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RESEARCH ARTICLE

Comparative effects of different insecticides on *spodoptera frugiperda* under laboratory conditions in Upper Egypt

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Abstract

The fall armyworm, *Spodoptera frugiperda*, is a highly destructive phytophagous pest of agricultural crops in various countries around the world. The study focused on evaluating the toxicity of six insecticides namely, emamectin benzoate, chlorfenapyr, indoxacarb, methomyl, azadirachtin and KZ oil against the 2nd, 3rd and 4th larvae of *S. frugiperda* under laboratory conditions using the Leaf-dip method. The results showed that the fourth instar larvae of *S. frugiperda* were less susceptible to the examined insecticides than the larvae in their second and third instars. Moreover, the treatment of Emamectin benzoate showed a higher residual mortality effect against second, third and fourth instars of *S. frugiperda* larvae with an average of 68.67% compared to other tested compounds. Mineral oil treatment showed a lower effect on residual mortality at 52.67%. The insecticides tested could be ranked in descending order as follows: emamectin benzoate, chlorfenapyr, indoxacarb, methomyl, azadirachtin and KZ oil. The corresponding LC_{50} values after 24 hours were 0.02, 0.07, 0.11, 0.14, 0.23 and 0.25 ppm for 2nd instar larvae , while for 3rd instar larvae, they were 0.04, 0.10, 0.21, 0.23, 0.28 and 0.29 ppm. For 4th instar larvae, the results could be arranged in descending order as follows: emamectin benzoate, chlorfenapyr, indoxacarb, methomyl, KZ oil and azadirachtin with corresponding LC_{50} values after 24 hours of 0.05, 0.12, 0.25, 0.34, 0.35 and 0.35 ppm. According to the results, emamectin benzoate is a good component of an integrated pest management program.

***Keywords*:** insecticides, fall armyworm, *Spodoptera frugiperda*, toxicity, maize

1. Introduction

In Egypt and other countries, maize (*Zea mays* L.) is considered one of the most significant food grain crops. This plant is a member of the family Graminaceae. After rice and wheat, it is the third most significant crop in the world. An annual plant, maize is a key commodity for global food security since it is consumed by people and animals and provides industrial raw materials for the production of bioproducts including alcohol, flour, and oil. Egypt planted 871,076.12 hectares of yellow corn in 2020, with an average production of 8154.48 tons/ha. (El-Rasoul *et al.*, 2020).

Numerous pests target maize plants from the beginning of their growth until harvest. One of the most harmful and destructive insect species that has recently infiltrated maize crops in Egypt and other nations is the fall armyworm (FAW), *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae) (Bakry and Abdel-Baky, 2023). Larvae of *S. frugiperda* devour leaves and stems. Economic crops like maize, sorghum, rice, sugarcane, wheat, cotton, and a variety of vegetables are among the foods that this pest consumes (Wu *et al.*, 2021). The most damaging pest has been identified based on its economic impact and damages (Anjorin *et al.*, 2022). The use of synthetic insecticides has long been a standard practice in agricultural pest management, especially in emergency scenarios where invasive species pose a threat to crops (Bakry and Gad, 2024). However, this approach has occasionally led to the emergence of powerful insecticide-resistant strains, as seen with *S. frugiperda* (El-Gaby *et al.,* 2024). Emamectin benzoate exhibited the highest toxicity against the third larval instar of *S. frugiperda* with the lowest LC_{50} value of 0.11 ppm (Dileep and Murali, 2022). The objectives of this study were to evaluate the efficacy of botanical extracts, mineral oil and some traditional insecticides against the 2^{nd}, 3^{rd} and 4^{th} instar larvae of *S. frugiperda* under laboratory conditions in Upper Egypt.

2. Materials and Methods

2.1. Larval Rearing

The culture of *S. frugiperda* was initiated with larvae collected from maize fields in different regions of Qena Governorate during the summer cultivations of 2023/2024. This study was conducted under laboratory conditions (at 30±1°C and 70±5% RH.), at Plant Protection Department, Faculty of Agriculture, South Valley University, Upper Egypt. To prevent cannibalism, the collected larvae were kept separately in plastic cups and fed fresh maize leaves until they pupated. Thereafter emerged adults were supplied with a piece of cotton soaked in a 10% sugar solution replaced daily and placed in small plastic cups at the bottom of the cages for adult nutrition. Eggs were collected and kept in another plastic cup until hatching.

2.2. Tested insecticides

Six insecticides, including emamectin benzoate, chlorfenapyr, indoxacarb, methomyl, azadirachtin and KZ oil, were tested against the 2^{nd}, 3^{rd} and 4^{th} larval stages of *S. frugiperda* using the leaf-dip method. The toxicity of plant extracts, and chemical compounds (Table 1) on the 2^{nd}, 3^{rd} and 4^{th} instar larvae of *S. frugiperda* was evaluated

2.3. Preparation of extracts and bioassay of tested compounds

To prepare the extracts, leaves of the wild plant, *Azadirachta indica* were collected from the South Valley University-Farm and brought directly to the lab. The leaves were dried in the shade for five days before being processed into aqueous extracts. The leaves of all plants, were thoroughly ground in a blender to obtain a powder. According to (References) One liter of distilled water and 150 grams of the powder were combined in beakers then placed in a water bath set at 50°C for an hour, The mixture was then transferred to a shaker for an additional one and a half hours before being, and finally filtered through filter paper in to glass beakers. The filtered solution was then distilled at 50°C and 200 rpm to remove the water and produce a dry powder. The dry powder was collected from the distillation apparatus and stored in tightly sealed containers until needed. Five concentrations (0.24, 0.12, 0.06, 0.03, and 0.015 ml/L) were evaluated, while, the control used only distilled

Table 1. Insecticides used in the study

Trade name of Compounds	Active Ingridients	Field Rate/Feddan
Speedo 7.5% WG	Emamectin benzoate	80 gm/200 L.w
Fanty 24 % SC	Chlorfenapyr	240 cm^3/200 L.w
Apezo 30 % WG	Indoxacarb	60 gm/200 L.w
Gold ben 90 % SP	Methomyl	300 gm/200 L.w
Azadirachta indica	Azadirachtin	300 cm^3/200 L.w
KZ oil 95% EC	Mineral Oil	3 liter/ 200 L.w

water. To prepare the solution for evaluation, the extract was mixed with one liter of distilled water and the desired concentration was achieved through a series of dilutions. The 2nd, 3rd and 4th instar larvae of *S. frugiperda* were exposed to the plant extracts by dipping them in the prepared quantities, drying them, and then feeding them to the larvae. Three replicates were conducted for each concentration with five larvae in each replicate placed separately. Mortality data were recorded after 24 hours (Abbott, 1925). Probit analysis (Finney, 1952) was used to determine the LC_{50} and LC_{90} values for each treatment.

3. Results and discussion

3.1. Potency of six insecticides against different instars of S. frugiperda larvae on maize leaves

Evaluation of six insecticides against the second, third, and fourth instars of *S. frugiperda* larvae was conducted as shown in Table 2 and Figures 1-3. The data showed that the percentages of mortality differed for the six insecticides against the second, third, and fourth instars of *S. frugiperda* larvae when compared to the second instar larvae, the average mortality percentage was 65.89%. Additionally, the LSD value was 4.48**, indicating highly significant variations in the mortality rate among the tested pesticides (Table 2). In this context, an average mortality rate of 59.56% was recorded against third-instar larvae. Mortality rates were also lower for all tested compounds against third-instar larvae compared to second-instar larvae mortality rates. The LSD value between the tested insecticides against the third instar larvae was 4.23** (Table 2). Moreover, the mortality rate against fourth instar larvae was lower than the mortality rate against third instar larvae in all different treatments with an average of (57.44%). Specifically, the mortality rates of treatments tested against larvae in their fourth instar showed significant differences (LSD value 2.56**, Table 2).

It is evident that the percentage effects of the tested insecticides against the second, third and fourth instars of *S. frugiperda* larvae were calculated using Abbott's formula as 65.89, 59.56 and 57.44%, respectively (Figs. 1 and 2). Emamectin benzoate treatment showed a higher residual mortality effect against second, third and fourth instars of *S. frugiperda* larvae with an average of 68.67% compared to other tested compounds. Mineral oil treatment showed a lower effect on residual mortality at 52.67% (Table 2 and Figure 3). The results concluded that the fourth instar larvae of *S. frugiperda* were less susceptible to the examined insecticides compared to the second and third instar larvae. Statistical analysis of the data showed highly significant differences between different treatments and different stages of *S. frugiperda* larvae (LSD value was 3.90**) (Table 2).

The above results are consistent with Jansson *et al.* (1997), who evaluated larval mortality in *S. frugiperda* populations exposed to different insecticides and found that *S. frugiperda* mortality was higher in populations exposed to emamectin benzoate. Abdel-Baky *et al.* (2019) indicated that emamectin benzoate at a concentration of 5.7% was the most potent insecticide against the larval stages of *S. littoralis* on tomato leaves. Idrees *et al*. (2022) mentioned that emamectin benzoate caused the highest mortality rate compared to other synthetic insecticides. Rizvi and Deole (2022) recorded that the highest larval mortality was caused by emamectin benzoate 5% SG.

3.2. Bioactivity testing of insecticides

Data in Tables (3, 4 and 5) and Figures. (4, 5 and 6) indicated the relative toxicity of the toxic action of emamectin benzoate, chlorfenapyr, indoxacarb, methomyl, azadirachtin and KZ oil against the 2nd instar larvae of *S. frugiperda* under laboratory conditions using the leaf dipping method at 24 hours post treatment. The data clearly show that the tested insecticides can be arranged in descending order as the following: emamectin

Table 2. Toxicity of tested insecticides against second, third and fourth instars of *S. frugiperda* larvae on maize leaves under laboratory conditions after 24 h.

Treatment	Mortality % ± S.E. (after 24 hours)			L.S.D. (Within instars) at 0.05	Residual Effect (%)
	2nd instar larvae	3rd instar larvae	4th instar larvae		
Azadirachtin	62.00	54.00	50.67	2.22 **	54.00
Mineral Oil	59.33	52.67	56.00	4.00 **	52.67
Methomyl	65.33	57.33	56.67	4.51 **	57.33
Indoxacarb	65.33	59.33	58.67	5.65 **	59.33
Chlorfenapyr	71.33	65.33	60.00	7.93 **	65.33
Emamectin benzoate	72.00	68.67	62.67	8.22**	68.67
Average Mortality % /instar	65.89	59.56	57.44	---------	59.56
L.S.D. (Within different treatments) at 0.05	4.48**	4.23**	2.56**	2.13**	1.11**
L.S.D. (Within different instars × treatments) at 0.05			3.90**		

** Highly significant at P ≤ 0.01

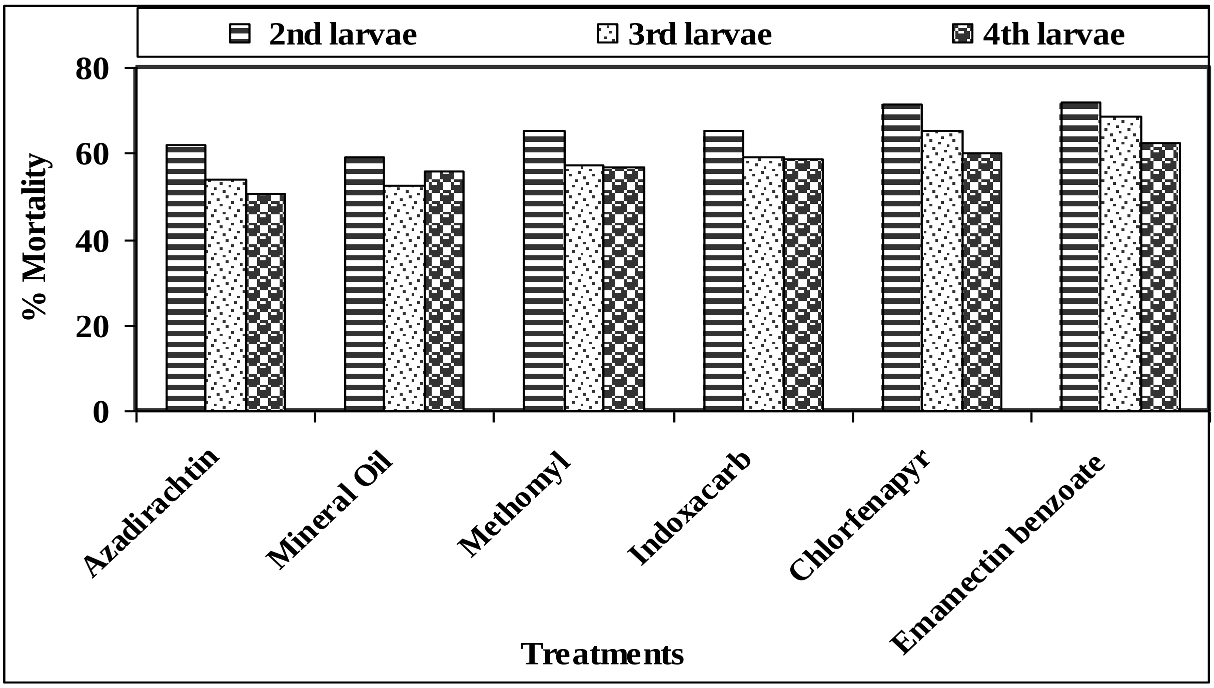

Fig. 1. Effect of exposure to tested insecticides against second, third and fourth instars of *S. frugiperda* larvae on maize leaves under laboratory conditions

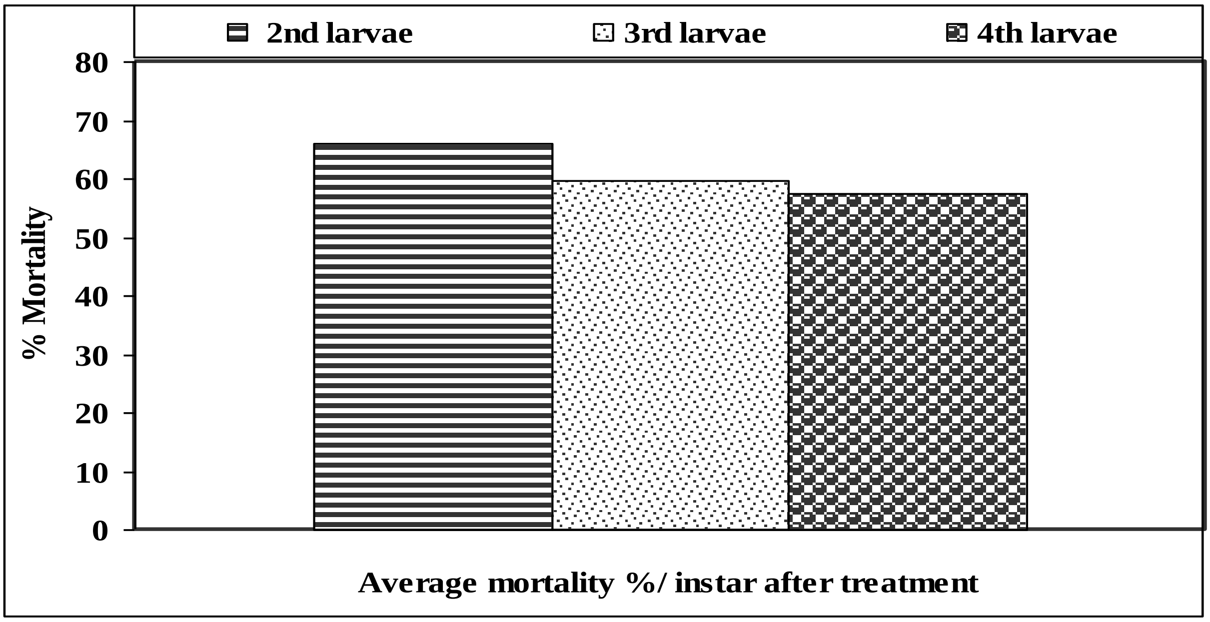

Fig. 2. Effects of exposure to tested insecticides against second, third and fourth instars of *S. frugiperda* larvae on maize leaves under laboratory conditions

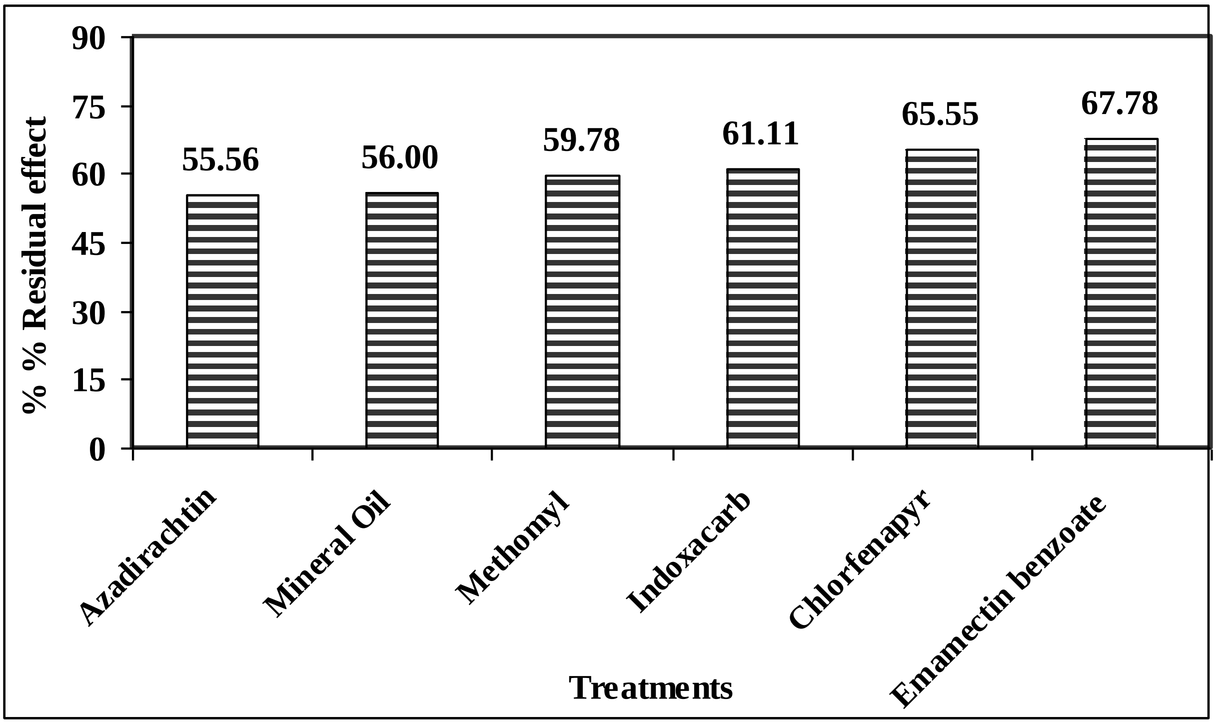

Fig. 3. Residual effects of exposure to tested insecticides against second, third and fourth instars of *S. frugiperda* larvae on maize leaves under laboratory conditions

benzoate, chlorfenapyr, indoxacarb, methomyl, azadirachtin and KZ oil. The corresponding LC_{50} values were 0.02, 0.07, 0.11, 0.14, 0.23 and 0.25ppm. As shown in Table (2) toxicity of tested insecticides against the 2nd instar larvae of *S. frugiperda* after 24 hours was noted. The toxicity index of emamectin benzoate, chlorfenapyr, indoxacarb, methomyl, azadirachtin and KZ oil were 100.0, 33.33, 19.64, 15.39, 9.48 and 8.80% at the LC_{50} level, respectively, as illustrated in Fig. (4). Data in Table 4 show the toxicity of tested insecticides against the 3rd instar larvae of *S. frugiperda* after 24 hours. It was observed that the toxicity index of emamectin benzoate, chlorfenapyr, indoxacarb, methomyl, azadirachtin and KZ oil were 100.0, 40.39, 20.29, 17.95, 14.89 and 14.48% at the LC_{50} level, respectively. The corresponding LC_{50} values after 24 h. were 0.04, 0.10, 0.21, 0.23, 0.28 and 0.29 ppm in the case of 3rd instar larvae, as illustrated in Fig. (5).

Table 3. Toxicity of tested insecticides against the 2nd instar larvae of *S. frugiperda* after 24 h

Insecticide	$\chi 2$	LC_{50} (ppm)	Confidence Limits		Toxicity Index	Slope ±	LC_{90} (ppm)
			Lower	Upper			
Emamectin benzoate	2.91	0.02	0.01	0.04	100.0	1.14±0.28	0.30
Chlorfenapyr	1.69	0.07	0.02	0.10	33.33	1.34±0.38	0.60
Indoxacarb	5.43	0.11	0.03	0.20	19.64	0.92±0.26	2.80
Methomyl	0.51	0.14	0.04	0.24	15.39	0.98±0.26	2.88
Mineral Oil	6.59	0.23	0.12	0.37	9.48	1.07±0.26	3.63
Azadirachtin	5.09	0.25	0.12	0.40	8.80	1.03±0.26	4.43

Toxicity index = [(LC_{50} of the most toxic tested compound/LC_{50} of the tested compound) x 100]

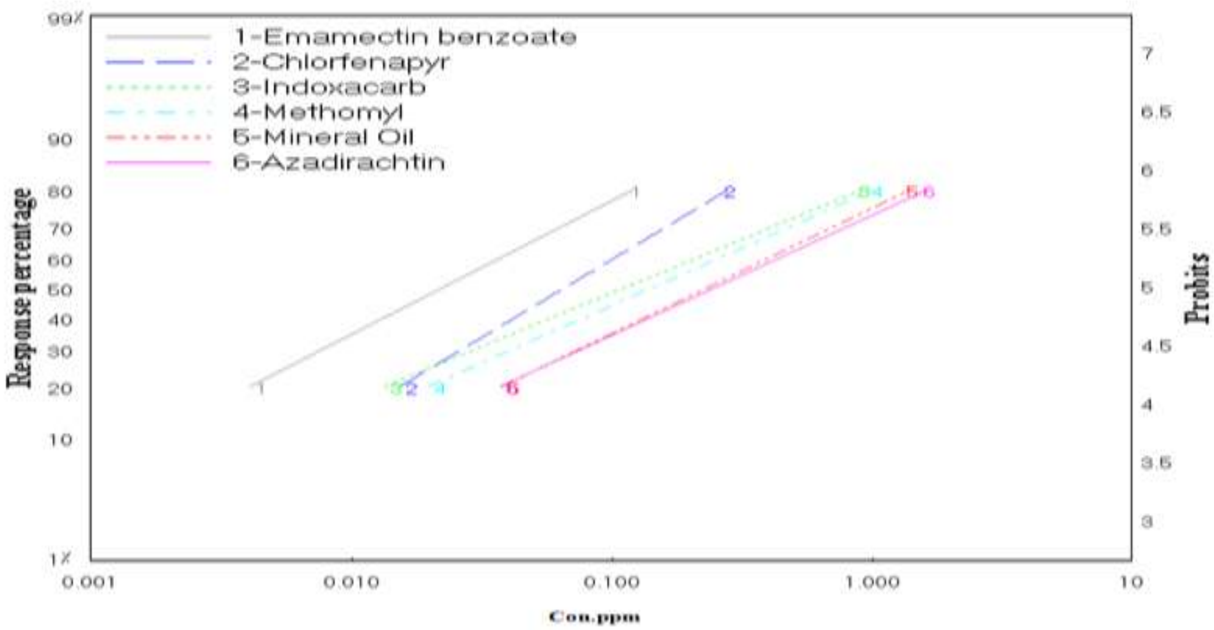

Fig. 4. Toxicity of tested insecticides against the second instar larvae of *S. frugiperda* after 24 h

Table 4. Toxicity of tested insecticides against the 3rd instar larvae of *S. frugiperda* after 24 h

Insecticide	$\chi 2$	LC_{50} (ppm)	Confidence Limits		Index	Slope ±	LC_{90} (ppm)
			Lower	Upper			
Emamectin benzoate	2.26	0.04	0.02	0.07	100.0	0.94±0.26	0.98
Chlorfenapyr	0.55	0.10	0.05	0.16	40.39	1.25±0.36	1.10
Indoxacarb	2.57	0.21	0.09	0.36	20.29	0.88±0.25	5.95
Methomyl	0.84	0.23	0.10	0.39	17.95	0.95±0.26	5.19
Azadirachtin	1.73	0.28	0.14	0.47	14.89	0.98±0.26	5.77
Mineral Oil	4.33	0.29	0.17	0.45	14.48	1.15±0.26	3.75

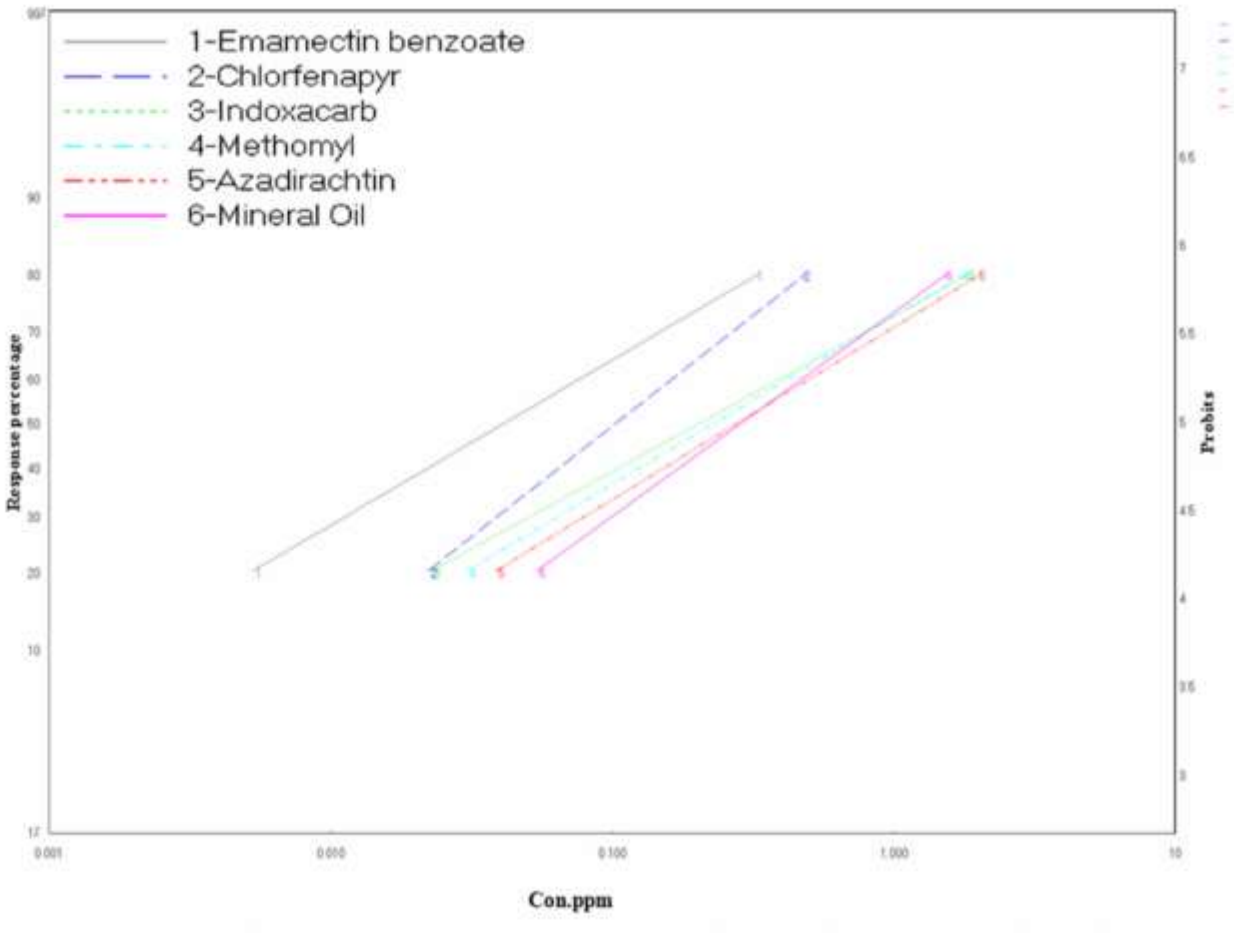

Fig. 5. Toxicity of tested insecticides against the third instar larvae of *S. frugiperda* after 24 h.

Data in Table (5) indicate the toxicity of tested insecticides against the 4th instar larvae of *S. frugiperda* after 24 hours. It was noted that the toxicity index of emamectin benzoate, chlorfenapyr, indoxacarb, methomyl, azadirachtin and KZ oil were 100.0, 42.74, 21.03, 15.68, 15.10 and 15.01% at the LC_{50} level, respectively. Additionally, Figure (5) presents the confidence limits of LC_{50}, and their overlap with others. For indoxacarb, methomyl, azadirachtin, and mineral oil, it is evident that the confidence limits overlap, indicating no significant difference between them. In the case of 4th instar larvae the corresponding LC_{50} values after 24 hours were 0.05, 0.12, 0.25, 0.34, 0.35 and 0.35 ppm while the LC_{90} values were 0.86, 1.34, 7.49, 7.17, 7.41 and 4.70 ppm. On the other hand, $\chi 2$ values were 2.46, 0.49, 1.88, 0.55, 1.52 and 3.77 respectively, as illustrated in Fig. (6). The data exhibited the emamectin benzoate was the most toxic compound against the 2nd, 3rd and 4th instars of *S. frugiperda* larvae after 24 hours and the difference between the values of LC_{50} was significant. It is obvious that emamectin benzoate had the steepest toxicity line and KZ oil had the flattest, however chlorfenapyr, indoxacarb, methomyl and azadirachtin line in between; this reflects the superiority of emamectin benzoate and inferiority of KZ oil, as shown in Tables (3, 4, 5) and Figures (4,5,6).

Table 5. Toxicity of tested insecticides against the 4th instar larvae of *S. frugiperda* after 24 h

Insecticide	$\chi 2$	LC_{50} (ppm)	Confidence Limits		Index	Slope ±	LC_{90} (ppm)
			Lower	Upper			
Emamectin benzoate	2.46	0.05	0.03	0.08	100.0	1.06±0.26	0.86
Chlorfenapyr	0.49	0.12	0.07	0.20	42.74	1.24±0.36	1.34
Indoxacarb	1.88	0.25	0.12	0.46	21.03	0.87±0.25	7.49
Methomyl	0.55	0.34	0.18	0.58	15.68	0.97±0.25	7.17
Azadirachtin	1.52	0.35	0.19	0.61	15.10	0.97±0.25	7.41
Mineral Oil	3.77	0.35	0.22	0.56	15.01	1.14±0.26	4.70

$\chi 2$ = Chi-square T. I. = Toxicity Index (compared with Emamectin benzoate)

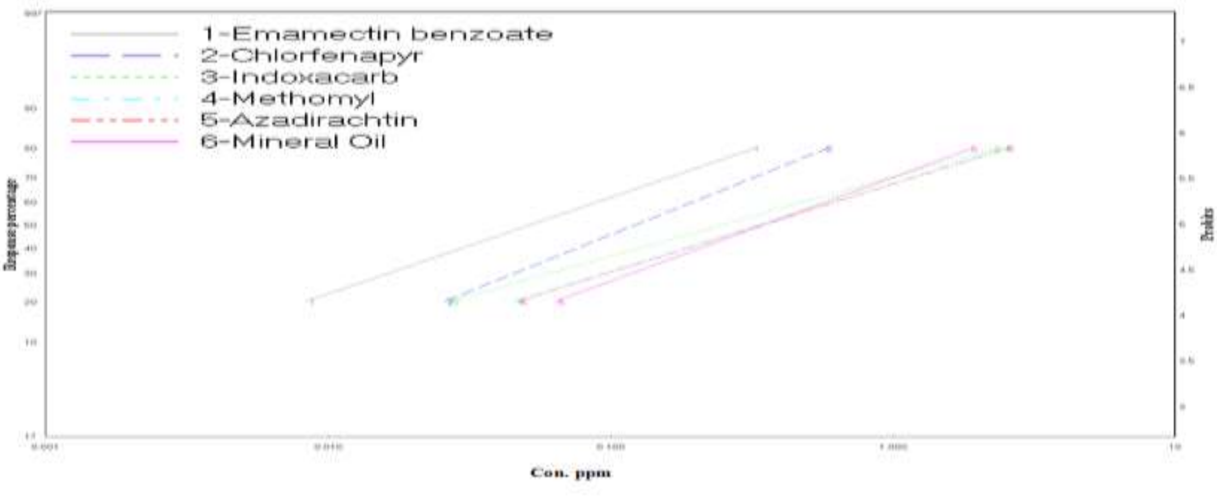

Fig. 6. Toxicity of tested insecticides against the fourth instar larvae of *S. frugiperda* after 24 h

Table 5 and figure 6 presented the extension of confidence limits of LC_{50}, and their overlap with others. It is clear that the confidence limits overlap for indoxacarb, methomyl, azadirachtin and mineral oil, but do not overlap for emamectin benzoate and chlorfenapyr. Thus, it is obvious that there is no significant difference between indoxacarb, methomyl, azadirachtin, chlorfenapyr and mineral oil, but there is significant difference with emamectin benzoate.

These results were in agreement with those of Ahmed *et al*. (2022), who demonstrated activity of emamectin benzoate, chlorpyrifos and against fall armyworm larvae in their third instar, with an LC_{50} value of 0.014

mg/L; however, the insecticide's efficacy declined on the tenth day of treatment. Additionally, Han *et al*., (2023) studied the fourth instar of *S. frugiperda* larvae to test the toxicity of the pesticide emamectin benzoate (5% SG). The LC_{50} value reached 0.0079 ppm, and a concentration of 0.02 ppm significantly contributed to the larvae's toxicity causing 77% death. However, Aly *et al*., (2024) discovered that the quantity of *S. frugiperda* larvae was reduced by an average of 0.51 larvae per plant when applied at a dosage of 0.15 g/L. Furthermore, Nasir *et al.*, (2021) and Shivakumara *et al*., (2024) showed efficacy in controlling *S. exigua* larvae, resulting in a notable reduction in the larval population and an antifeedant impact studying concentrations of up to 43 g/L,. The significance of oleander extract was demonstrated by Putri *et al.*, (2023), who found that over the course of 20 days of observation, a concentration of 1.25 and 0.23% resulted in a mortality rate of 100 and 5%, respectively. The higher extract concentration increased the more toxic the effect was on *S. frugiperda* larvae, with LC_{50} and LC_{95} values of 0.54 and 1.76%, respectively. The efficiency of castor seed aqueous extract against *S. frugiperda* larvae was investigated by Kombieni *et al.*, (2023) and assessed in a lab setting. According to the findings, larvae died in the lab at rates of 60.3% and 75.8%, at concentrations of 200 and 250 g/L, respectively. While Abdullah *et al*., (2024) tested the toxicity of castor extract on *S. frugiperda* larvae in their third larval instar; they discovered that the LC_{50} was 2241 ppm after 24 hours.

4. Conclusion

According to the results of the bioassay of the tested insecticides, emamectin benzoate was the most toxic compound, whereas KZ oil was the least toxic against *S. frugiperda*. It may be advisable to spray emamectin benzoate on maize plants to control this pest because the findings of the investigation showed that it provides protection against *S. frugiperda*. To reduce of resistance, pesticide residues, soil contamination, and promote sustainable agricultural yields, alternative pest management techniques such as plant extracts should be utilized.

Declarations

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All Institutional Review Board Statements are confirmed and approved
Data Availability Statement
Data presented in this study are available on fair request from the respective author
Ethics Approval and Consent to Participate
Not applicable
Consent for Publication
Not applicable
Conflicts of Interest
The authors disclosed no conflict of interest

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