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The efficacy of some insecticides against fall Armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae), in maize fields

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Abstract
Field experiments were conducted in Kafr El-Sheikh Governorate - Egypt during 2022 and 2023 seasons to study five insecticides namely chlorfenapyr, indoxacarb, methomyl, emamectin benzoate and chlorantraniliprole against Fall armyworm, *Spodoptera frugiperda* in Maize fields as well as the infestation and damage on maize. Also, Lab experiments was evaluated the toxicity of tested insecticides. The results displayed that, under lab condition the emamectin benzoate insecticide was more toxicity with LC_{50} values 0.089 and 0.464ppm for second and fourth larval instar, respectively. The infestation was minimal when treated with emamectin benzoate in both seasons as the general reduction of FAW larvae reached 71.5 and 73.2% in the 2022 and 2023 season, respectively. the initial effect (after one day of treatment), was maximum effect against FAW larvae, with the reduction percentage being more than 90% compared to the days following the test after application in both seasons. In season 2022, the cob damage percentage in all treatments was decrease compare than untreated and that the percentage of damage ranged between 22 – 35% and grain yield was similar in the case of treatment with the two compounds emamectin benzoate and chlorantraniliprole and was the highest compared to the other tested insecticides were 2100.0 and 2062.5 kg/feddan. Also, In 2023 season, cob damage percentage in all treatments was decrease compare than untreated, and that the percentage of damage ranged between 20 – 30%, and the lowest cob damage percentage was recorded in the treatment with chlorantraniliprole insecticide with value 20% and grain yield was 1912.5 kg/feddan while indoxacarb insecticide had the highest percentage cob damage and methomyl gave the lowest grain yield was 1800.0 kg/feddan.

Keywords: *Spodoptera frugiperda*, maize, insecticides, cob damage, grain yield

Introduction

Spodoptera frugiperda, commonly known as the fall armyworm (FAW), is a species of moth that is considered a serious pest in agriculture. It is native to tropical and subtropical regions of the Americas but has spread to other parts of the world, including Africa and Asia, where it has caused significant crop damage. FAW is a voracious feeder and can cause significant damage to crops such as maize, rice, sorghum, cotton, and vegetables. The larvae of the fall armyworm are the most damaging stage, as they feed on the leaves of the plant, creating "windowpane" like holes that can greatly reduce the plant's ability to photosynthesize and produce a good yield. They can also bore into the ear or cob of the plant, damaging the reproductive structures and reducing yield.

Control measures for fall armyworm include the use of chemical pesticides, biological control agents, and cultural practices such as crop rotation and early planting. However, controlling the pest can be challenging due to its ability to rapidly reproduce and spread over long distances. (FAW), *S. frugiperda*, is a pest of great economic importance, especially on maize crops in most African countries and many cultivars of maize that are not resistant to fall armyworm, therefore, traditional or biological pesticides must be used without harming the environment (Nboyine *et al*., 2021) [20]. Although it is resistant to many insecticides belonging to different groups, such as carbamates, organophosphates and pyrethroids (Prasanna *et al*., 2018; Carvalho *et al*., 2013; Yu *et al*., 1991, Gutierrez-Moreno *et al*., 2019 and Herrera-Mayorga *et al*., 2018) [30, 31, 32, 34, 35] Therefore, it is important to manage FAW resistance by selecting pesticide groups and including them in integrated pest management programs. In addition to indoxacarb, chlorantraniliprole, emamectin benzoate and lufenuron had been high effects on FAW larvae (Zhao *et al*., 2022; Wu *et al*., 2022a; Beuzelin *et al*., 2022) [28, 26, 7].

Chlorfenapyr is an insecticide and acaricide used to control various pests in agriculture. It belongs to the pyrrole chemical class as it significantly reduces the density of pest eggs and larvae by disrupting cellular respiration in the target pests, ultimately leading to their death (Darabian and Yarahmadi, 2017; Hou *et al*., 2022) [9, 15]. Indoxacarb belongs to the chemical class of oxadiazines and acts as a sodium channel blocker in insects, disrupting their nervous system function in pests and it effective against pests that have developed resistance to other insecticides. This characteristic has led to its widespread use in managing pests (Mokbel *et al*., 2017) [17] and it has a clear effect in combating lepidoptera on various crops (Khaled and Farag, 2015; Wu *et al*., 2022b) [16, 27]. Methomyl belongs to the chemical class of carbamates and works to inhibit the activity of the acetylcholinesterase enzyme and is characterized by being fast-acting after application and it is commonly used to control the population levels of cotton leafworm and fall armyworm (Dewer *et al*., 2016; Shaker *et al*., 2017; Ríos-Díez and Saldamando-Benjumea, 2011) [10, 23, 22,]. Emamectin benzoate used in a wide range of crops and belongs to the avermectin chemical class and works by disrupting the nervous system of target insects leading to paralysis and death (Zhu *et al*., 2022; Muraro *et al*., 2021;

Abdel-Hamid *et al*., 2021; Abdel Aziz, 2019; Abdel Aziz *et al*., 2024) [29, 19, 3, 4, 5]. Chlorantraniliprole mode of action targets the ryanodine receptors in the muscles of insects, leading to muscle paralysis and causing death and belonging to chemical class of anthranilic diamides. chlorantraniliprole is its selectivity towards target pests while having minimal impact on beneficial insects and the environment when used correctly and It's effective against lepidoptera as cotton leafworm and fall armyworm (Barrania, 2013; Falin *et al*., 2019; Wang *et al*., 2022; Beuzelin *et al*., 2022) [6, 12, 25, 7].

In this study, the toxicity of the insecticides chlorfenapyr, indoxacarb, methomyl, emamectin benzoate and chlorantraniliprole was laboratory tested on FAW larvae. In addition, a field experiment was also conducted to evaluate the effect of treatment with the aforementioned insecticides using field application on FAW in maize fields as well as the infestation and damage on maize.

Materials and methods

Chemical insecticides

Insecticides were used when infection starts with five different insecticides against *S. frugiperda* (FAW) which are:

1. Chlorfenapyr (24% SC) with the trade name Challenger Super®, the application rate is 60 cc/ 100 Liter water from BASF Limited Egypt
2. Indoxacarb (15% SC) with the trade name Carbodox®, the application rate is 26.5 cc/ 100 Liter water from Sand Valley.
3. Methomyl (90% SP) with the trade name Lannate®, the application rate is 300 g/ Feddan from DuPont Egypt.
4. Emamectin benzoate (5.7% SG) with the trade name Radison®, the application rate is 60 g/ Feddan from Green M for agricultural services.
5. Chlorantraniliprole (20% SC) with the trade name Coragen®, the application rate is 60 cc/ Feddan from Fmc International Switzerland Sarl.

Laboratory bioassay of selected insecticides against FAW

A FAW was collected from an unsprayed maize farm at Al-Khawalid village of Sidi Salem Center in Kafr El-Sheikh Governorate. Approximately 100 - 200 larvae were collected and were placed into jars (approximately 2 liter) in the lab and fed with maize leaves collected from maize plants. The pupae were collected and placed in clean jar and as a food source for the emerging adults, sterile cotton soaked in a sugar solution was placed inside the oviposition jars. Eggs were collected from the oviposition jars and placed in sterile new jars and when the first instars emerged, they were provided with fresh maize leaves. Rearing was performed constant conditions at 26 ± 2 ˚C and 50± 2 % RH.

The five insecticides tested (chlorfenapyr, indoxacarb, methomyl, emamectin benzoate and chlorantraniliprole) were prepared at a range of concentrations (8, 4, 2, 1, 0.5, 0.25, 0.125 and 0.0625 ppm) in the laboratory. Fresh maize leaves were dipped for 5 sec in each concentration of the prepared then left to dry in room temperature then fed second and fourth instars larvae. Fresh maize leaves treated with water were as a control. Ten newly molted larvae of second or fourth larvae pleased in clean jar and repeated five times for each tested concentration. Larvae were fed for 24 h on the treated leaves then fed on fresh untreated leaves for four days and the corrected mortality was recorded then the lethal concentration (LC_{50}, LC_{90}) of the five insecticides tested were investigated.

Field experiments

Field experiments were conducted in Al-Khawalid village of Sidi Salem Center in Kafr El-Sheikh Governorate - Egypt during 2022 and 2023 seasons to study five insecticides against Fall Armyworm in Maize. The trials were carried out in a Completely Randomized Design.

The area of the experiment was about one feddan and divided into 24 plots (each 175 m2) and planted with Maize, *Zea mays* (variety: white maize hybrid trio 323) on August 15th 2022 and August 22th 2023, where the number of replicates for each treatment was 4 replicates. Four plots were left without any treatment as a check. It was sprayed with a knapsack sprayer on the 12th and 30th of October 2022 and 2023 respectively, taking into consideration the spray solution directed it to the plant whorl by modifying the hollow cone nozzle. All usual agricultural practices were carried out except for the treatment with insecticides other than those used. Then the second spray was done 15 days after the first spray. Ten plants were selected randomly from each replicate, the plants were inspected to count alive larvae inside them before spraying and after 1, 3, 7 and 10 days after treatment and at harvest 10 plants were randomly selected for each replicate, and the number of healthy and damaged cobs was recorded and the grain yield of each plot was recorded at harvesting time and converted into feddan basis before statistical analysis.

Statistical analysis

To calculate the adjusted mortality of larvae the equation (Abbott, 1925) [1] was used and, the LC_{50} and slop values were determined by applying formula (Finney, 1971) [13] by using LDP Line software. Alive larvae were accounted and recorded, and reduction percentages was calculated by the equation of (Henderson and Tilton, 1955) [14]. The means number Analyzed to compare the differences between them of one-way variance analysis (ANOVA) at ($P<0.05$) by (Duncan, 1955) [11] using software Costat system for Windows, Version 6.311(Costat, 2006) [8].

Results and discussion

Toxicity data against larvae of *Spodoptera frugiperda* (FAW)

Toxicity data of the tested insecticides against the second and fourth larval instars of FAW is shown in Table (1) under laboratory conditions. Data indicated that emamectin benzoate and chlorantraniliprole had the highest toxicological activity against both instars, the field of study, while had the lowest effect was indoxacarb. In case of second instar the LC_{50} values of emamectin benzoate and chlorantraniliprole were close (0.09, 0.12ppm), also methomyl and indoxacarb were close, being 3.15 and 3.34 ppm, respectively and LC_{50} values reached the lowest and greatest being 0.464 and 10.79ppm when treated fourth larval instar with chlorantraniliprole and indoxacarb, respectively. Data agree with (Abd Elmageed *et al*., 2022) [2] reported that, emamectin benzoate had the greatest effect on FAW larvae after treated maize plants in the field compare with other tested insecticides, namely indoxacarb, methomyl and emamectin benzoate + lufenuron where methomyl recorded the lowest effect.

Table 1: Toxicity data of tested insecticides against the 2nd and 4th instar larvae of FAW

Treatments	LC_{50} (confidence limits)	Slope	LC_{25}	LC_{90}	Index
	Second larval instar				
emamectin benzoate	0.089 (0.05-0.13)	1.13	0.02	1.22	100.00
chlorantraniliprole	0.119 (0.07-0.16)	1.20	0.03	1.40	74.79
chlorfenapyr	0.811 (0.65-1.03)	1.83	0.35	4.07	10.97
methomyl	3.15 (2.32-5.26)	1.48	1.10	23.22	2.83
indoxacarb	3.342 (2.55-5.15)	1.76	1.39	17.83	2.66
	Fourth larval instar				
emamectin benzoate	0.464 (0.35-0.67)	1.36	0.15	4.07	100.00
chlorantraniliprole	0.546 (0.45-0.70)	2.12	0.26	2.20	84.98
chlorfenapyr	1.901 (1.52-2.58)	1.75	0.78	10.27	24.41
methomyl	8.578 (6.71-11.89)	1.62	3.29	52.86	5.41
indoxacarb	10.789 (8.70-14.49)	2.06	5.08	45.15	4.30

Semi field studies on fall armyworm (FAW)

The data in Tables 2 and 3 show the effect of field-tested insecticide treatments against FAW larvae in two consecutive seasons of infested maize fields. The infestation was minimal when treated with emamectin benzoate in both seasons as the general reduction of FAW larvae reached 71.5 and 73.2% in the 2022 and 2023 season, respectively.

In the 2022 season, the initial effect, after one day of treatment, was maximum against fall armyworm larvae for methomyl where reduction values were 97.3 and 96.5% at first and second application respectively, although the reduction percentage for methomyl reached a minimum after 10 days was 14.3% at second application. The reduction percentage records the highest values after 24 hours then it gradually decreases over time until it reaches the lowest values on day 10 after treatment, except for emamectin benzoate, in which the reduction percentage is highest on day 3 after the treatment (92.5%). Regarding general mean reduction the tested insecticides grouped in descending order as follows: emamectin benzoate, chlorantraniliprole, methomyl, indoxacarb and chlorfenapyr with percent 71.5, 60.3, 59.5, 58.1 and 51.5%, respectively (Table 2).

Table 2: Effect of field-tested insecticides on FAW larvae that infect maize plants in the 2022 season.

Treatments	Reduction percentage of FAW larvae after										General mean after application
	First application					Second application					
	1day	3days	7days	10days	mean	1day	3days	7days	10days	mean	
Chlorfenapyr	81.3	62.5	50.0	35.0	57.2	85.2	56.3	25.0	16.7	45.8	51.5
Indoxacarb	92.5	62.5	47.5	52.0	63.6	95.5	55.0	40.0	20.0	52.6	58.1
Methomyl	97.3	89.3	51.8	44.3	70.7	96.5	67.9	14.3	14.3	48.2	59.5
Emamectin benzoate	88.8	92.5	73.8	70.0	81.3	89.7	85.0	52.0	20.0	61.7	71.5
Chlorantraniliprole	90.6	68.8	53.1	45.0	64.4	91.2	68.8	40.0	25.0	56.2	60.3

Regarding the 2023 season, reduction percentage of FAW were higher than the 2022 season and in all tested insecticides the initial effect (after one day of treatment), was maximum effect against FAW larvae, with the reduction percentage being more than 90% compared to the days following the test after both application.

The reduction percentage records the highest values after 24 hours being 93.8, 91.1, 96.9, 93.8 and 90.6% after first application and being 94.2, 89.9, 95.4, 94.3 and 91.3% for after second application chlorfenapyr, indoxacarb, methomyl, emamectin benzoate and chlorantraniliprole, respectively, then it gradually decreases over time until it reaches the lowest values on the tenth day after treatment, methomyl had the lowest reduction (8.3%) on the tenth after second application and its mean reduction was 65.8 and 56.8% after first and second application respectively. Regarding general mean reduction the tested insecticides grouped in descending order as follows: emamectin benzoate, chlorfenapyr, chlorantraniliprole, indoxacarb and methomyl with percent 73.2, 64.3, 61.9, 60.7 and 56.8%, respectively (Table 3). The results agree with (Abd Elmageed *et al*., 2022) [2] which study four insecticedes namely emamectin benzoate, methomyl, emamectin benzoate + lufenuron and indxacarb data indicated that emamectin benzoate had the highest percentage reduction of Of Fall Armyworm larvae recording 76.66%, while, on the contrary in case of indxacarb insecticide recording 38.33% the lowest percentage reduction. Neomyl (methomyl) exhibiting showed a clear effect on larval instar of the fall armyworm where had range of percentage reduction from 62.14 to 91.4% at time period from 24hrs to 10 days after treatment with an average reduction 79.05% (Mourad *et al*., 2022) [18].

Table 3: Effect of field-tested insecticides on FAW larvae that infect maize plants in the 2023 season.

Treatments	Reduction percentage of FAW larvae after										General mean after application
	First application					Second application					
	1day	3days	7days	10days	mean	1day	3days	7days	10days	mean	
Chlorfenapyr	93.8	75.0	68.8	50.0	71.9	94.2	62.5	45.0	25.0	56.7	64.3
Indoxacarb	91.1	64.2	55.3	47.5	64.5	89.9	58.2	42.7	36.4	56.7	60.7
Methomyl	96.9	87.5	43.8	35.0	65.8	95.4	62.5	25.0	8.3	47.8	56.8
Emamectin benzoate	93.8	87.5	78.1	70.0	82.3	94.3	68.8	60.0	33.3	64.1	73.2
Chlorantraniliprole	90.6	75.0	53.1	45.0	65.9	91.3	75.0	40.0	25.0	57.8	61.9

Efficacy of tested insecticides on cob damage and grain yield caused by fall armyworm in maize

Data on cob damage percentage and grain yield caused by fall armyworm after treatments by the tested insecticides in Table (4). In season 2022, the data showed that, cob damage percentage in all treatments was decrease compare than untreated, and that the percentage of damage ranged between 22 – 35%, where the lowest cob damage percentage was recorded in the treatment with emamectin benzoate, which amounted to 22% but the highest recorded in the treatment with methomyl, which amounted to 35%, while the percentage of damage to the untreated cob reached 60%.

The results in Table (4) display that, grain yield was similar in the case of treatment with the two compounds emamectin benzoate and chlorantraniliprole and was the highest compared to the other tested insecticides were 2100.0 and 2062.5 kg/feddan and yield increased over control were 712.5 and 675.0 kg/feddan, respectively. Grain yield was increased in all treatments compare untreated where the highest significant grain yield was recorded with the treatment with emamectin benzoate reached 2100.0 kg/feddan followed by chlorantraniliprole, chlorfenapyr, indoxacarb and methomyl were 2062.5, 1875.0,1800.0 and 1725.0 kg/feddan, respectively while in case of untreated was 1387.5 kg/feddan. In season 2023, the results similar to season 2023 where cob damage percentage in all treatments was decrease compare than untreated, and that the percentage of damage ranged between 20 – 30%, and the lowest cob damage percentage was recorded in the treatment with chlorantraniliprole insecticide with value 20% and grain yield was 1912.5 kg/feddan and yield increased over control was 525.0 kg/feddan, while indoxacarb insecticide had the highest percentage cob damage and methomyl gave the lowest grain yield was 1800.0 kg/feddan. (Suthar *et al*., 2020) [24] reported that, chlorantraniliprole has a highly significant effect on the number of armyworm larvae that infect maize in the field, as well as the percentage of damage and damaged cobs, and an increase in grain yield. (Prasanna *et al*., 2018) [21] reported that, FAW cause damage to maize in the field where in young plants, FAW larvae cause core death and in older plants, FAW larvae infects them, resulting in reduced yield or quality due to feeding on corn cobs and kernels. Data agreement with (Mourad *et al*., 2022; Abd Elmageed *et al*., 2022) [18, 2] where reported that, use the insecticides emamectin benzoate, lambada cyhalothrin, indoxacarb, lufenuron, teflubenzuron and methomyl reduced the damage of plants compared to control.

Table 4: Effect of tested insecticides on cob damage and grain yield resulting from fall armyworm infestation of maize at 2022 and 2023 seasons

Treatments	2022 season			2023 season		
	Cob damage (%)	Grain yield (kg/ feddan) ± SE	Yield increased over control	Cob damage (%)	Grain yield (kg/ feddan)	Yield increased over control
Chlorfenapyr	28	1875.0 ± 65.4b	487.5	26	1837.5 ± 50.6b	450.0
Indoxacarb	32	1800.0 ± 21.2b	412.5	30	1875.0 ± 32.0b	487.5
Methomyl	35	1725.0 ± 49.4b	337.5	24	1800.0 ± 78.5b	412.5
Emamectin benzoate	22	2100.0 ± 78.9a	712.5	22	2160.0 ± 64.9a	772.5
Chlorantraniliprole	26	2062.5 ± 58.5a	675.0	20	1912.5 ± 64.0a	525.0
untreated	60	1387.5 ± 50.2c	-	66	1462.5 ± 164.6c	-

SE = standard error, means in the same column followed by the same letter have no significant differences

Conclusion

From this study observed that, application of the tested insecticides; namely chlorfenapyr, indoxacarb, methomyl, emamectin benzoate and chlorantraniliprole were effective and significantly against FAW larvae and emamectin benzoate was more toxicity with LC_{50} values 0.089 and 0.464ppm for second and fourth larval instar, respectively and when application all tested insecticides in the field led to reduction of FAW larvae and the infestation was minimal when treated with emamectin benzoate in both seasons as the general reduction of FAW larvae reached 71.5 and 73.2% in the 2022 and 2023 season, respectively and reduced damage plants and cob damage percentage and grain yield was increased.

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