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Bio-efficacy of selected insecticides against fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Noctuidae: Lepidoptera), in maize

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Abstract
Bio-efficacy of insecticides belonging to ten chemical groups were assessed against the fall armyworm in maize during *Rabi* 2018 and *Kharif* 2019. Insecticides were sprayed two times at 14-day interval. Insecticides were directed into the whorl portion of the plants. Among the insecticides assessed spinetoram was found highly effective in reducing the larval population and leaf damage, followed by novaluron and chlorantraniliprole with 97.32, 93.09 and 90.43% reduction in larval population respectively, over untreated control. The plot treated with spinetoram recorded highest grain yield (33.48 q/ha), followed by novaluron (32.07 q/ha) and chlorantraniliprole (31.13 q/ha). These insecticides belong to different chemical group with varied modes of action. Hence, it is possible to include effective chemicals found in this research in the fall armyworm management schedule. This would help in effective management of the pest and also delaying the development of resistance against these molecules.

Keywords: Fall armyworm, *Spodoptera frugiperda*, Management schedule, insecticide resistance, spinetoram

1. Introduction

The fall armyworm, *Spodoptera frugiperda* (Smith) (Noctuidae: Lepidoptera), is a polyphagous pest that feeds on 353 plant species belonging to 76 families and causes significant loss in crop production (Montezano *et al*., 2018) [1]. The larvae feed on several plant species *viz*., maize, rice, sorghum, sugarcane, cabbage, beet, peanut, soybean, alfalfa, onion, tomato, potato and cotton (Pogue, 2002; CABI 2016) [2, 3]. Among these host plants, maize and sorghum are most preferred by *S. frugiperda*. The fall armyworm is native to the Americas. This pest is found in most parts of the Western Hemisphere, from southern Canada to Chile and Argentina. Of late, the fall armyworm was noticed in West Africa and East Africa during 2016 and 2017, respectively. Currently, this pest is damaging crops in over 20 African countries (Goergen *et al*., 2016; Abrahams *et al*., 2017; Cock *et al*., 2017) [4, 5, 6]. In Brazil, the fall armyworm causes up to 34% reduction in maize grain yield that amounts to an annual loss of US$ 400 million (Lima *et al*., 2010) [7] and causes annual crop losses of over US$ 500 million throughout the south-east United States and the Atlantic coast (Young and Mcmillian, 1979) [8]. Yield losses in maize due to fall armyworm damage reaches up to 32% in the United States (Wiseman and Isenhour, 1993) [9] and 45-60% in Nicaragua (Hruska and Glandstone 1988) [10]. Recently during August 2018, fall armyworm was reported for the first time in India, near Bangalore, Karnataka state on the maize crop (Ganiger *et al*., 2018) [11]. In subsequent months this species was also reported from other maize growing states of India *viz*., Tamil Nadu, Andhra Pradesh, Telangana, Maharashtra, Gujrat and several North eastern states (Sharanabasappa *et al*., 2018; Swamy *et al*., 2018; Srikanth *et al*., 2018; Chormule *et al*., 2019) [12, 13, 14, 15]. In Karnataka, a quick roving survey suggested the damage ranging from 9 to 62.5% on maize (Ganiger *et al*., 2018; Shylesha *et al*., 2018) [11, 16]. Maize is one of the important cereal crops grown in India. This new invasive species has been occurring in serious proportions, causing significant damage to the maize crop, thus posing serious treat for maize production in the country. The fall armyworm persists on maize crop from the early crop stage till cob maturity, thus necessitating spraying of insecticides multiple times. Repeated application of chemicals with similar mode of action would hasten the development of Resistance.

Hence, to delay the development of resistance to insecticides, it is essential to rotate the chemicals having different modes of action. In the current research we assessed the bio-efficacy of insecticides belonging to different chemical groups on the fall armyworm for two cropping seasons in India. Going forward, effective insecticides belonging to the slightly hazardous categories found in this study may play a prominent role in integrated management programme of the fall armyworm.

2. Materials and Methods

Insecticides belonging to different chemical groups were assessed on fall armyworm in the field for successive two seasons during *Rabi* 2018 and *Kharif* 2019. Maize crop (variety GK 3015) was raised with 60 cm × 30 cm spacing. The experiment was laid out in randomised block design (RCBD) and consisted of 12 treatments with three replications each (refer Table 1 for treatment details). In this research 11 insecticides belonging to 10 chemical groups were assessed. Insecticides were sprayed two times during the study period. First spray was initiated when sufficient infestation was noticed and it coincided with the 18-22 days old crop (V4 stage). Second spraying was given 15 days after the first spray. During spraying, insecticides were directed specifically at the whorl region using a knapsack sprayer. The larval counts and per cent leaf damage was estimated. Observations were recorded before imposing the treatments (pre-treatment counts) and post treatment observations were recorded at 7 and 14 days after each application. The extent of leaf damage (per cent leaf damage) caused by larvae of fall armyworm was estimated through visual scoring in 0-9 scale as described by Davis & Williams (1992) [17].

Reduction in pest population and leaf area damage over untreated control was calculated by using the formula suggested by Henderson & Tilton (1955). The data on larval population was subjected to square root transformation and data on per cent leaf damage was subjected to arcsine transformation. Later, transformed values were analysed using ANOVA.

Table 1: Treatment details

Treatments	Dose (gram a.i./ha)	Dosage (ml/l or g/l)
Spinetoram 11.7 SC	30.00	0.50
Spinosad 45 SC	67.5	0.30
Emamectin benzoate 5 SG	10	0.40
Thiodicarb 75 WP	750	1.00
Azadirachtin 1% EC	10	2.00
Lambda cyhalothrin 2.5EC	12.5	1.00
Indoxacarb 14.5 SC	72.5	1.00
Chlorpyriphos 20% EC	200	2.00
Bacillus thuringiensis 8L	-	2.00
Novaluron 10 EC	50	1.00
Chlorantraniliprole 18.5 SC	27.75	0.30
Untreated control	-	-

3. Results and Discussion

Conventional and new generation insecticide molecules were assessed in the field against the *S. frugiperda* so that wider options in choosing insecticides would be available for its management.

Prior to imposition of treatments, mean larval population ranging from 1.33 to 1.50 larvae/plant was recorded in the experimental plots and the population was statistically on par, indicating uniformity of pest population in the experimental plot.

At 14 days after first spraying, reduction in pest population was noticed in all the treatments. The mean larval population in pesticide applied plants ranged from 0.08 to 0.82 larvae/plant, and in untreated control higher larval density of 1.22/plant was noticed. The results suggested that the insecticide application was effective in reducing the larval population in the experimental field. At 14 days after first spraying, spinetoram (0.08 larvae/plant) was found to be significantly superior in reducing the larval population as compared to novaluron (0.15 larvae/plant), chlorantraniliprole (0.22 larvae/plant), spinosad (0.23 larvae/plant), thiodicarb (0.30 larvae/plant), emamectin benzoate (0.32 larvae/plant), indoxacarb (0.48 larvae/plant), *Bacillus thuringiensis* toxin (0.57 larvae/plant), lambda cyhalothrin (0.70 larvae/plant), chlorpyrifos (0.70 larvae/plant) and azadirachtin 1% (0.82 larvae/plant) (Table 2). The spinetoram recorded highest per cent reduction in larval population (91.21%) over untreated control, followed by novaluron (86.93%), chlorantraniliprole (80.26%), spinosad (79.61%,), thiodicarb (73.75%), emamectin benzoate (72.65%), *Bacillus thuringiensis* toxin (62.09%), indoxacarb (58.55%), lambda cyhalothrin (47.98%), chlorpyrifos (40.70%) and azadirachtin 1% (36.93%) after 14 days of first spray (Table 2).

A second round of sprays with the insecticides further resulted in significant reduction of existing fall armyworm larval population. At 14 days after second spraying (DAS) the mean larval population across the treatments with insecticide sprays ranged from 0.03 to 0.58 larvae/plant and in untreated control population was 1.15 larvae/plant. Spinetoram (0.03 larvae/plant) was found to be significantly superior in reducing the larval population compared to novaluron (0.08 larvae/plant), chlorantraniliprole (0.11 larvae/plant), spinosad (0.12 larvae/plant), thiodicarb (0.18 larvae/plant), emamectin benzoate (0.20 larvae/plant), indoxacarb (0.34 larvae/plant), *Bacillus thuringiensis* toxin (0.44 larvae/plant), lambda cyhalothrin (0.45 larvae/plant), chlorpyrifos (0.53 larvae/plant) and azadirachtin 1% (0.58 larvae/plant) (Table 2). The maximum reduction in larval population over untreated control was noticed in spinetoram (97.32%), followed by novaluron (93.09%), chlorantraniliprole (90.43%), spinosad (89.57%,), thiodicarb (83.57%), emamectin benzoate (82.37%), indoxacarb (68.96%), *Bacillus thuringiensis* toxin (62.50%), lambda cyhalothrin (60.33%), chlorpyrifos (50.55%) and azadirachtin 1% (46.28%) after 14 days of second spray (Table 2).

In addition to larval mortality, per-cent of leaf damage caused by fall armyworm larva was also recorded to understand the role of chemicals in minimizing leaf damage. The pre-treatment observation recorded 1 day prior to spraying suggested that leaf damage was uniform among all the plots and it was varied from 54.83 to 59.00%. Spraying of insecticides resulted in significant reduction in leaf damage by fall armyworm. At 14 days after first spray, spinetoram recorded minimum leaf damage (17.33%) and it was found to be significantly superior to novaluron (21.58%), chlorantraniliprole (23.42%), spinosad (23.17%), thiodicarb (23.42%), emamectin benzoate (25.58%), indoxacarb (31.50%), *Bacillus thuringiensis* toxin (38.42%), lambda cyhalothrin (41.83%), chlorpyrifos (46.00%) and azadirachtin 1% (48.67%). In untreated control plot higher leaf damage of 69.92% was noticed (Table 3).

The leaf damage caused by the fall armyworm larvae further reduced after second spraying. At 14 days after the second application, spinetoram recorded lowest leaf damage (6.50%) and it was followed by other insecticides *viz*., novaluron (10.92%), spinosad (11.92%), chlorantraniliprole (12.50%), thiodicarb (13.67%), emamectin benzoate (15.08%), indoxacarb (24.58%), *Bacillus thuringiensis* toxin (24.83%), lambda cyhalothrin (31.33%), chlorpyrifos (33.58%) and azadirachtin 1% (37.58%). While, in untreated control plots damage increased to 74.58% (Table 3).

All the plots with insecticide sprays recorded significantly higher grain yield compared to untreated control. The highest yield (33.48 q/ha) was recorded in spinetoram 11.7 SC treated plot. This was followed by novaluron, chlorantraniliprole, spinosad, thiodicarb, emamectin benzoate, indoxacarb, *Bacillus thuringiensis* toxin, lambda cyhalothrin, chlorpyrifos and azadirachtin 1% treated plots. In these treatments grain yield ranged from 22.33 to 32.07 q/ha. Lowest yield was recoded in untreated control (19.45 q/ha) (Table 4).

In this study, the insecticides like spinetoram, novaluron, chlorantraniliprole and spinosad have found highly toxic to fall armyworm larvae, as these insecticides demonstrated high larval mortality compared to other insecticides. These insecticides also demonstrated a significant reduction in leaf damage compared to untreated control, which is attributed to reduced number of larvae in treated plants. Consequently, higher grain yields were recorded in these insecticides treated plots compared to untreated control.

As is common with other insect pest species, synthetic insecticides are important management options in fall armyworm control in the Americas (Andrews 1988) [18]. In Florida, fall armyworm is one of the most important sweetcorn pests, and synthetic insecticides are applied against this pest to protect both the vegetative stages and reproductive stage of corn (Capinera, 2017) [19]. Hardke *et al*., (2011) [20] evaluated field efficacy of newer compounds and with conventional insecticides which were recommended against fall armyworm. At 3 DAT Chlorantraniliprole (10.0%), cyantraniliprole (12.5%), and novaluron (15.0%) significantly reduced fall armyworm infested whorls compared to that in the non-treated control plots (50.0%). At 7 DAT newer compounds *viz*., chlorantraniliprole, cyantraniliprole, and flubendiamide reduced fall armyworm infestations by 2.5-fold below that in the non-treated control. Similarly Smith (2009) [21] evaluated efficacy of insecticide against fall armyworm in maize, At 3 DAT lannate was found very effective in reducing the fall armyworm larva population. At 15 DAT Coragen and Diamond were found most effective. In Mexico the application of methyl parathion, chlorpyrifos, methamidophos and phoxim were found effective in control of fall armyworm on Maize (Malo *et al*., 2004) [22].

In 2019, Worku and Ebabuye [23] evaluated field efficacy of insecticides against fall armyworm, chlorpyriphos ethyl (48.99), profenaphos+ lamdacyhalothrin (44.99), profenaphos+ cypermethrin (47.99), spinosad (39.99) and indoxacarb (37.99) recorded maximum larval mortality. Similarly in 2012 Belay *et al*., [24] recorded more than 60% mortality of fall armyworm, when fall armyworm exposed Radiant, Orthene, and Larvin. In Ethiopia, fall armyworm was effectively controlled using insecticides *viz*., spinetoram, chlorantraniliprole, spinosad and lambda cyhalothrin (Sisay *et al*., 2019) [25]. In another study intrepid 2 F, Lannate 2.4 LV, Sevin XLR Plus 4 F, and Tracer 4 SC effectively reduced fall armyworm larvae under field condition (Daves *et al*., 2009) [26].

In 2016, the invasion of fall armyworm caused damage to crops in over 20 African countries and as an emergency response multiple pesticide spraying program was recommended in fall armyworm affected areas, mainly to maize fields to protect against crop damage and prevent the expansion of the pest. In recent surveys conducted in Kenya and Ethiopia, it has been noted that farmers are applying different types of unregistered synthetic insecticides (Kumela *et al*., 2018) [27]. The recent invasion of fall armyworm has alarmed maize growing farming community of India and as an emergency control approach Ministry of Agriculture, Govt. of India suggests (as adhoc recommendation) application of insecticide *viz*., spinetoram, chlorantraniliprole possibly because of the invasive nature of the pest, which requires a rapid response. In the present study several insecticides belonging to different chemical groups were found effective on the fall armyworm. Now, it provides wider options in the management of this dreaded pest. As it requires multiple rounds of insecticide applications, spraying of insecticides with different modes of action would go a long way in delaying the development of resistance.

Table 2: Efficacy of insecticides on larvae of *Spodoptera frugiperda* in maize

Treatments	Pooled mean of number of larvae/plant (average of 10 plants)							Percent reduction over control	
	Pre-treatment population	Spray I			Spray II				
		7 DAT	14 DAT	Mean	7 DAT	14 DAT	Mean	After Spray I	After Spray II
Spinetoram	1.43 (1.39)	0.18 (0.83)	0.08 (0.76)	0.13	0.07 (0.75)	0.00 (0.71)	0.03	91.21	97.32
Spinosad	1.47 (1.40)	0.38 (0.94)	0.23 (0.86)	0.31	0.17 (0.82)	0.07 (0.75)	0.12	79.61	89.57
Emamectin benzoate	1.45 (1.40)	0.50 (1.00)	0.32 (0.90)	0.41	0.25 (0.87)	0.15 (0.81)	0.20	72.65	82.37
Thiodicarb	1.40 (1.38)	0.45(0.97)	0.30 (0.89)	0.38	0.20 (0.84)	0.15 (0.81)	0.18	73.75	83.57
Azadirachtin 1%	1.38 (1.37)	0.98 (1.22)	0.82 (1.15)	0.90	0.63 (1.06)	0.53 (1.02)	0.58	36.93	46.28
Lambda cyhalothrin	1.45 (1.40)	0.85 (1.16)	0.70 (1.10)	0.78	0.52 (1.01)	0.38 (0.94)	0.45	47.98	60.33
Indoxacarb	1.40 (1.38)	0.72 (1.10)	0.48 (0.99)	0.60	0.42 (0.96)	0.27 (0.88)	0.34	58.55	68.96
Chlorpyriphos	1.37 (1.37)	0.98 (1.22)	0.70 (1.10)	0.84	0.53 (1.02)	0.52 (1.01)	0.53	40.70	50.55
Bt insecticide	1.50 (1.41)	0.70 (1.10)	0.57 (1.03)	0.63	0.48 (0.99)	0.40 (0.95)	0.44	59.38	62.50
Novaluron	1.48 (1.41)	0.25 (0.87)	0.15 (0.81)	0.20	0.12 (0.79)	0.05 (0.74)	0.08	86.93	93.09
Chlorantraniliprole	1.47 (1.40)	0.38 (0.94)	0.22 (0.85)	0.30	0.15 (0.81)	0.07 (0.75)	0.11	80.26	90.43
Untreated control	1.47 (1.40)	1.82 (1.52)	1.22 (1.31)	1.52	1.23 (1.32)	1.07 (1.25)	1.15	-	-
S.Em (±)	0.01	0.01	0.009	-	0.008	0.009	-	-	-
CD (*P*= 0.05)	0.03	0.03	0.02	-	0.02	0.02	-	-	-
CV (%)	1.50	1.68	1.62	-	1.60	1.82	-	-	-

*DAT: Days after treatment

Table 3: Efficacy of insecticides on leaf damage (per cent) caused by *Spodoptera frugiperda* in maize

Treatments	Pooled mean of per cent leaf damage/plant (average of 10 plants)							Percent reduction over control	
	Pre-treatment population	Spray I			Spray II				
		7 DAT	14 DAT	Mean	7 DAT	14 DAT	Mean	After Spray I	After Spray II
Spinetoram	56.67 (48.83)	21.67 (27.74)	13.00 (21.13)	17.33	8.50 (16.95)	4.50 (12.24)	6.50	74.20	90.93
Spinosad	58.67 (49.99)	26.33 (30.87)	20.00 (26.57)	23.17	14.83 (22.65)	9.00 (17.45)	11.92	66.68	83.93
Emamectin benzoate	56.50 (48.74)	27.17 (31.41)	24.00 (29.33)	25.58	18.17 (25.23)	12.00 (20.27)	15.08	61.80	78.89
Thiodicarb	55.67 (48.25)	25.00 (30.00)	21.83 (27.86)	23.42	16.50 (23.96)	10.83 (19.22)	13.67	64.50	80.57
Azadirachtin 1%	56.83 (48.93)	46.67 (43.09)	50.67 (45.38)	48.67	43.17 (41.07)	32.00 (34.45)	37.58	27.73	47.69
Lambda cyhalothrin	59.00 (50.19)	38.67 (38.45)	45.00 (42.13)	41.83	36.50 (37.17)	26.17 (30.77)	31.33	40.17	57.99
Indoxacarb	55.50 (48.16)	31.17 (33.93)	31.83 (34.35)	31.50	29.33 (32.79)	19.83 (26.45)	24.58	52.11	64.96
Chlorpyriphos	54.83 (47.77)	45.00 (42.13)	47.00 (43.28)	46.00	38.17 (38.15)	29.00 (32.58)	33.58	29.21	51.55
Bt insecticide	55.33 (48.06)	32.67 (34.86)	44.17 (41.65)	38.42	27.83 (31.84)	21.83 (27.86)	24.83	41.41	64.50
Novaluron	57.67 (49.41)	24.83 (29.89)	18.33 (25.35)	21.58	13.83 (21.83)	8.00 (16.42)	10.92	68.42	85.02
Chlorantraniliprole	56.17 (48.54)	26.83 (31.20)	20.00 (26.56)	23.42	15.50 (23.18)	9.50 (17.95)	12.50	64.82	82.40
Untreated control	59.00 (50.19)	63.67 (52.93)	76.17 (60.78)	69.92	74.83 (59.89)	74.33 (59.56)	74.58		
S.Em (±)	0.007	0.006	0.006		0.006	0.007			
CD (*P*= 0.05)	0.02	0.02	0.01		0.01	0.02			
CV (%)	1.45	1.93	1.70		2.04	3.01			

* DAT: Days after treatment

Table 4: Effect of insecticide application on grain yield of maize

Treatments	Yield (q/ha)
Spinetoram	33.48
Spinosad	30.29
Emamectin benzoate	29.18
Thiodicarb	29.57
Azadirachtin 1%	22.33
Lambda cyhalothrin	24.43
Indoxacarb	26.94
Chlorpyriphos	23.98
Bt insecticide	25.92
Novaluron	32.07
Chlorantraniliprole	31.13
Untreated control	19.45
S.Em (±)	0.09
CD (*P*= 0.05)	0.26
CV (%)	0.60

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