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CP Mallapur
Department of Agricultural Entomology, University of Agricultural Sciences, Dharwad Karnataka, India

Anjan Kumar Naik
Department of Agricultural Entomology, University of Agricultural Sciences, Dharwad Karnataka, India

Sireesh Hagari
Department of Agricultural Entomology, University of Agricultural Sciences, Dharwad Karnataka, India

Praveen T
Department of Agricultural Entomology, University of Agricultural Sciences, Dharwad Karnataka, India

Manjunath Naik
Department of Agricultural Entomology, University of Agricultural Sciences, Dharwad Karnataka, India

Correspondence
CP Mallapur
Department of Agricultural Entomology, University of Agricultural Sciences, Dharwad Karnataka, India

Laboratory and field evaluation of new insecticide molecules against fall armyworm, *Spodoptera frugiperda* (J. E. Smith) on maize

CP Mallapur, Anjan Kumar Naik, Sireesh Hagari, Praveen T and Manjunath Naik

Abstract
Fall armyworm, *Spodoptera frugiperda* (Noctuidae: Lepidoptera) has become a serious pest in maize after its introduction to India. In order to evaluate the efficacy of certain selected newer insecticide molecules both laboratory and field experiments were conducted at Dharwad, Karnataka during 2018. The laboratory results revealed that spinetoram 11.7 SC and emamectin benzoate 5 SG were significantly superior over other treatments with cent per cent mortality at 60 hours after treatment. The field trial also indicated that spinoteram, emamectin benzoate and spinosad 45 SC were significantly superior over all other treatments with the larval reduction of 98.13, 96.26 and 96.26 per cent, respectively at 7 days after treatment imposition. Among other tested molecules, thiamethoaxam 0.25%WG and fipronil 0.5 SC were least effective (68.65 and 73.14% mortality, respectively).

Keywords: Fall armyworm, *Spodoptera frugiperda,* spinetoram, emamectin benzoate

1. Introduction
Maize being called "Queen of cereals" is one of the important cereal as well as commercial crop in India. This crop is mainly used as food, fodder, fuel, poultry feed and for baby food production. The cultivation of this crop is relatively easy and quite remunerable requiring less crop protection measures. Maize is affected by as many as 141 insect pests (Reddy and Trivedi, 2008) [17]. Among these, only few are considered as major pests in India *viz*., shoot fly, stem borers, armyworm (*Mythimna separata*) and *Helicoverpa armigera*. However, the recent invasion of the fall armyworm, *Spodoptera frugiperda* (Noctuidae: Lepidoptera) has become a great threat for maize cultivation in northern Karnataka causing damage ranging from 0 to 100 per cent on maize crop (Mallapur *et al*., 2018) [14].
The pest being native to South America, has spread to many other countries such as, West Africa and Sub-Saharan Africa (Goergen [8], Kumar; 2016) [12]. Recent reports confirmed the occurrence of fall armyworm in 28 other countries of Africa (Cock *et al*., 2017 and Day *et al*., 2017) [4, 6]. Although the pest has been reported for the first time in Asia that too in India during 2018 (Sharanabasappa *et al*., 2018) [19], it has already spread to Thailand (FAO, 2018[7]) and Bangladesh and Srilanka (Anon., 2018) [2]. Agriculture experts believe that the pest has also reached Myanmar and China. The fast and wide spread of this pest is mainly attributed to its strong flying ability, higher fecundity and polyphagous nature having ample number of alternate hosts (Abrahams *et al*., 2017; Day *et al*., 2017) [1, 6] coupled with the availability of host crops throughout the year. Yield losses up to 34 per cent have been observed by Carvallo *et al*., 1970 [3]; Williams and Davis, 1990 [22] and Cruz, 1996 [5].

2. Materials and Methods
Owing to the extent of loss caused by fall armyworm in maize, an attempt has been made to curtail its menace by using effective insecticide molecules. Both laboratory and field evaluation of newer insecticides (Table 1) were undertaken during late *kharif* 2018 at Department of Agricultural Entomology, University of Agricultural Sciences, Dharwad and on farmers field at Hosatti village of Dharwad district.
Under laboratory condition, fourteen insecticides were evaluated by following completely randomized design (CRD) with three replications. For this purpose, laboratory reared second instar larvae of *S. frugiperda* were used. Pieces of fresh tender maize leaves were subjected to

insecticidal spray. Treatment were imposed using potter tower and then shade dried. For each treatment, 10 larvae per replication were released into petriplates containing treated maize leaves. After 24 hours, normal fresh maize leaves were provided until the larvae die or undergo pupation. Observations were recorded on larval mortality at 12 hours interval up to 72 hours.

The same chemicals were also evaluated against the fall armyworm under field condition by selecting severely infested maize field. The experiment was conducted with 15 treatments replicated thrice in randomized complete block design (RCBD). Single insecticidal application was made by directing the spray towards leaf whorl. The observations were recorded on number of live larvae on one day before spray and one, three, five and seven days after the spray. Observations were also taken on per cent leaf damage before spray and after seven days of application. The data were subjected to statistical analysis for interpretation.

3. Results and Discussions

3.1 Laboratory evaluation

Data from table 2 indicated that at 12 hours after release of larvae onto the treated leaves, the mortality ranged between 37.29 to 62.71 per cent in different treatments. Highest mortality was recorded in lambda cyhalothrin + chlorantriniliprole treatment (62.71%) which was significantly superior over all other treatments. All other treatments were on par with each other, mortality range being 37.29 to 57.63 per cent. However, no mortality was observed in untreated control. After 24 hours of treatment, lambda cyhalothrin + chlorantriniliprole, spinosad, emamectin benzoate and spinetoram stood on par with each other (81.04, 75.86, 75.86 and 75.86%mortality, respectively). These treatments were followed by chorantraniliprole (74.14%) and cyantriniliprole (60.35% mortality). The least mortality was observed in Chlorfenapyr 10 SC (46.55%), fipronil 5 SC (50.00%) and novaluron (50.00%).

As high 87.72 per cent mortality was recorded in spinetoram, lambda cyhalothrin + chlorantriniliprole at 36 hours of treatment followed by emamectin benzoate (82.46%) which were on par with each other and significantly superior over all other treatments. These were followed by spinosad (78.95%) and chorantraniliprole (78.90%). However, after 48 hours, spinosad recorded 96.55 per cent mortality followed by spinetoram, lambda cyhalothrin + chlorantriniliprole and emamectin benzoate (89.66 to 91.38% mortality) which were on par among each other. Next best treatment was Lassenta which recorded 87.93 per cent mortality. Thiodicarb and flubendiamide treatments recorded 77.59 per cent mortality.

Cent per cent mortality was recorded in spinosad treatment which was significantly superior over other treatments at 60 hours after treatment. Spinetoram, emamectin benzoate, lambda cyhalothrin + chlorantriniliprole, chlorantriniliprole 18.5 SC and lessanta were the next best treatments with per cent mortality of 96.49, 94.74, 92.98, 91.23 and 91.23, respectively. Flubendiamide, novaluron and cyantriniliprole were on par with each other (78.95 to 82.46%). Similarly, at 72 hours of release, spinetoram, emamectin benzoate, chlorantriniliprole and lambda cyhalothrin + chlorantriniliprole registered 98.28, 96.55, 94.83 and 94.83 per centmortality, respectively. Next to follow were lessanta and cyantriniliprole treatments (93.10 and 87.93%) followed by flubendiamide, lambda cyhalothrin and novaluron with 84.48,84.48 and 82.76 per cent mortality, respectively. However, the thiomethoxam treatment was least effective against fall armyworm (56.90% mortality).

3.2 Field evaluation:

The average number of larvae per 25 plants on one day before spray ranged between 40.33 to 46.33 among various treatments (Table 3). After one day of spray imposition, all the treatments were significantly superior over the untreated control. The lowest population was recorded in spinetoram (2.33 larvae/25 plants) and found to be superior over other treatments followed by emamectin benzoate (3.67 larvae/25 plants). Whereas, spinosad, lessanta, cyantraniliprole, flubendiamide and lambda cyhalothrin + chlorantriniliprole treatments were on par with each other with the larval population of 8.67, 6.67, 7.67, 6.67 and 7.67, respectively. However, maximum numbers of larvae were noticed in chlorantraniliprole, thiomethoxam, thiodicarb, fipronil and clothianidin treatments (12.23 to 16.67larvae). The per cent reduction of population over day before spay was highest in spinetoram followed by emamemctin benzoate (91.73). However, spinosad, imidaclopride + fipronil, cyantriniliprole, flubendiamide and lambda cyhalothrin + chlorantriniliprole also recorded 79.20 to 83.87 per cent reduction. Whereas, least reduction of population was observed in thiomethaxam, chlorantraniliprole, thiodicarb, fipronil, novaluron, chlorfenapyr and clothianidin (59.02 to 73.38%).

Observations at three days after spray indicated that spinetoram was significantly superior over other treatments with larval population of 2.33 and treatments such as emamectin benzoate, spinosad, cyantraniliprole, imidacloprid + fipronil, lambda cyhalothrin + clorantraniliprole were on par with the larval population of 3.33, 4.33, 4.33, 4.67, 4.33, respectively. However, thiomethaxam, fipronil and chlorantraniliprole treatments recorded 14.33, 12.67 and 12.67 larvae per 25 plants, respectively. Highest per cent reduction of population was observed in spinetoram (97.5), emamectine benzoate (96.37), cyantriniliprole (94.81), lambda cyahalothrin + chlorantriniliprole (94.79), spinosad (94.53) and imidacloprid + fipronil (94.44). Similarly, spinetoram and spinosad were significantly superior over other treatments and were on par with emamectin benzoate at 5 days of treatment application with the larval population of 1.67, 1.67 and 2.33, respectively followed by imidacloprid + fipronil (3.33 larvae / 25 plants). Cyantraniliprole and lambda cyhalothrin + clorantraniliprole were on par with each other (3.67 larvae). Other treatments recorded maximum number of larvae ranging between 5.67 and 15.33 per 25 plants compared to 41.33 larvae in untreated control. The highest per cent reduction of larvae was observed in spinetoram (98.29) and spinosad (98.24) treatments followed by emamectin benzoate (97.58). However, the least larval reduction was observed in chlorfenapyr treatment (82.68%) followed by chlorantraniliprole (82.71%).

Among all the insecticides evaluated, spinetoram was significantly superior with 0.67 number of larvae per 25 plantsat seven days after treatment. Spinosad, emamectin benzoate, imidacloprid + fipronil and cyantrniliprole were on par with each other with the larval population of 1.33, 1.33, 2.33 and 2.33 larvae/ 25 plants, respectively. Remaining treatments registered higher larval population 3.33 to 6.67 larvae/ 25 plants). Spinetoram treatment recorded highest reduction over untreated control (98.13%) at seven days followed by emamectin benzoate and spinosad(96.26%). Cyantraniliprole and imidacloprid+fipronil recorded 93.46per cent whereas, clothianidin and lambda cyhalothrin + clorantraniliprole recorded 90.66 per cent reduction over control. However, least reduction was recorded in fipronil treatment (73.13%) [Table 3].

As the literature pertaining to efficacy of different insecticides on *S. frugiperda* is limited, the related information on other lepidopteran pests have been reviewed. The efficacy studies revealed that spinoteram, emamectin benzoate and spinosad recorded significantly higher mortality ranging from 90.40 to 96.22 and 98.28 to 100 per cent under *in vitro* and *in vivo* condition, respectively. The present study corroborates the reports of Kumar and Muthukrishnan (2017) [13] who observed 69.00 to 84.40 per cent reduction of *Spodoptera litura* using spinetoram 12 SC at varying doses in ground nut. Similarly, Vishnupriya and Muthukrishnan (2017) [21] observed 72.4 to 83.9 per cent reduction of *Helicoverpa armigera* in okra. Kumar *et al*. (2015) [12] observed 72.82 to 91.88 per cent mortality of *S. litura* in emamectin benzoate 5 SG 0.005 per cent treated groundnut plots. The mortality among the different dosages of emamectin benzoate ranged from 94.30 to 100and 88.10 to 100 per cent at 10 and 15 days after spray, respectively (Kambrekar *et al.*, 2012) [10]. Similarly, three sprays of spinosad 45 SC at 200g/ha resulted in 80.33 and 80.88 per cent reduction of *S. litura* population during successive years in cabbage (Jat *et al.*, 2017) [9].Under laboratory conditions, Sanjeevikumar and Muthukrishnan (2017) [18] and Muthukrishnan *et al.* (2013) [15] observed that spinetoram 12 SC at 0.14 ml/l resulted in 98.86 and 99.10 per cent mortality of *Exelastis atomosa* and *S. litura*, respectively. Similarly, Karthik *et al.* (2018) [11] and Rabari *et al.* (2016) [16] observed 100 and 87.49 per cent mortality of *H. armigera* and *S. litura* with emamectin benzoate 5 SG and spinosad 45 SC, respectively.

Table 1: Treatment details

Tr. No.	Insecticide	Trade name	Dosage (ml or g/l)
T1	Spinosad 45 SC	Tracer	0.20
T2	Fipronil 5 SC	Regent	1.00
T3	Novaluron 10 EC	Rimon	1.00
T4	Chlorfenapyr 10 SC	Intripid	2.00
T5	Thiomethaxam 0.25%WG	Actara	0.25
T6	Imidacloprid 40% + Fipronil 40% (80WG)	Lessanta	0.20
T7	Clothianidin 50 WDG	Dantop	0.75
T8	Thiodicarb 75 WP	Larvin	1.00
T9	Cyantraniliprole10.26 OD	Cyaziper	0.30
T10	Flubendiamide 39.35 SC	Fame	0.10
T11	Lambda cyhalothrin 4.6 + Chlorantrinilliprole 9.3 ZC	Ampligo	0.50
T12	Spinetoram 11.7 SC	Delegate	0.50
T13	Chlorantraniliprole18.5SC	Coragin	0.20
T14	Emamectin benzoate 5 SG	Proclaim	0.20
T15	Control	-	-

Table 2: Evaluation of selected insecticides against fall armyworm, *Spodoptera frugiperda* under laboratory condition

		Per cent mortality of larvae					
	Treatment	12 hr	24 hr	36 hr	48 hr	60 hr	72 hr
1	Spinosad 45 SC	57.63 (24.73)^{abc}	75.86 (28.66)^{a}	78.95 (29.33)^{ab}	96.55 (32.58)^{ab}	100 (33.21)^{a}	100 (33.21)a
2	Fipronil 5 SC	40.68 (20.70)^{de}	50.00 (23.18)^{cd}	50.88 (16.00)^{e}	65.52 (20.00)^{cd}	75.44 (23.00)^{def}	79.31 (24.00)^{d}
3	Novaluron 10 EC	42.37 (21.12)^{de}	50.00 (23.18)^{cd}	59.65 (18.50)^{cde}	75.86 (23.00)^{bc}	80.70 (24.50))^{de}	82.76 (25.00)^{cd}
4	Chlorfenapyr 10 SC	47.46 (22.38)^{cde}	56.90 (24.73)^{bc}	63.16 (19.50)^{cde}	77.59 (23.50)^{bc}	84.21 (25.50)^{bcd}	84.48 (25.50)^{cd}
5	Thiomethaxam 0.25%WG	37.29 (19.82)^{e}	46.55 (22.38)^{d}	52.63 (16.50)^{de}	53.45 (16.50)^{e}	54.39 (17.00)^{g}	56.90 (17.50)f
6	Imidacloprid 40% + Fipronil 40% (80WG)	42.37 (21.12)^{de}	51.73 (23.57)^{bcd}	66.67 (20.50)^{bcd}	87.93 (26.50)^{b}	91.23 (27.50))^{abc}	93.10 (28.00)^{ab}
7	Clothianidin 50 WDG	45.76 (21.97)^{de}	51.73 (23.57)^{bcd}	54.39 (17.00)^{de}	62.07 (19.00)^{de}	66.67 (20.50)^{f}	72.41 (22.00)^{e}
8	Thiodicarb 75% WP	47.46 (22.38)^{cde}	50.00 (23.18)^{cd}	54.39 (24.35)^{de}	65.52 (26.57)^{de}	66.67 (28.32)^{f}	70.69 (27.62)^{e}
9	Cyantraniliprole10.26 OD	50.85 (23.18)^{bcd}	60.35 (25.47)^{b}	73.68 (22.50)^{abc}	77.59 (23.50)^{b}	78.95 (24.00)^{de}	87.93 (26.50)^{bc}
10	Flubendiamide 39.35 SC	42.37 (21.08)^{de}	50.00 (23.18)^{cd}	50.88 (16.00)^{e}	77.59 (23.50)^{b}	82.46 (25.00)^{cde}	84.48 (25.50)^{cd}
11	Lambda cyhalothrin4.6 + Chlorantrinilliprole9.3 ZC	62.71 (25.84)^{a}	81.04 (29.66)^{a}	87.72 (26.50)^{a}	91.38 (27.50)^{a}	92.98 (28.00)^{ab}	94.83 (28.50)^{ab}
12	Spinetoram 11.7 SC	57.63 (24.73)^{abc}	75.86 (28.65)^{a}	87.72 (30.98)^{a}	91.38 (31.63)^{a}	96.49 (32.58)^{a}	98.28 (32.90)^{a}
13	Chlorantraniliprole18.5SC	61.02 (25.47)^{ab}	74.14 (28.32)^{ab}	78.90 (29.33)^{ab}	84.40 (30.33)^{ab}	91.23 (31.63)^{abc}	94.82 (32.27)^{ab}
14	Emamectin benzoate 5 SG	57.63 (24.73)^{abc}	75.86 (28.66)^{a}	82.46 (30.00)^{a}	89.66 (31.31)^{a}	94.74 (32.27)^{a}	96.55 (32.58)^{a}

15	Untreated control	0.00 (2.87)^{f}	0.00 (5.74)^{e}	0.00 (1.50)^{f}	0.00 (1.00)^{f}	0.00 (1.50)^{h}	0.00 (1.00)^{g}
C.D.		2.992	1.77	2.691	2.135	1.68	0.898
C.V.		6.698	3.516	5.047	3.724	2.837	1.502

Figures within the parenthesis are arc sign transformed values.
In a column, mean followed by same alphabet (s) do not differ significantly by DMRT (P = 0.05).

Table 3: Field efficacy of selected insecticides against fall armyworm on maize

Tr. No	Treatments	Larval count per 25 plants										Larval reduction (%)**
		DBS	1 DAS	Larval reduction (%)*	3 DAS	Larval reduction (%)*	5 DAS	Larval reduction (%)*	7 DAS	Larval reduction (%)*	Mean larval count	
1	Spinosad 45 SC	41.67	8.67 (3.03)^{e}	79.20	4.33 (2.20)^{ef}	94.53	1.67 (1.47)^{h}	98.24	1.33 (1.35)^{gh}	98.64	4.00	96.26
2	Fipronil 5 SC	40.33	14.67 (3.89)^{bc}	63.64	12.67 (3.63)^{bc}	80.10	9.33 (3.14)^{bc}	88.35	6.67 (2.68)^{bc}	92.45	10.83	81.31
3	Novaluron 10 EC	37.67	12.33 (3.58)^{cd}	67.26	9.67 (3.19)^{cd}	85.63	8.33 (2.97)^{cd}	90.27	5.33 (2.42)^{cd}	94.09	8.92	85.05
4	Chlorfenapyr 10 SC	42.33	11.67 (3.56)^{d}	72.44	9.67 (3.26)^{cd}	77.17	7.33 (2.85)^{cd}	82.68	5.67 (2.58)^{cd}	86.61	8.75	84.11
5	Thiomethaxam 0.25%WG	40.67	16.67 (4.14)^{b}	59.02	14.33 (3.85)^{b}	75.71	11.67 (3.49)^{bc}	84.59	8.33 (2.97)^{b}	90.15	12.75	76.64
6	Imidacloprid 40% + Fipronil 40% (80WG)	41.33	6.67 (2.68)^{e}	83.87	4.67 (2.27)^{e}	94.44	3.33 (1.96)^{g}	96.47	2.33 (1.68)^{fg}	97.58	4.25	93.46
7	Clothianidin 50 WDG	46.33	12.33 (3.58)^{cd}	73.38	7.33 (2.80)^{d}	90.01	6.33 (2.61)^{de}	92.96	3.33 (1.96)^{ef}	96.41	7.33	90.66
8	Thiodicarb 75% WP	41.67	15.67 (4.02)^{bc}	62.40	9.33 (3.14)^{cd}	85.04	7.67 (2.86)^{cd}	90.98	4.67 (2.27)^{de}	94.87	9.33	86.92
9	Cyantraniliprole10.26 OD	46.33	7.67 (2.86)^{e}	83.45	4.33 (2.20)^{ef}	94.81	3.67 (2.04)^{fg}	96.13	2.33 (1.68)^{fg}	97.57	4.50	93.46
10	Flubendiamide 39.35 SC	40.67	6.67 (2.68)^{e}	83.61	7.67 (2.86)^{d}	90.83	5.67 (2.48)^{ef}	93.76	4.67 (2.27)^{de}	95.02	6.17	86.92
11	Lambda cyhalothrin 4.6 + Chlorantrinilliprole 9.3 ZC	45.67	7.67 (2.86)^{e}	83.21	4.33 (2.20)^{ef}	94.79	3.67 (2.04)^{fg}	96.13	3.33 (1.96)^{ef}	96.53	4.75	90.66
12	Spinetoram 11.7 SC	46.33	2.33 (1.68)^{f}	94.96	2.33 (1.68)^{f}	97.54	1.67 (1.47)^{h}	98.29	0.67 (1.08)^{h}	99.32	1.75	98.13
13	Chlorantraniliprole18.5SC	44.33	16.67 (4.20)^{b}	62.41	12.67 (3.69)^{bc}	71.43	7.67 (2.94)^{cd}	82.71	3.33 (2.06)ef	92.48	10.08	72.90
14	Emamectin benzoate 5 SG	44.33	3.67 (2.04)^{f}	91.73	3.33 (1.96)^{ef}	96.37	2.33 (1.68)^{gh}	97.58	1.33 (1.35)^{gh}	98.63	2.67	68.23
15	Untreated control	45.67	40.33 (6.39)^{a}	11.68	39.33 (6.31)^{a}	13.87	41.33 (6.47)^{a}	9.49	35.67 (6.01)^{a}	35.67		96.26
C.D.			0.15		0.16		0.15		0.13			
C.V.			7.65		9.24		8.93		9.09			

Note: * : Reduction over DBS ** : Reduction over Untreated control DBS : Day before spray DAT – Days after treatment
Figures within the parenthesis are square root transformed values.
In a column, mean followed by same alphabet (s) do not differ significantly by DMRT (P = 0.05).

4. Conclusion

Present study was implied to know the effectiveness of certain selected insecticides both under field and laboratory condition against the invasive pest fall armyworm. The results revealed that spinetoram recorded 98.13 per cent reduction over control at seven days after treatment followed by emamectin benzoate and spinosad recording 96.26 per cent reduction while, thiamethoaxam 0.25%WG and fipronil 0.5 SC were least effective (68.65 and 73.14% mortality, respectively).

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