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The Efficacy of Selected Synthetic Insecticide Formulations against Fall Armyworm *Spodoptera frugiperda* (J.E. Smith) Under Laboratory, Semi-Field and Field Conditions

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MZM and MA conceived and designed the experimental protocols. HM and MQ performed the experiments. MA and AM performed statistical analyses. HM and MZM prepared the manuscript. MA and MZM provided technical assistance in experiments. MZM and AM proofread the manuscript.

Key words
Fall armyworm, Synthetic insecticides, Laboratory evaluation, Field efficacy, Chlorantraniliprole, Abamectin

ABSTRACT

The invasive fall armyworm species, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae), was first time reported in Pakistan during March 2019 causing severe damage to maize crop. As a new pest, there is little information available on its susceptibility to insecticides in Pakistan. We evaluated selective synthetic insecticides with different modes of action to control *S. frugiperda* larvae in the laboratory as well as under semi-field and field conditions. All insecticides performed well in controlling *S. frugiperda* larvae under laboratory conditions. Though, chlorantraniliprole @ 50 mL/100L (58.0–100%), abamectin @ 400 mL/100L (56.0–100%), lambda-cyhalothrin @ 250 mL/100L (52.0–100%) and chlorpyrifos @ 1000 mL/100L (52.0–98.0%) showed significantly ($P < 0.05$) higher mortality than other chemicals. Higher concentrations of abamectin (6000 ppm), chlorpyrifos (12000 ppm) and chlorantraniliprole (700 ppm) showed 100% larval mortality at 24 h post-exposure. Lambda-cyhalothrin (3500 ppm) showed 95% larval mortality at 24 h and 100% mortality at 48 h of application. The medium dose rate of abamectin (4000 ppm) and chlorantraniliprole (600 ppm) also showed 100% larval mortality at 48 h of application. In semi-field and field conditions, chlorantraniliprole showed 100% larval mortality at 48 h, while abamectin and chlorpyrifos showed 87–89% and 94–81% larval mortality respectively in semi-field to field conditions after 72 h of application. Overall study results demonstrate the effectiveness of chlorantraniliprole, abamectin and chlorpyrifos and these synthetic insecticides should be considered as components of integrated management of *S. frugiperda* in Pakistan.

INTRODUCTION

The fall armyworm species, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) is an invasive pest and causes huge crop losses. This pest is endemic to the tropical regions of the Western Hemisphere (Prowell *et al*., 2004; Murúa *et al*., 2009), and was reported first time in sub-Saharan Africa in December 2015 (Goergen *et al*., 2016). Its year-round distribution is usually limited to warm and moist areas, due to the inability to diapause under harsh conditions (Nagoshi *et al*., 2012). This pest is a serious threat to global food security as the populations of *S. frugiperda* have become established in Africa, India and China (Goergen *et al*., 2016; Wu *et al*., 2019), where maize and rice are staple food crops. In Pakistan, it was first reported in Sindh province on maize and vegetable crops during 2019 (Ullah *et al*., 2019) and now it has been well-established in almost all maize-producing areas of the country. *S. frugiperda* endures a threat to food security due to its wide range of host plants (Montezano *et al*., 2018), having high reproductive potential, short life cycle (Sparks, 1979), great dispersal abilities (Johnson, 1987), and adaptability to diverse agro-ecological conditions (Cokola *et al*., 2021).

S. frugiperda feeds on a wide range of host plants and over 353 host plants belonging to 76 different families including Poaceae (106 species), Asteraceae (31 species), and Fabaceae (31 species) have been reported (Montezano *et al*., 2018). It can attack almost all stages of maize crop and neonate larvae feed on the underside of the leaves and make transparent patches, called windows. Mature larvae normally penetrate the leaf whorls (Capinera, 2017;

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FAO, 2018). About 33% loss of maize has been reported previously due to feeding of *S. frugiperda*, causing a loss of around 1 million tons in maize production annually in Kenya (De Groote *et al*., 2020).

Control of *S. frugiperda* is difficult due to its feeding behavior under the protection of leaves and whorls; however, the application of synthetic insecticides remains the main option. Thus, there is a need to determine the effectiveness of insecticides against *S. frugiperda* to add to IPM practices. In India, use of chlorantraniliprole, spinetoram and thiamethoxam plus lambda cyhalothrin has been recommended by the Central Insecticide Board and Registration Committee (CIBRC) for the effective management of *S. frugiperda* population in the field (DPPQS, 2019). With the introduction of this pest in Pakistan, farmers are using different synthetic insecticides without knowing their efficacy. As the larva of this pest remains in the whorl of maize plants during its whole life, its contact with insecticides is minimal (FAO, 2018). Further, multiple applications of insecticides may enhance the resistance level of pests against insecticides, as has been reported previously (Gutierrez-Moreno *et al*., 2019). To provide baseline data and to find out the most effective insecticides, a study of dose-mortality response to various insecticides is needed (Cook *et al*., 2004).

Although, various differential-chemistry (other than conventional ones) synthetic insecticides having different modes of action have been in practice to control lepidopteran pests, the effective synthetic insecticides against *S. frugiperda* have yet to be explored. Many insecticides are reported to be effective against *S. frugiperda*, but no insecticide is registered in Pakistan. As a new pest in our country, it is necessary to determine the most effective insecticides and share information about the dose rate, application method, and time with maize growers. Extensive use of insecticides may impact the sustainability of farmers and thus those insecticides should be used that are economically justifiable. Keeping in view the economic losses of this new pest and no recommended insecticide against this pest in our country, the study was conducted to assess the toxicity of different synthetic insecticides in the laboratory, semi-field and field conditions.

MATERIALS AND METHODS

S. frugiperda *culture*

Larvae of *S. frugiperda* were collected from the maize field of research area of the College of Agriculture (32°08'07.9"N: 72°41'14.4"E) and brought to the laboratory of Entomology and were kept in clean Petri-plates. The culture was maintained under controlled conditions of 25±2ºC, 60±5% RH and 16:8 (L: D) photoperiod. Insects were fed on a chickpea flour based artificial diet described by Sorour *et al*. (2011). Pupae were kept in Petri-plates over moist filter paper and after emergence; adults were shifted into the rearing box for mating and ovipositioning. The adults were fed on 10% honey solution. Eggs of *S. frugiperda* were collected from cages on daily basis and were kept in Petri-plates containing a layer of artificial diet (Silva and Parra, 2013). The F_3 generation of *S. frugiperda* was used in the bioassay.

Screening of nine insecticides in the laboratory

Nine synthetic insecticides were used for laboratory bioassay. Detail of selected insecticides having different groups with a different mode of action is given in Table I. The recommended doses of selected insecticides were tested against *S. frugiperda* larvae to screen out the effective insecticide in laboratory conditions. Total 10 treatments were used including nine insecticides with control (water). The leaf dip bioassay method was used to check the toxicity of these insecticides against *S. frugiperda*. Fresh leaves of cauliflower were collected from the field and brought into the laboratory. Leaves were washed with tap water and kept for drying at room temperature for 1h. After drying, leaf disks were prepared according to the size of the Petri-plate. Agar (1.5%) solution was prepared and was poured as 1mm layer into each glass Petri-plates (9 cm wide and 2.5 cm deep) and was allowed to dry at room temperature for 20–30 min. Leaf disks were dipped into treatment solutions for 5–10 sec. Then these discs were dried at ambient temperature for 10–15 min before placing them into glass Petri-plates. Five 2nd instar larvae were released on each treated leaf disc in glass Petri-plates and all plates were placed in controlled conditions (same as rearing condition). Complete randomized design (CRD) layout was used with ten replications of each treatment. Mortality data was recorded after 3, 6, 12, 24, 48 and 72 h of post-exposure.

Dose-mortality response of S. frugiperda *to insecticides in laboratory*

After the screening of various insecticides, four most effective insecticides were used further to evaluate lethal effects on *S. frugiperda* larvae. The same bioassay was performed as in study 1. A stock solution of each insecticide was prepared and further serial dilution was made. Five concentrations of each insecticide were prepared (in parts per million). The experiment was conducted with completely randomized design with six replications per concentration. Data of larval mortality were recorded after 3, 6, 12, 24, 48 and 72 h of post-exposure.

Table I. List of selected synthetic insecticides evaluated against 2nd instar larvae of *Spodoptera frugiperda* in this study.

Trade name	Active ingredient	IRAC group	Formu-lation	Mode of action	Label dose (ml)
Chacha®	Abamectin	28 Diamides	1.8% EC	Glutamate-gated chloride channel allosteric modulator	400
Coragen®	Chlorantraniliprole	1B Organophosphate	20% SC	Ryanodine receptor modulator	50
Chopat®	Chlorpyrifos	6 Avermectins	40% EC	Acetylcholinesterase (AChE) inhibitors	1000
Decis Super®	Deltamethrin	3A Pyrethroid	2.8% EC	Sodium channel modulators	80
Proclaim®	Emamectin benzoate	6 Avermectins	19% EC	Glutamate-gated chloride channel allosteric modulator	200
Fipronil®	Fipronil	2B Phenylpyrazoles	5% SC	GABA-gated chloride channel blockers	480
Lambda®	Lambda-cyhalothrin	3A Pyrethroid	2.5% EC	Sodium channel modulators	250
Match®	Lufenuron	15 Benzoylureas	50% EC	Chitin synthesis inhibitor (IGR)	200
Curacron®	Profenophos	1B Organophosphate	50% EC	Acetylcholinesterase (AChE) inhibitors	750

Efficacy of insecticides against S. frugiperda *under greenhouse/semi-field conditions*

Cauliflower planting was performed in plastic pots containing peat moss and soil with 1:1 ratio. The pots were watered as required. After 2 months of germination when plant height reached 6 to 7 inches, the plants were used in the experiment. The solutions of the four most effective insecticides were prepared according to their label recommended doses and were sprayed on the plants. Four plants were selected for each insecticide considering each plant as a replication. In the control treatment, water was applied. Five 2nd instar larvae from the laboratory-reared F3 generation were released on each potted plant. Data of larval mortality were recorded at 12, 24, 48 and 72 h of post-exposure time.

Field-efficacy of selected insecticides against S. frugiperda

Cauliflower (*Brassica oleracea* L. Botrytis) was planted in the research area of University. Ten seedlings in one ridge and total 100 plants were maintained in 10 ridges were sown in the field. All the crop-raising practices were followed to retain healthy plants. No insecticides except those included in our study were applied on the plants. When the height of cauliflower leaves was reached 7 to 8 inches in the field, the four most effective insecticides were applied on label recommended dose. Insecticide was applied with a hand sprayer. Five 2nd instar larvae of *S. frugiperda* were released on each plant and data of larval mortality were recorded after 12, 24, 48 and 72 h of insecticide application. The control plots were sprayed with water. Randomized Complete Block Design (RCBD) was used for the experiment with four replications.

Data analysis

Data for percent larval mortality recorded from all laboratory and field trials were subjected to a one-way analysis of variance (ANOVA) by keeping insecticide as the main factor. Median lethal time (LT_{50}) values for selected differential-chemistry synthetic insecticides were calculated by probit analysis. Means were separated by using Tukey's honest significant difference test ($\alpha = 0.05$). All statistical analyses were performed using the Minitab 17.0 statistical software.

RESULTS

Efficacy of insecticides against 2nd instar larvae of S. frugiperda *under laboratory conditions*

The results showed that there was a significant difference in larval mortality after application of insecticides at 12 h ($F = 17.6$, $P < 0.001$), 24 h ($F = 20.2$, $P < 0.001$), 48 h ($F = 36.2$, $P < 0.001$) and 72 h ($F = 82.2$, $P < 0.001$). All the insecticides showed good results in controlling *S. frugiperda* larvae. At 72 h of exposure time, chlorantraniliprole, abamectin, and lambda-cyhalothrin showed 100% larval mortality. Furthermore, considerable larval mortality (86–98%) was recorded for chlorpyrifos, fipronil, deltamethrin and lufenuron after 72 h of application (Table II). Moreover, median lethal time (LT_{50}) values indicated the same trend in the effectiveness of insecticides against 2nd instar larvae of *S. frugiperda*. Probit analysis showed chlorantraniliprole, abamectin and chlorpyrifos as effective insecticides with LT_{50} values of 8.32 h (0.55–16.09), 9.71 h (2.58–16.88) and 10.39 h (1.919–18.80), respectively (Table III).

Table II. Percent larval mortality (means ± SE) of 2nd instar larvae of *Spodoptera frugiperda* exposed to label-recommended dose rates of different synthetic insecticides.

Insecticides	12 h	24 h	48 h	72 h
Deltamethrin [B]	48.0±3.26a	63.0±3.0a	69.0±7.06b	89.5±3.53ab
Lufenuron [B]	48.0±3.26a	61.0±5.67a	69.0±7.06b	85.5±5.29ab
Chlorantraniliprole [A]	58.0±4.67a	73.0±5.17a	96.0±2.67a	100.0a
Emamectin benzoate [B]	48.0±3.26a	61.0±5.67a	67.0±5.58b	85.5±4.37ab
Abamectin [A]	56.0±4.98a	71.0±6.75a	95.5±3.02a	100.0a
Fipronil [B]	48.0±3.26a	61.5±3.34a	68.0±5.33b	90.0±4.47ab
Lambda-cyhalothrin [A]	52.0±5.33a	68.0±6.11a	96.0±2.67a	100.0a
Profenophos [B]	48.0±3.26a	61.0±5.67a	69.0±7.66b	83.5±5.06b
Chlorpyrifos [A]	52.0±3.26a	67.0±3.67a	92.0±4.42a	98.0±2.0ab
Control [C]	0.00b	0.00b	0.00c	0.00c

Means sharing similar letters within a column are not significantly different at $P > 0.05$. Capital letters show overall statistical difference among the insecticidal treatments (factorial ANOVA followed by HSD at $\alpha = 0.05$).

Table III. Median lethal time (LT_{50}) values for selected differential-chemistry synthetic insecticides evaluated against 2nd instar larvae of *Spodoptera frugiperda* at 12, 24, 48 and 72 h post-exposure time under laboratory.

Treatment	LT_{50} (hr)	Lower–upper 95% fiducial limit (hr)	X^2	P value
Deltamethrin	12.43	1.373–26.25	807.7	< 0.001
Lufenuron	12.24	3.373–27.86	193.9	< 0.001
Chlorantraniliprole	8.323	0.554–16.09	427.6	< 0.001
Emamectin benzoate	12.60	3.227–28.42	586.1	< 0.001
Abamectin	9.731	2.582–16.88	448.8	< 0.001
Fipronil	13.87	0.473–27.28	357.8	< 0.001
Lambda-cyhalothrin	12.29	6.151–18.43	464.3	< 0.001
Profenophos	11.49	5.540–28.53	212.3	< 0.001
Chlorpyrifos	10.39	1.919–18.80	320.2	< 0.001

*Since the significance level is less than 0.15, a heterogeneity factor is used in the calculation of confidence limits.

Toxicity of effective insecticides at different concentrations against S. frugiperda

A significant difference in larval mortality was recorded after application of insecticides at 6 h (F =13.1, P < 0.001), 12 h (F = 26.9, $P < 0.001$), 24 h (F = 37.5, $P < 0.001$), 48 h (F = 32.1, $P < 0.001$) and 72 h (F = 25.9, $P < 0.001$). Abamectin at 6000 ppm concentration gave 65.0% larval mortality after 6 h, 90.0% after 12 h and 100% after 24 h. When this insecticide was tested at 5000 ppm, it showed 60.0, 90.0 and 100% larval mortality after 12, 24 and 48 h of application. Similarly, abamectin at 4000 ppm showed 70.0% larval mortality after 24 h and 100% after 48 h. The lowest concentrations (3000 and 2000 ppm, respectively) of abamectin showed 90.0% and 80.0% larval mortality after 72 h of application. Lambda-cyhalothrin at 2500 ppm gave 90% mortality of larvae after 72 h and 3000 ppm gave similar control at 48 h. A higher concentration (3500 ppm) of lambda-cyhalothrin controlled 95% larvae at 24 h and 100% at 48 h of application. The lowest concentrations of chlorpyrifos didn't perform well in controlling larvae of *S. frugiperda*. However, 11000 ppm concentration of chlorpyrifos showed 90% mortality at 72 h and 12000 ppm showed 100% larval mortality at 24 h of application. Similar findings were observed in the case of chlorantraniliprole which showed 70% larval mortality at 400 ppm. By using a higher concentration (500 ppm) of this insecticide, 100% of larvae were found to be dead at 24 h of exposure (Table IV).

Efficacy of insecticides against 2nd instar larvae of S. frugiperda *under semi-field conditions*

When insecticides were tested under semi-field conditions, a significant difference in larval mortality was recorded after application of insecticides at 12 h (F = 19.2, $P < 0.001$), 24 h (F = 49.3, $P < 0.001$), 48 h (F = 36.5, $P < 0.001$) and 72 h (F = 42.6, $P < 0.001$). After 24 h, about 93.8% larval mortality was recorded with the application of chlorantraniliprole which was increased to 100% at 48 h. Chlorpyrifos gave 93.7% control of *S. frugiperda* larvae after 72 h of application. While 87.5% mortality was recorded with the application of abamectin and 76.3% with lambda-cyhalothrin at 72 h exposure time (Fig. 1).

Table IV. Percent larval mortality (means ± SE) of 2nd instar larvae of *Spodoptera frugiperda* exposed to different concentrations of synthetic insecticides.

Insecticides	Conc. (ppm)	6 h	12 h	24 h	48 h	72 h
Abamectin A	2000	15.0±5.00cde	25.0±3.04e-h	45.0±5.01cd	65.0±5.00b-e	80.0±2.02abc
	3000	15.0±5.00cde	35.0±5.00d-g	50.0±5.77cd	75.0±9.57abc	90.0±5.77ab
	4000	30.0±5.77bcd	50.0±5.77b-e	70.0±4.77bc	100.0a	100.0a
	5000	35.0±9.57bc	60.0±8.16bcd	90.0±3.37ab	100.0a	100.0a
	6000	65.0±9.57a	90.0±5.77a	100.00a	100.0a	100.0a
Lambda-cy-halothrin B	1500	0.00e	20.0±1.00fgh	25.0±2.32d-g	55.0±9.57c-f	65.0±5.00cde
	2000	5.0±0.02de	25.0±1.00e-h	35.0±2.43def	60.0±8.16cde	70.0±5.77b-e
	2500	10.0±1.77cde	25.0±1.00e-h	45.0±3.04cd	65.0±5.00b-e	90.0±5.77ab
	3000	30.0±2.77bcd	45.0±3.00c-f	70.0±5.54bc	90.0±5.77ab	100.0a
	3500	45.0±5.00ab	70.0±5.34abc	95.0±5.00ab	100.0a	100.0a
Chlorpyrifos C	8000	0.00e	0.00h	10.0±1.23fg	30.0±2.54fg	50.0±5.77e
	9000	0.00e	0.00h	15.0±1.65efg	30.0±2.22fg	55.0±5.00de
	10000	0.00e	10.0±1.77gh	25.0±2.00d-g	45.0±5.00def	75.0±9.57bcd
	11000	15.0±2.00cde	25.0±2.00e-h	50.0±5.43cd	70.0±5.77bcd	90.0±5.77ab
	12000	30.0±2.77bcd	70.0±5.77abc	100.0a	100.0a	100.0a
Chlorantra-niliprole B	300	0.00e	0.00h	15.0±1.00efg	40.0±0.00ef	65.0±5.00cde
	400	10.0±1.77cde	25.0±3.00e-h	40.0±1.55de	55.0±9.57c-f	70.0±5.77b-e
	500	10.0±1.77cde	30.0±5.77efg	50.0±5.77cd	75.0±9.57abc	90.0±5.77ab
	600	25.0±2.00b-e	50.0±5.77b-e	85.0±5.00ab	100.00a	100.0a
	700	50.±5.77ab	75.0±5.00ab	100.0a	100.00a	100.0a
Control D		0.00e	0.00h	0.00±0.00g	5.00±0.02g	10.0±1.12f

Means sharing similar letters within a column are not significantly different at $P > 0.05$. Capital letters show overall statistical difference among the insecticidal treatments (factorial ANOVA followed by HSD at α = 0.05).

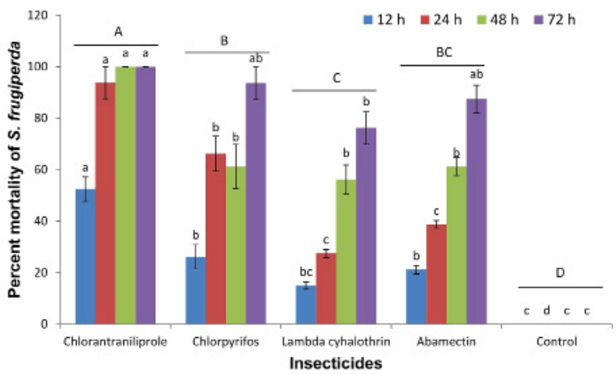

Fig. 1. Percent larval mortality (means ± SE) of 2nd instar larvae of *Spodoptera frugiperda* exposed to label-recommended dose rates of different synthetic insecticides under semi-field conditions. Small letters show statistical difference among the treatments for each time interval, while capital letters show overall statistical difference among the insecticidal treatments (factorial ANOVA followed by HSD at α = 0.05).

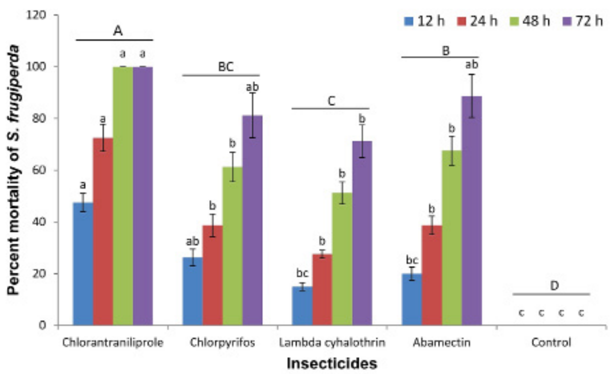

Fig. 2. Percent larval mortality (means ± SE) of 2nd instar larvae of *Spodoptera frugiperda* exposed to label-recommended dose rates of different synthetic insecticides under field conditions. Small letters show statistical difference among the treatments for each time interval, while capital letters show overall statistical difference among the insecticidal treatments (factorial ANOVA followed by HSD at α = 0.05).

Efficacy of effective insecticides against 2nd instar larvae of S. frugiperda *in field conditions*

In field conditions, similar results of selected insecticides were found as in semi-field conditions. Chlorantraniliprole showed 100% mortality at 48 h of application that was significantly (F = 37.4, $P < 0.001$) higher than other chemicals. Abamectin showed 88.7% larval mortality after 72 h of application in the field. Chlorpyrifos showed 26.2–81.2% and lambda-cyhalothrin showed 15.0–71.2% larval mortality in the field (Fig. 2).

DISCUSSION

S. frugiperda has a wide range of host plants and damages various economic crops including rice, maize, cabbage, cauliflower, sugarcane, millet and cotton (Clark *et al*., 2007; Day *et al*., 2017; Montezano *et al*., 2018). As a new pest in our country, farmers are using different synthetic insecticides to suppress the population of this pest, while there is no registered product available in the market yet. We evaluated different insecticides against this pest in laboratory and field conditions. In laboratory study, all tested insecticides showed good results in controlling *S. frugiperda* larvae. Some insecticides showed greater mortality of 2nd instar larvae in the laboratory trials and high to moderate larval mortality was achieved with chlorantraniliprole, lambda-cyhalothrin, abamectin, chlorpyrifos, fipronil, deltamethrin, lufenuron, emamectin benzoate and profenophos. However, more than 95% larval mortality was achieved by chlorantraniliprole, lambda-cyhalothrin, abamectin and chlorpyrifos at 72 h. The LT_{50} of chlorantraniliprole, abamectin and chlorpyrifos against *S. frugiperda* larvae were found to be low; therefore, the high insecticidal toxicity and rapid efficiency of these insecticides make them a good candidate to manage *S. frugiperda* larval population. Findings of dose-mortality response demonstrated that higher concentrations of abamectin (6000 ppm) and chlorantraniliprole (700 ppm) and chlorpyrifos (12000 ppm) had 100% efficacy against *S. frugiperda* at 24 h post-exposure. By increasing the concentration of insecticides, mortality of *S. frugiperda* larvae was also increased.

Our results corroborate the findings of Ahmed *et al*. (2022) showing significant morality of 3rd instar larvae of *S. frugiperda* by emamectin benzoate, chlorpyrifos and chlorantraniliprole. Lambda-cyhalothrin is a combination of isomers of cyhalothrin that is a synthetic organic insecticide (Robert, 2002). As a broad-spectrum pyrethroid insecticide, it is used to manage several insect pests in different crops (Leistra *et al*., 2004). Chlorpyrifos is an organophosphate insecticide used to kill a wide range of insect pests (Rathod and Garg, 2017). Abamectin is classified in the group of avermectins, made by the soil microorganism known as *Streptomyces avermitilis* (Burg *et al*., 1979). Abamectin acts as an agonist to GABA receptors in insect's nervous system (White *et al*., 1997) and is well documented as an effective insecticide against various insect pests (Ahmad *et al*., 2003; Gouamene-Lamine *et al*., 2003; Fitzgerald, 2004; Seal *et al*., 2006). Chlorantraniliprole is a newer class of insecticides, anthranilic diamides and it is highly selective to ryanodine receptors in insect's body (Cordova *et al*., 2006; Lahm *et al*., 2007). Chlorantraniliprole has been reported earlier as a good candidate to control *Spodoptera* spp. (Sisay *et al*., 2019; Kong *et al*., 2021; Ahmed *et al*., 2022; Altaf *et al*., 2022).

In greenhouse and field trials, the most effective insecticides from laboratory bioassay were tested against *S. frugiperda* larvae. The findings demonstrated that chlorantraniliprole, abamectin and chlorpyrifos were effective to control *S. frugiperda*. About 87–100% larval mortality was achieved at 72 h of application in greenhouse and field conditions. It was also noted that the mortality of 2nd instar larvae was increased over time after the application of synthetic insecticides in the laboratory and field, showing the residual toxicity of these insecticides to *S. frugiperda*.

The recent attack of *S. frugiperda* has forced the farmers to massive spraying of synthetic insecticides on maize fields for quick control of this pest. Due to heavy damage to maize crop, farmers are using synthetic chemicals not recommended yet against this pest. This massive use of insecticides may increase the chances of resistance development in this pest against insecticides. As recently, Gutierrez-Moreno *et al*. (2020) reported that field-collected *S. frugiperda* might be developing resistance to different insecticides including diamides, chlorantraniliprole and flubendiamide. Thus, resistance monitoring in *S. furgiperda* is also needed.

Due to having multiple generations, dispersal ability and feeding on various host plants makes *S. frugiperda* difficult pest to control. As a new threat to global food security, quick action, national, regional and international collaboration are needed to suppress the population of this pest. An effective integrated pest management strategy is required to tackle the adverse effects of this pest. Our findings, therefore, are helpful to the management of this pest in screening effective insecticides. However, these insecticides should be the last option in the IPM program of *S. frugiperda*. Other control measures including the use of biopesticides, natural enemies and cultural practices should be integrated into the IPM program for this pest.

CONCLUSIONS

This study demonstrates that the application of the synthetic insecticides chlorantraniliprole, abamectin and chlorpyrifos are effective in controlling *S. frugiperda*. These insecticides had the highest toxicity and fastest knockdown effect on *S. frugiperda* larvae in the field. These synthetic insecticides are hence recommended combating *S. frugiperda* infestations in maize. However, there is a need of IPM approach to control this pest, as only chemical control may increase the chance of *S. frugiperda* resistance to insecticides.

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Statement of conflict of interest

The authors have declared no conflict of interest.

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