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RESEARCH ARTICLE

Acute and Persistent Toxicity of Newer Insecticide Molecules Against Invasive Pest of Maize, Fall Armyworm *Spodoptera frugiperda* (J.E.Smith)

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ABSTRACT

Laboratory and pot culture experiments were conducted to assess the acute and persistent toxicity of new molecular insecticides against the notorious invasive pest of maize, *Spodoptera frugiperda* during 2020-2021 at Department of Agricultural Entomology, Tamil Nadu Agricultural University, Coimbatore. Results revealed that, the LC_{50} value of emamectin benzoate, chlorantraniliprole, spinetoram, flubendiamide and novaluron were 0.05, 4.08, 0.1, 85.89 and 0.91 ppm, respectively for second instar larvae and 0.03, 5.63, 0.02, 162.99 and 0.99 ppm for third instar larvae of fall armyworm. Among insecticides tested emamectin benzoate and spinetoram showed high toxicity to *S. frugiperda* than other insecticides by registering a minimum LC_{50} value. But in the persistent toxicity studies, the same insecticides showed less persistence on maize crop. Hence, insecticides like flubendiamide and chlorantraniliprole need to be recommended in the early stage of the crop period (within 20 days after sowing) and less persistent insecticides *viz.,* emamectin benzoate and spinetoram should be recommended in the middle stage (25 to 40 days) of the maize crop for the management of *S. frugiperda* so that the residues may not accumulate in the harvested produce both in the stalk and grain.

Keywords: *Maize; Spodoptera frugiperda; Baseline study; Acute toxicity; Persistent toxicity.*

INTRODUCTION

Maize (*Zea mays* L.) is one of the extensively cultivated crops occupying around 180.63 m ha in 165 countries worldwide (APEDA, 2019). It is the third most important cereal crop after rice and wheat in India is extensively used for food, feed, fodder and raw material for industrial applications (Rakshit, *et al.,* 2017). Maize is mostly grown as rainfed crop in tropical and sub- tropical conditions and the productivity (3.1 tonnes/ha) is much lower than the world average (5.62 tonnes/ha) (Rakshit and Chikkappa, 2018). Among various factors responsible for the low productivity of maize, insect pests contribute to the maximum loss. This crop is encountered by more than 141 insect pest species causing a different level of damage, of which only two pests *viz.,* spotted stem borer (*Chilo partellus* Swinhoe), and shoot fly (*Atherigona* spp.) were causing major damage to the crop (Suby *et al.,* 2020). These pests were managed by the structured package of practices and timely application of insecticides. However, recent invasion of polyphagous lepidopteran pest fall armyworm (FAW), cause serious disturbance in maize crop and heavily affecting the productivity of the crop.

Fall armyworm (FAW; *Spodoptera frugiperda* (J. E. Smith)) is a notorious pest, native to America and spread across the North and South American continent, causing severe economic losses in a variety of crops such as rice, cotton, maize, soybean and feeds on a number of weeds (Nabity *et al.* 2011, Bueno *et al.* 2010; Pogue 2002; Nagoshi *et al.* 2007). *S. frugiperda* is a sporadic migratory pest, adult moths can travel several miles continent migration within a day or week (Westbrook *et al.,* 2016; Early *et al.,* 2018). There are two different

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strains infesting crops belongs to Poaceae, primarily on maize, rice and fodder grasses (Dumas *et al.,* 2015). There are about 353 host plants recorded as alternate host plants for *S. frugiperda* (Montezano *et al.,* 2018). This pest invaded Africa during 2016 (Goergen *et al.,* 2016) and Asia during 2018 and is threatening food security of the millions of people. In India FAW has been reported first in the state of Karnataka (Shylesha *et al.,* 2018; Sharanabasappa *et al.,* 2018a) followed by Andhra Pradesh, Madhya Pradesh, Maharashtra, Tamil Nadu, Telangana, Gujarat and Chhattisgarh (Mahadevaswamy *et al.* 2018; Sisodiya *et al.* 2018; Sonali Deole and Nandita Paul, 2018). In the absence of natural biological control, fall armyworms can cause significant yield loss in maize and other crops (Kebede and Shimalis, 2019).

Insecticides are used as a prime tool in fall armyworm management in western countries (Tomquelski and Martins 2007; Sisay *et al.* 2019). Farmers in the invaded area were not prepared for this devastating pest, resulting in heavy losses on one hand and a drastic increase of insecticide use on the other (Kansiime *et al.,* 2019). Use of insecticide cocktails and over dose of insecticide in the maize ecosystem to manage the notorious invasive pest is common among the maize growing farmers in the FAW infested areas. After intensive discussion with the State Agricultural Universities, the Central Insecticide Board and Registration Committee (CIBRC) of Government of India had given the *ad-hoc* recommendation for the management of FAW during 2019. There is no baseline data available for any of the insecticides used for the management of FAW in India. Hence, this study was conducted to develop the baseline toxicity and persistence toxicity data for the important and effective insecticides used for the FAW management to optimize the dose and accommodate the right insecticide in the right stage of the crop.

MATERIAL AND METHODS

Target Insect:

Second and third instar larvae of *S. frugiperda* were used for the bioassay study. Larvae of uniform age group were taken from the fall armyworm mass culture laboratory, Department of Agricultural Entomology, Tamil Nadu Agricultural University, Coimbatore where the insects were reared on the specially prepared *lab lab* based semi synthetic diet (composition pending patent). Three hundred uniform - sized larvae were obtained per bioassay. Totally 32 bioassays were conducted for the range finding test, baseline susceptibility study and persistent toxicity study in which more than ten thousand larvae (both second and third instar larvae) were utilized for the study.

Insecticides

Five newer insecticides *viz.,* emamectin benzoate 5 SG, chlorantraniliprole 18.5 SC, spinetoram 11.7 SC, flubendiamide 20 WG and novaluron 10 EC were used for this study. These insecticides were selected based on the *ad-hoc* recommendation of the CIBRC, Government of India for the management of *S. frugiperda* on maize in India. All the formulations were purchased from the pesticide dealers in Coimbatore. The insecticide dilution required for various bioassays were freshly prepared by dissolving the required quantity of insecticide formulations in water.

Baseline susceptibility of the FAW to different insecticides

Six well bio assay tray was used for the bioassay study. Tender maize leaves were taken from the field, washed under tap water, and sandwiched gently in blotting paper to remove the water. Leaf discs of 5 cm diameter were taken from the leaves using a metal lid. To sustain the turgidity of the leaf in the bioassay plate, one per cent agar medium was added in to the bioassay plates up to 0.5 cm thick layer. This was prepared by adding 1 gm agar to 99 mL water and dispersing the agar properly by constant stirring. The solution was heated until boiling, allowed to cool until it reaches 65ºC after which 0.3 mL of anti-mould solution (4.5 mL phosphoric acid and 42 mL propionic acid to 53.5 mL water) was added.

A preliminary range finding test was conducted with laboratory-cultured populations of *S. frugiperda* with wide range of test insecticide to fix the test dose range causing 20 to 80 per cent mortality approximately. Based on this, 6 doses were fixed in geometric progression and working standards were prepared. Triton X 100 @ 0.01 % was added as surfactant. Leaf discs were dipped individually in the test liquid for 5 s with gentle agitation and placed on a paper towel for surface drying.

Each bioassay study was performed with seven treatments (six insecticide doses and one control) replicated thrice with ten insects in each replication. Thirty leaf discs were treated in each dilution. After treatment, the leaf discs were placed gently inside the well over the agar medium and one larva was

released per well. After release of larva the plate was covered with white muslin cloth to avoid the escape of the larva and kept undisturbed in the ambient environment (28ºC ± 5ºC and 75 ± 5 % RH). Untreated control was maintained by dipping the leaf disc in the distilled water over which larvae were released. After 24 hrs of exposure, live larvae were fed with untreated leaves. Larval mortality was recorded at 8 h interval up to 72 h after exposure period. A larva was considered dead if it failed to move in co-ordinated manner, when probed with camel hair brush. Based on the mortality in different insecticidal treatments, the LC_{50} value of insecticide was calculated (Finney, 1971) after applying the correction for the control mortality (Abbott, 1925).

$$\text{Per cent corrected mortality} = \frac{\text{\% Test mortality} - \text{\% Control mortality}}{(100 - \text{Percentage control mortality})}$$

Persistent toxicity of insecticides against S. frugiperda on maize

Pot culture experiment was conducted to assess the persistent toxicity of insecticides against FAW. One week old maize seedlings (grown under hydroponics) were transplanted on the 30 cm wide earthen pots @ 4 seedlings per pot. Fifteen days after transplanting (DAT) following insecticides were sprayed in X (recommended dose) and 2X dose (double the recommended dose) on the 20 potted plants each, respectively.

Insecticide	Concentration (per ha)		Test dose (per liter of water)	
	Active ingredient (g a.i./ha)	Formulation (g or mL/ha)	X dose	2X Dose
Emamectin benzoate 5% SG	10.0	200.0	0.4 g/lit	0.8 g/lit
Chlorantranilip -role 18.5% SC	40.0	200.0	0.4 mL /lit	0.8 mL /lit
Flubendiamide 20% WG	50.0	250.0	0.5 g/lit	1.0 g/lit
Spinetoram 11.7% SC	30.0	250.0	0.5 mL /lit	1.0 mL /lit
Novaluron 10% EC	75.0	750.0	1.5 mL /lit	3.0 mL /lit

Leaf samples were collected on 0 (2 hrs after spray), 1, 2, 3, 4, 5, 7, 10, 15, 20, 25 and 30 days after spray and bioassay was conducted. Six well bioassay tray was used for bioassay study. Two 3 cm leaf bits from each treatment were placed gently inside the well over the agar medium and one larva was released per well. After 24 hrs exposure live larvae were fed with untreated leaf. For each treatment thirty larvae were used and percent mortality of larva was observed on 24, 48 and 72 h after treatment.

RESULTS AND DISCUSSION

The results of the bioassay study performed for emamectin benzoate against *S. frugiperda* revealed that, the LC_{50} value is 0.05 ppm for second instar larva and 0.03 ppm for third instar larva. The LC_{99} and χ^2 value recorded were 7.51 & 6.40 and 2.23 & 0.37 respectively for second and third instar larva (Table 1). The slope of the baseline curve was almost equal (6.38 and 6.53) for two stages of the larva tested. The LC_{50} values of chlorantraniliprole against second and third instar larva of *S. frugiperda* were 4.08 and 5.63 ppm, respectively. The slope, LC_{99} and χ^2 value recorded was 4.38, 853.64 ppm and 0.12 for second instar larva and 4.35, 12.37.79 ppm and 1.55 for third instar larva. The values of LC_{50}, LC_{95} and LC_{99} values for flubendiamide against second instar larva of *S. frugiperda* were 85.89, 1648.38 and 5606.04 ppm and third instar larva were 162.99, 4821.66 and 19618.43 ppm, respectively. Spinetoram recorded LC_{50} values of 0.1 and 0.02 ppm for for second and third instar larva, respectively. The χ^2 value and slope of the baseline curve were 3.74 and 0.82, 5.69 and 7.05, respectively for second and third instar larva of *S. frugiperda*. Insect growth regulator novaluron recorded LC_{50} value of 0.91 and 0.63 ppm, LC_{95} value of 64.16 and 12.79 and LC_{99} value of 374.78 and 44.60 ppm, respectively.

The results of the persistent toxicity study revealed that, toxicity of emamectin benzoate persisted up to 10 days in the maize leaves and produced mortality of *S. frugiperda* larva (Table 2). More than 90 per cent mortality was observed during first four days after treatment in X dose, whereas in 2X dose cent percent mortality was observed during the same period. On 10 DAT, 6.67 and 10.0 per cent mortality was observed on 72 HAT in emamectin benzoate 5 SG @ X and 2X dose, respectively (Table 2). Chlorantraniliprole 18.5 SC persisted in the maize leaves up to 20 days in X dose and 25 days in 2X dose (Table 3).

It was observed that the toxicity of chlorantraniliprole 18.5 SC on the day of spraying was less than one day after spraying. Up to 5 DAT, more than 80 per cent mortality of the test population was observed which declined later.

The toxicity of flubendiamide 20 WG against the third instar larva of *S. frugiperda* remained up to 25 days after treatment (DAT) in both the doses but only 3.33 percent mortality in X dose and 16.67 percent mortality in 2x dose was observed during 72 hours after treatment (HAT) at 25 DAT (Table 4). Cent per cent mortality was observed up to 2 DAT at X dose and 3 DAT at 2X dose but in 2 X dose 90 per cent mortality was observed till 5 DAT. Toxicity of novaluron 10 EC was very less at 24 hours after exposure but it attained peak during 72 HAT (Table 5). Cent percent mortality of test population was observed up to 1 DAT in the plants treated with novaluron 10 EC @ X dose where as it was up to 3 DAT in the plants treated with novaluron 10 EC @ 2X dose (Table 5). More than 80 per cent mortality was observed up to 5 DAT at both the test doses of novaluron 10 EC. Toxicity of novaluron against *S. frugiperda* persisted upto 10 and 15 DAT respectively on novaluron 10 EC @ X and 2X dose. Toxicity of spinetoram 11.7 SC against *S. frugiperda* persisted up 15 and 20 DAT on maize plant treated with spinetoram 11.7 SC @ X dose and 2X dose respectively (Table 6). Cent per cent mortality was recoded up to 3 DAT in spinetoram 11.7 SC @ X dose and 4 DAT in spinetoram 11.7 SC @ 2X dose.

The studies were conducted to identify the median lethal concentration of different insecticides which the farmers in India predominantly use to manage the recently introduced polyphagous pest *S. frugiperda* on maize. The results revealed that the LC_{50} value of emamectin benzoate, chlorantraniliprole, spinetoram, flubendiamide and novaluron were 0.05, 4.08, 0.1, 85.89 and 0.91 ppm, respectively for second instar larva and 0.03, 5.63, 0.02, 162.99 and 0.99 for third instar larvaof fall army worm. Present results are in accordance with the findings of Zhang *et al.,* (2021) who reported that the LC_{50} values of susceptible strain of *S. frugiperda* against chlorantraniliprole, spinosad and emamectin benzoate were 0.07 - 2.00, 8.00 - 10.00 and 0.40 to 0.90 µg mL^{-1}, respectively and different populations *S. frugiperda* to indoxacarb, chlorantraniliprole, cyantraniliprole, spinosad, emamectin benzoate and chlorfenapyr were 16.35 – 99.67 µg mL^{-1}, 1.28 – 2.34 µg mL^{-1}, 1.49 – 4.64 µg mL^{-1}, 598.57 – 3878.74 µg mL^{-1}, 1.94 – 4.59 µg mL^{-1} and 87.03 – 128.43 µg mL^{-1}. The population of *S. frugiperda* tested for this study has less LC_{50} than the susceptible strain of the above findings. It shows the strain present in India is highly susceptible than the strains present in China. During 1990, *S. frugiperda* collected from southern and central Florida showed 3 to 264 fold resistance to pyrethroid, 11 to 517 fold resistance to organophosphorus and 10 to 507 fold resistance to oxadiazine (Yu, 1992). Yu *et al.,* (2003) reported that population of *S. frugiperda* collected from Citra, Florida recorded 562 fold resistance to carbaryl and 354 fold resistance to parathion - methyl. Field strains of *S. frugiperda* collected from northern Florida during 2007 registered 30 to 39 fold resistance to parathion-methyl and 626 to 1159 fold resistance to carbaryl (Yu and McCord 2007). It infers that this polyphagous pest can develop resistance to insecticides faster than other lepidopteran pests. Even though the LC_{50} is very less in the populations collected at Coimbatore, Tamil Nadu the probability of development of resistance is more due to increased frequencies of insecticide spray to supress this pest in this region. Song and Wu *et al.* (2020) reported that the spraying frequency of emamectin benzoate, which had a high efficiency on FAW, increased to 6.83 times in summer 2019 in west Yunnan since FAW invaded China. Hence continued monitoring of resistance development especially for the recommended insecticides is important to overcome massive destruction expected from this pest on the various food crops.

The results of persistent toxicity study revealed that, all the recommended insecticides cause more than 80 percent mortality up to 5 DAT except emamectin benzoate and spinetoram (Fig. 1 and 2). Among insecticides tested emamectin benzoate and novaluron have the shortest persistency of 10 DAT followed by spinetoram, chlorantraniliprole and flubendiamide in the recommended dose. Toxicity of emamectin benzoate, chlorantraniliprole, flubendiamide, novaluron and spinetoram at double the recommended dose persisted upto 10, 25, 25, 15 and 20 days, respectively. Vinothkumar *et al.,* (2018), reported that the residues of emamectin benzoate persisted up to 3 and 5 days after treatment and further dissipated to Below Detectable Limit (BDL < 0.05 µg g^{-1}) on 5 and 7 days after treatment at @ 10 g a.i ha^{-1} and 20 g a.i ha^{-1}, respectively. Wang *et al.* (2012), reported that

the dissipation half-life of emamectin benzoate in cabbage, apple and soil were 1.34 - 1.72 day, 2.75 - 3.09 day and 1.89 - 4.89 day, respectively. Minghui Li *et al.* (2011), reported that the half-life of emamectin benzoate in paddy plants, water and soil were 2.04-8.66 days, 2.89 -4.95 days and 3.65 - 5.78 days with a dissipation rate of 90% over 7 days after application, respectively. Emamectin benzoate (Proclaim 5 SG) at 68.1 and 136.2 g a.i. ha^{-1}, dissipated below the limit of quantification (LOQ) of 0.05 mg kg^{-1} after 5 days at both the dosages on okra fruits (Gagan Jyot *et al.,* 2014). Preethi *et al.,* (2019) reported that the persistence of flubendiamide in cabbage at tropical region sprayed at recommended dose 18.24 g a.i ha^{-1} and double the recommended dose 36.48 g a.i ha^{-1} reached Below Detectable Limit (BDL) of less than 0.01 µg g^{-1} on 15 days after treatment. Sharma and Parihar (2013), recorded the initial deposit of flubendiamide on tomato fruits were 0.295 and 0.641 µg g^{-1} and the residues reached below detectable level of 0.01 mg kg^{-1} after 5 and 7 days of application of single dose (48 g a.i. ha^{-1}) and double the dose (96 g a.i. ha^{-1}). Deepak *et al.* (2017) reported the initial deposit of flubendiamide on okra fruits was 1.49 µg g^{-1} and it dissipated below detectable level of 0.01 µg g^{-1} on 10^{th} day when sprayed at 60 g a. i. ha^{-1}.

Persistence of chlorantraniliprole on cabbage sprayed at 10 g a.i ha^{-1} and 20 g a.i ha^{-1} reached Below Detectable Limit (BDL) of less than 0.05 µg g^{-1} on 7 and 10 days after treatment, respectively (Preethi *et al.,* 2019). Chlorantraniliprole residues on cauliflower reached BDL on 3 and 5 days after treatment (Ioriatti, *et al.,* 2009).The spinetoram residues in tomatoes were below the codex maximum residue level (0.06 mg kg^{-1}) after 10 days of application when sprayed at recommended concentration (Malhat, 2013). Whereas Hafez *et al.,* (2016) reported that spinetoram residues reach below detectable limit of (below the quantification limit 0.03 mg / kg) in tomato fruit on 21 days after spraying. The efficacy studies revealed that spinoteram, emamectin benzoate and spinosad recorded significantly higher mortality ranging from 90.40 to 96.22, 92.47 to 98.73 and 98.28 to 100 per cent under in vitro and in vivo condition, respectively (Mallapur *et al.,* 2019). Piw das *et al.,* (2007) and Anita *et al.,* (2018) reported that novaluron @37.5 g. a.i ha^{-1} and 75 g. a.i ha^{-1} persisted for seven and ten days, respectively in chilli, brinjal and tomato ecosystem whereas it was 10 and 15 days on fresh and dry chilli peppers (Visalkumar *et al.,* 2018).

A mostly persistence study was carried out through quantification of insecticide residues (physical method) on the plant using chromatographic techniques and the impact of trace amount of insecticide on the target organism was not evaluated. The fates of insecticides reported below quantification level on target organism were also not assessed. In this study, the biological evaluation of the persistence of insecticide using the susceptible stage of target organism was assessed. Presence of trace quantity of insecticide residue will create mortality on susceptible insects. This study clearly indicated that the persistence of test insecticides were more than the earlier reported period which indicated that the presence of minor quantity recorded below the limit with sophisticated instruments also greatly impacted the target organism in the field. Hence, the more persistence insecticides like flubendiamide and chlorantraniliprole need to be recommended in the early stage of the maize crop (within 20 days after sowing) and less persistence insecticides *viz.,* emamectin benzoate and spinetoram should be recommended in the middle stage (25 to 40 days) of the maize crop for the management of FAW so that the residues may not accumulate in the harvested produce both in the stalk and grain.

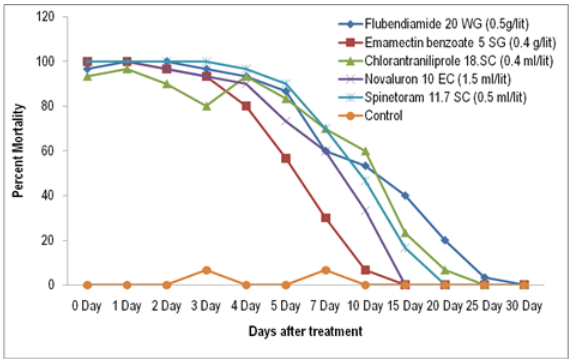

Fig. 1. Persistence toxicity of insecticides at recommended dose

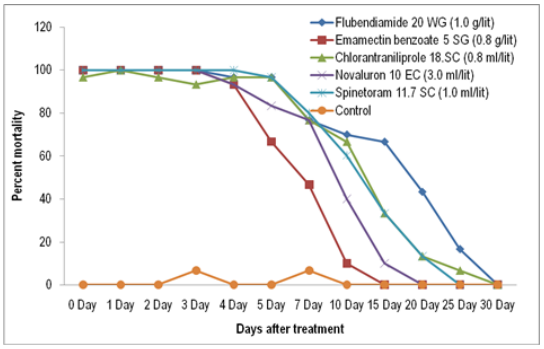

Fig. 2. Persistence toxicity of insecticides at double the recommended dose

Table 1. Baseline susceptibility of the maize fall armyworm to different insecticides

Insecticide	Larval Stage	Regression Equation	LC_{50} (LL - UL)	LC_{95} (LL - UL)	LC_{99} (LL - UL)	X^2
Emamectin benzoate	Second Instar	Y = 6.38 + 1.09 x	0.05 (0.04 - 0.08)	1.77 (0.47 - 6.67)	7.51 (1.20 - 47.03)	2.23
	Third Instar	Y = 6.53 + 0.99 x	0.03 (0.02 - 0.04)	1.31 (0.28 - 6.21)	6.40 (0.74 - 55.43)	0.37
Chlorantraniliprole	Second Instar	Y = 4.38 + 1.00 x	4.08 (2.59 - 6.41)	178.38 (42.58 - 747.24)	853.64 (113.40 - 6425.63)	0.12
	Third Instar	Y = 4.25 + 0.99x	5.63 (3.60 – 8.80)	254.98 (53.29 – 1237.79)	1237.79 (141.59 – 10820.88)	1.55
Flubendiamide	Second instar	Y = 2.52 + 1.28x	85.89 (59.94 – 123.09)	1648.38 (640.66 – 4241.02)	5606.04 (1506.37 - 20863.17)	0.43
	Third instar	Y = 2.52 + 1.12x	162.99 (107.71- 246.66)	4821.66 (1227.12 - 18945.56)	19618.43 (3079.53 - 124981.12)	1.24
Spinetoram	Second Instar	Y = 5.69 + 0.70x	0.1 (0.05 - 0.22)	22.76 (2.69 - 192.92)	213.12 (12.14 - 3741.94)	3.74
	Third Instar	Y = 7.05+ 1.13 x	0.02 (0.01 - 0.02)	0.44 (0.13 - 1.46)	1.76 (0.33 - 9.32)	0.82
Novaluron	Second instar	Y = 5.04 + 0.89x	0.91 (0.47 – 1.76)	64.16 (13.76 –299.13)	374.78 (37.89 –3706.81)	1.67
	Third instar	Y = 5.25+ 1.26x	0.63 (0.42 – 0.93)	12.79 (5.11 –32.03)	44.60 (12.13 - 163.99)	1.66

LL – Lower limit, UL – Upper limit

Table 2. Persistence toxicity of emamectin benzoate 5% SG against *S. frugiperda*

Days	Emamectin benzoate 5% SG @ X Dose			Emamectin benzoate 5% SG @ 2X Dose		
	24 HAT	48 HAT	72 HAT	24 HAT	48 HAT	72 HAT
0 Day	96.67	96.67	100.00	100.00	100.00	100.00
1 Day	90.00	100.00	100.00	93.33	100.00	100.00
2 Day	73.33	93.33	96.67	90.00	100.00	100.00
3 Day	53.33	73.33	93.33	76.67	83.33	100.00
4 Day	43.33	73.33	80.00	66.67	80.00	93.33
5 Day	23.33	26.67	56.67	46.67	46.67	66.67
7 Day	3.33	3.33	30.00	20.00	26.67	46.67
10 Day	0.00	0.00	6.67	0.00	6.67	10.00
15 Day	0.00	0.00	0.00	0.00	0.00	0.00

HAT – Hours after treatment

Table 3. Persistence toxicity of Chlorantraniliprole 18.5% SC against *S. frugiperda*

Days	Chlorantraniliprole 18.5% SC @ X Dose			Chlorantraniliprole 18.5% SC @ 2X Dose		
	24 HAT	48 HAT	72 HAT	24 HAT	48 HAT	72 HAT
0 Day	73.33	83.33	93.33	83.33	90.00	96.67
1 Day	90.00	93.33	96.67	93.33	96.67	100.00
2 Day	66.67	83.33	93.33	80.00	86.67	96.67
3 Day	66.67	80.00	90.00	76.67	90.00	96.67
4 Day	63.33	73.33	83.33	73.33	80.00	93.33
5 Day	43.33	56.67	80.00	53.33	76.67	86.67
7 Day	40.00	46.67	70.00	50.00	53.33	76.67
10 Day	10.00	30.00	60.00	16.67	56.67	66.67
15 Day	3.33	16.67	23.33	16.67	23.33	33.33
20 Day	0.00	0.00	6.67	0.00	6.67	13.33
25 Day	0.00	0.00	0.00	0.00	3.33	6.67
30 Day	0.00	0.00	0.00	0.00	0.00	0.00

HAT – Hours after treatment

Table 4. Persistence toxicity of flubendiamide 20% WG against *S. frugiperda*

Days	Flubendiamide 20% WG @ X Dose			Flubendiamide 20% WG @ 2X Dose		
	24 HAT	48 HAT	72 HAT	24 HAT	48 HAT	72 HAT
0 Day	70.00	93.33	96.67	93.33	96.67	100.00
1 Day	86.67	96.67	100.00	100.00	100.00	100.00
2 Day	83.33	90.00	100.00	93.33	96.67	100.00
3 Day	83.33	90.00	96.67	90.00	93.33	100.00
4 Day	83.33	86.67	93.33	86.67	90.00	96.67
5 Day	50.00	60.00	86.67	70.00	80.00	96.67
7 Day	46.67	53.33	60.00	56.67	63.33	76.67
10 Day	36.67	43.33	60.00	46.67	66.67	70.00
15 Day	33.33	43.33	53.33	40.00	63.33	66.67
20 Day	0.00	10.00	20.00	6.67	26.67	43.33
25 Day	0.00	3.33	3.33	3.33	13.33	16.67
30 Day	0.00	0.00	0.00	0.00	0.00	0.00

HAT – Hours after treatment

Table 5. Persistence toxicity of novaluron 10% EC against *S. frugiperda*

Days	Novaluron 10% EC @ X Dose			Novaluron 10% EC @ 2X Dose		
	24 HAT	48 HAT	72 HAT	24 HAT	48 HAT	72 HAT
0 Day	10.00	93.33	100.00	10.00	97.67	100.00
1 Day	13.33	80.00	100.00	16.67	100.00	100.00
2 Day	10.00	73.33	96.67	20.00	80.00	100.00
3 Day	10.00	66.67	93.33	23.33	76.67	100.00
4 Day	16.67	53.33	90.00	20.00	76.67	93.33
5 Day	10.00	53.33	73.33	16.67	70.00	83.33
7 Day	6.67	50.00	60.00	10.00	66.67	76.67
10 Day	3.33	26.67	33.33	6.67	33.33	40.00
15 Day	0.00	0.00	0.00	0.00	6.67	10.00
20 Day	0.00	0.00	0.00	0.00	0.00	0.00

HAT – Hours after treatment

Table 6. Persistence toxicity of spinetoram 11.7% SC against *S. frugiperda*

Days	Spinetoram 11.7% SC @ X Dose			Spinetoram 11.7% SC @ 2X Dose		
	24 HAT	48 HAT	72 HAT	24 HAT	48 HAT	72 HAT
0 Day	100.00	100.00	100.00	100.00	100.00	100.00
1 Day	100.00	100.00	100.00	100.00	100.00	100.00
2 Day	100.00	100.00	100.00	100.00	100.00	100.00
3 Day	90.00	96.67	100.00	96.67	100.00	100.00
4 Day	83.33	90.00	96.67	90.00	100.00	100.00
5 Day	66.67	83.33	90.00	76.67	93.33	96.67
7 Day	53.33	66.67	70.00	66.67	80.00	80.00
10 Day	30.00	30.00	46.67	43.33	46.67	60.33
15 Day	13.33	13.33	16.67	20.00	26.67	33.33
20 Day	0.00	0.00	0.00	0.00	3.33	13.33
25 Day	0.00	0.00	0.00	0.00	0.00	0.00

HAT – Hours after treatment

Conclusion

The LC_{50} value of emamectin benzoate, chlorantraniliprole, spinetoram, flubendiamide and novaluron were 0.05, 4.08, 0.1, 85.89 and 0.91 ppm, respectively for second instar larva and 0.03, 5.63, 0.02, 162.99 and 0.99 for third instar larva of fall armyworm. Among insecticides tested emamectin benzoate and spinetoram showed high toxicity to *S. frugiperda* than other insecticides by registering minimum LC_{50} value. But in persistent toxicity study, same insecticides show less persistence on maize crop. Hence, insecticides like flubendiamide and chlorantraniliprole need to be recommended in the early stage of the maize crop (within 20 days after sowing) and less persistence insecticides *viz.,* emamectin benzoate and spinetoram should be recommended in the middle stage (25 to 40 days) of the maize crop for the management of *S. frugiperda* so that the residues may not accumulate in the harvested produce both in the stalk and grain.

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Ethics statement

No specific permits were required for the described field studies because no human or animal subjects were involved in this research.

Originality and plagiarism

The authors assure that the contents were written by us and were not plagiarized.

Consent for publication

All the authors agreed to publish the content.

Competing interests

There were no conflict of interest in the publication of this content

Data availability

All the data of this manuscript are included in the MS. No separate external data source is required. If anything is required from the MS, certainly, this will be extended by communicating with the corresponding author through corresponding official mail.

Author contributions

Research grant	NS, KP, SVK
Idea conceptualization	BVK, NS, SVK
Experiments	BVK, GA, TS, PSS, SJ, AS
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