantraniliprole @ 250 ml/ha & 200 ml/ha respectively over control, Whereas Lambda cyhalothrin + Thiamethoxam @ 125ml/ha and carbofuran 3%CG @ 33kg/ha were less effective with% ROC of 50.58 and 36.03. (Table No:4)

The effectiveness of chlorantranilliprole against fall army worm closely follows the results of Dileep Kumar and Murali mohan 2020 who reported that spraying of chlorantraniliprole resulted in significant reduction in leaf damage (%ROC) to an extent of 64.82 and 82.40 after 1st and 2nd sprays respectively, whereas lambda-cyhalothrin was less effective in reducing the leaf damage by fall army worm in maize. Suthar 2020 reported that Carbofuran 3% was less effective in reducing leaf damage by fall army worm in maize.

Phytotoxicity: The pooled data of 2 years of our study clearly indicated that, none of the phytotoxicity symptoms *viz*., yellowing, Stunting, necrosis, epinasty, hyponasty, wilting and rosetting were observed in chlorantraniliprole@40 g.a.i./ha, chlorantraniliprole @80 g.a.i./ha and untreated plot of Maize. (Table 5)

Yield: Pooled analysis of *rabi* 2018-19 and *Kharif*, 2019 data revealed that all the treatments with insecticide sprays recorded significantly higher grain yield compared to untreated control except chlorantraniliprole @100 ml/ha. Yield in different treatments ranged from 6332 to 9357 kg/ha. The maximum grain yield of 9357 kg/ha was recorded in chlorantraniliprole @ 250 ml/ha followed by chlorantraniliprole @ 200 ml/ha (9006 kg/ha) and both were at par with each other and significantly different from other treatments. The next effective treatments were chlorantraniliprole @ 150 ml/ha (7997 kg/ha), thiamethoxam + lambda cyhalothrin (7786 kg/ha) and carbofuran 3%CG @1000 g.a.i./ha(7663 kg/ha). Lowest yield was recorded in untreated control (6332 kg/ha). An additional yield of 3025 kg/ha and 2674 kg/ha were recorded in chlorantraniliprole @ 250 and 200ml/ha respectively over control. (Table No:6). This may be due to significant reduction in percent plant infestation and leaf damage by fall army worm compared to other treatments. The present findings were confirmed with the results of Sharanabasappa *et al*., (2020) [21] who found that higher efficacy of chlorantraniliprole against fall army worm larva resulted in higher yields than the other insecticides tested and control. Chlorantraniliprole belongs to the anthranilic diamide insecticide group has low mammalian toxicity and high insecticidal activity as main characteristics (Lahm *et al*., 2007) [14]. These insecticides bind to ryanodine receptors of the insect in muscle cells, causing the uncontrolled exit of calcium from the sarcoplasmic reticulum caused by channel opening, thereby resulting in muscle paralysis and insect death (Cordova *et al*., 2006) [14]. Only two (2) insecticidal sprays provided enough protection to maize crop from fall armyworm, and subsequently resulted in higher yields compared with the untreated plots during two years of study. But, frequency of applications depends on the pest density, climatic factors etc. Thus keeping plants free of infestation by larvae during the vegetative period can help to reduce the number of sprayings needed at the silking stage. Therefore, most effective insecticide chlorantraniliprole can be recommended for the management of fall army worm. Insecticides are not ultimate solution for the management of fall army worm as they are prone to resistance development by insect. Hence, it can be used in IPM along with other management practices to manage the pest below ETLs.

Table 3: Effect of Insecticides on percent plant infestation by fall army worm (*Rabi*, 2018-19 and *Kharif*, 2019).

Treatments	Formulation (ml/g)/ha	Pooled mean of% plant infestation of fall army worm								
		Pre treatment	1st spray				2nd spray			
			7 DAS	14 DAS	Mean	% ROC	7 DAS	14 DAS	Mean	% ROC
T1: Chlorantraniliprole 18.5% SC	100	33.88 (38.12)	47.68 (41.75)	45.02 (42.65)	46.35	16.21	29.07 (32.61)	41.02 (39.80)	35.04	41.15
T2: Chlorantraniliprole 18.5% SC	150	34.73 (37.97)	23.28 (27.84)	22.82 (29.06)	23.05	58.33	15.45 (22.94)	23.56 (29.02)	19.51	67.24
T3: Chlorantraniliprole 18.5% SC	200	37.68 (37.96)	13.45 (21.25)	14.43 (21.30)	13.94	74.80	7.60 (15.88)	12.35 (20.51)	9.98	83.24
T4: Chlorantraniliprole 18.5% SC	250	37.78 (38.59)	9.84 (18.53)	10.80 (19.39)	10.32	81.35	6.83 (15.06)	11.60 (19.89)	9.22	84.52
T5: Carbofuran 3% CG	33300	29.07 (35.90)	26.72 (31.26)	29.43 (32.44)	28.07	49.25	25.72 (30.44)	37.92 (37.98)	31.82	46.57
T6: Thiamethoxam 12.6% + Lambda cyhalothrin 9.5% ZC	125	42.75 (41.58)	36.63 (37.0)	35.50 (36.52)	36.07	34.81	31.47 (34.11)	38.94 (38.56)	35.20	40.88
T7: Untreated Control		44.07 (43.56)	55.95 (47.49)	54.70 (47.60)	55.32	-------	57.82 (49.48)	61.27 (51.50)	59.55	------
F- Test		NS	Sig	Sig			Sig	Sig		
CD(P=0.05)		----	4.18	2.17			4.26	3.79		
CV(%)		7.11	7.23	3.70			8.27	6.22		

Table 4: Effect of Insecticides on Leaf damage scores by fall army worm (*Rabi*, 2018-19 and Kharif, 2019)

Treatments	Formulation (ml/g)/ha	Pooled mean of leaf damage scores based on Davis scale								
		Pre treatment	1st spray				2nd spray			
			7 DAS	14 DAS	Mean	% ROC	7 DAS	14 DAS	Mean	% ROC
T1: Chlorantraniliprole 18.5% SC	100	6.44	5.29	6.27	6.00	13.67	5.12	5.72	5.42	31.73
T2: Chlorantraniliprole 18.5% SC	150	6.04	2.46	3.33	3.94	43.31	2.36	3.14	2.75	65.37
T3: Chlorantraniliprole 18.5% SC	200	6.26	1.56	2.50	3.47	50.07	1.39	1.42	1.40	82.34

T4: Chlorantraniliprole 18.5% SC	250	6.77	1.24	2.17	3.39	51.22	1.04	1.19	1.12	85.94
T5: Carbofuran 3% CG	33300	6.46	4.85	6.39	5.90	15.10	4.45	5.70	5.08	36.03
T6: Thiamethoxam 12.6% + Lambda cyhalothrin 9.5% ZC	**125**	6.52	4.08	5.34	5.31	23.59	3.64	4.20	3.92	50.58
T7:Untreated Control	---	6.36	6.97	7.52	6.95		7.81	8.08	7.94	
F- Test		NS	Sig	Sig			Sig	Sig		
CD(P=0.05)		----	0.35	0.55			0.46	0.43		
CV(%)		6.7	5.2	6.4			7.0	5.6		

Conclusion

This study provides valuable information about the efficacy of insecticides with different modes of action to control fall army worm. Statistically similar grain yields were obtained at both the concentrations of chlorantraniliprole @ 250ml and 200 ml/ha without any significant difference in efficacy against fall army worm pertaining to percent plant infestation and foliar damage without showing any phytotoxic symptoms to the maize crop. Hence, we can recommend a lower dose of chlorantraniliprole @ 200 ml/ha against maize fall army worm as foliar spray. This can be integrated with other IPM practices for successful management of fall army worm.

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