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Lethal and sublethal effects of different insecticides against the fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae)

Heba, S. Abd El-Aty; Abd El-Salam, A. Farag; El-Zahi, Saber El-Zahi and Ahmed, A. A. Abdel-Aziz

Plant Protection Research Institute, Agricultural Research Center, Dokki , Giza , Egypt.

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Abstract

The fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae), which has entered Egypt in the current decade, is considered one of the most destructive pests of economic agricultural crops, mainly maize. This pest is difficult to control without using chemical insecticides because of its rapid spread over fields with severe infestations. In this study, the chemical insecticides indoxacarb, hexaflumuron, profenofos, methoxyfenozide, spinosad, tolfenpyrad, and lufenuron were tested for their acute and latent activity against *S. frugiperda*. The insect growth regulators lufenuron, methoxyfenozide, and hexaflumuron proved to be the most toxic to *S. frugiperda* larvae, followed by indoxacarb and spinosad. The tested insecticides affected the biological aspects of the consequent development stages of treated larvae. Hexaflumuron and lufenuron resulted in the lowest pupation percentage. Tolfenpyrad induced the highest percentage of deformed pupae, while methoxyfenozide resulted in the least percentage of normal adults. Based on the outcomes of this study, lufenuron, methoxyfenozide, hexaflumuron, and tolfenpyrad could be effectively used to face the menace of *S. frugiperda* on host plants.

Introduction

Maize, *Zea mays* L., stands out as one of the most crucial cereal crops on our planet, playing a vital role in food security, animal feed, and various industrial applications. In countless regions, it serves as a staple food and significantly boosts rural economies, especially in developing countries where agriculture is not just a livelihood but a way of life. The corn plant, classified as *Z. mays*, belongs to the Poaceae family and is

increasingly recognized for its agricultural significance both locally and globally (Idikut and Kara, 2013). Its demand continues to rise across the world, largely due to the remarkable diversity found among its grains, coupled with its impressive capacity for high yields and adaptability (Yaşak *et al.*, 2003). Each ear of corn tells a story of resilience and versatility, making it a cherished crop in the ever-evolving landscape of agriculture.

According to scientific research, the fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae), is a dangerous enemy in the field of agriculture. This insect is a danger to crops worldwide because of its amazing capacity for long-distance migration and its varied diet. Because of its ability to adapt, it has become a significant agricultural threat that transcends national boundaries and continents (Goergen *et al.*, 2016, and Kuate *et al.*, 2019). *S. frugiperda* is a native insect pest of the Americas. The first indications of its invasion were seen in 2019 in Yunnan Province, China (Zhang *et al.*, 2019). Since then, it has swept through provinces like an unstoppable force, causing havoc and causing local farmers to suffer terrible financial losses, especially in corn production (Huang *et al.*, 2020, and Wu *et al.*, 2021). Nigeria was where it initially surfaced in Africa in January 2016 (Goergen *et al.*, 2016). It was first identified in sub-Saharan Africa (Abrahams *et al.*, 2017) and then in Senegal (Brévault *et al.*, 2018). Later, it was discovered in a maize field in a village in Kom Ombo city (Aswan Governorate, Upper Egypt) by the Ministry of Agriculture's Agricultural Pesticide Committee (APC) in Egypt. In 2019, it spread to the northern region of Egypt (Rashed *et al.*, 2022).

The larvae damage the plants by eating the leaves. The larvae feed mainly on the leaf epidermis and bore holes in the leaves, which is a typical symptom of fall armyworm damage. The whorls of leaves provide nutrients to the seedlings, resulting in leaf death. In older plants, the larger larvae in the whorls feed on the cobs or kernels, reducing yield and quality (Abrahams *et al.*, 2017 and Capinera, 2017).

In many parts of the world, managing the pest is a problem for maize productivity

(Blanco *et al.*, 2016; Day *et al.*, 2017 and Li *et al.*, 2021). The prompt application of various efficient management techniques is necessary to combat this pest. Objective assessments of these tactics' capacity to safeguard the crop should be used to justify their application in order to cut down on wasteful spending and stop significant financial losses brought on by pest infestations. To combat this pest, integrated pest management strategies have been developed to combat this pest, including agronomic practices such as crop rotation and the use of resistant varieties, as well as biological control agents (FAO, 2021). Chemical insecticides remain the most widely applied method due to their fast action and effectiveness in controlling severe infestations, particularly when other options are limited or ineffective (Harrison *et al.*, 2019 and Tejeda-Reyes *et al.*, 2023). Their use must be regulated carefully. For instance, a study conducted in Nepal assessed five chemical insecticides and found that spinosad 45% SC, spinetoram 11.7% SC, and chlorantraniliprole 18.5% SC consistently outperformed other treatments in reducing larval infestation and damage symptoms in maize crops (Bajracharya and Binu, 2024). Similarly, research in India during the kharif season demonstrated that spinetoram 11.7 SC, chlorantraniliprole 18.5 SC, and emamectin benzoate 5 SG significantly lowered larval density and leaf damage compared to untreated controls (Sahana *et al.*, 2024).

Therefore, this study aims to evaluate some insecticides from different chemical groups to determine the most effective against the fall armyworm in terms of acute toxicity and sublethal effects.

Materials and methods

1. Insecticides:

Data on the insecticides used in this study are given in the following Table (1).

Table (1): Characteristics of the insecticides evaluated in this study.

Common name	Commercial name	Formulation	Chemical group	Manufacturing company
Indoxacarb	Easo	30% WG	Oxadiazine	Nantong Shezhoang Chemical LTD, China
Hexaflumuron	Scorch	10% EC	Insect growth regulator	Dezhou Luba Fine Chemical Co. Ltd, China
Profenofos	Selian	72% EC	Organophosphates	UPL Co. LTD, India
Methoxyfenozide	Winsor	24% SC	Insect growth regulator	Agrobrest Grup Tarim Co, Turkey
Spinosad	Master Top	48% SC	Spinosyn	Qilu Pharmaceutical (Inner Mongolia) Co. LTD, China
Tolfenpyrad	Tolficide	15% SC	Pyrazole	Hailir Pesticide and Chemical Group Co. LTD, China
Lufenuron	Matchoron	5% EC	Insect growth regulator	Zhejiang Segal Science and Technology, China

2. Insects:

A field strain of *S. frugiperda* was collected from infested maize fields at Kafr El-Sheikh governorate and transmitted to Sakha Agricultural Research Station. The insects were reared on castor leaves, *Ricinus communis* (L.), for three generations under laboratory conditions of $27 \pm 2^\circ\text{C}$, 65 ± 5 RH., and 14:10 (L:D) photoperiod, according to Eldefrawi *et al.* (1964), with some modifications to minimize cannibalistic behavior of the insect. The newly molted second and fourth instar larvae were homogeneously chosen for the different tests in this study.

3. Toxicity of the test insecticides on *Spodoptera frugiperda*:

To determine the toxicity of the tested insecticides on 2nd and 4th instar larvae of *S. frugiperda*, the leaf-dipping technique was adopted. A series of seven concentrations were prepared from each insecticide using tap water for dilution. Fresh castor leaves were immersed in each concentration for 20 seconds and in water only for the control treatment and then left at room temperature to dry. Ten newly molted 2nd or 4th instar

larvae were distributed in a plastic pot of 15 cm diameter (representing one replicate) and fed on treated leaves for 24 hrs. Ten replicates were made for each concentration. The number of dead larvae was recorded 24 and 72 hrs. after exposure to conventional insecticides and insect growth regulators, respectively. Percentages of mortality were corrected versus control using the equation of Abbott (1925) and submitted to probit analysis (Finney, 1971).

4. Sublethal effects:

The effects of the tested insecticides on the biological aspects of *S. frugiperda* were studied by exposing the 4th instar larvae to LC₂₅ values using the leaf-dipping method. LC₂₅ of each insecticide was prepared, and the 4th instar larvae were treated as described above. The surviving larvae were transferred to uncontaminated new pots and monitored till complete development. The biological aspects, including percentages of pupation, normal and deformed pupae, and normal and malformed adults, were recorded.

5. Statistical analysis:

The results obtained were submitted for one-way analysis of variance (ANOVA). Means were separated for significance at the LSD 0.05 level by the software of the Statistical Analysis System (SAS) Institute (2002).

Results and discussion

1. Susceptibility of *Spodoptera frugiperda* to some insecticides:

The results given in Table (2) illustrated that lufenuron significantly exhibited the highest activity against the 2nd instar larvae of *S. frugiperda* with LC₅₀ value of 9.51 mg a.i./L followed by hexaflumuron with LC₅₀ value of 19.62 mg a.i./L. Based on the criterion of confidence limits overlapping, hexaflumuron, methoxyfenozide, and indoxacarb did not differ significantly from each other, with LC₅₀ values ranging from 19.62 to 23.37 mg a.i./L. Spinosad and tolfeprad had overlapping confidence limits and insignificant differences between them in their effect on the 2nd instar larvae of the fall armyworm, recording LC₅₀ values of 48.56 and 59.37 mg a.i./L, respectively.

Comparatively, profenofos were the least toxic to the 2nd instar larvae of *S. frugiperda* with LC₅₀ value of 231.54 mg a.i./L. The high slope values demonstrated that *S. frugiperda* larvae were of high homogeneity towards the chemical compounds evaluated.

Concerning the toxicity of the tested insecticides to the 4th instar larvae of *S. frugiperda*, data presented in Table (3) showed that indoxacarb was the most toxic, with LC₅₀ of 18.14 mg a.i./L. Lufenuron, methoxyfenozide, and hexaflumuron showed good activity against the 4th instar larvae of *S. frugiperda* with LC₅₀ values of 24.39, 25.14, and 28.27 mg a.i./L without significant differences among them.

The organophosphorus compound, profenofos, indicated the least activity

against this pest showing 284.24 mg a.i./L. From data on slope value, it could be noticed that the 4th instar larvae showed homogeneity to test insecticides except for tolfeprad.

2. Effect on the biological aspects of *Spodoptera frugiperda*:

Regarding the effect of the tested insecticides on some biological aspects of *S. frugiperda*, percentages of pupation, normal pupae, deformed pupae, normal adults, and malformed adults were studied (Table 4). The percentage of pupation was significantly affected after exposure of *S. frugiperda* 4th instar larvae to sublethal concentrations of the tested insecticides. The insect growth regulators, hexaflumuron and lufenuron, were the most potent in decreasing the percentage of pupation (21.5 and 30.6%, respectively), followed by indoxacarb (56.7%) and tolfeprad (59.2%).

On the contrary, profenofos resulted in the highest percentage of pupation (76.8%) compared to 97.8% pupation in control. The highest percentage of deformed pupae was found in tolfeprad treatment (63.4%), whereas the lowest percentages were recorded in profenofos (17.7%) and lufenuron (10.8%) as compared to the control treatment (4.4%). The emergence of normal adults was affected significantly after exposure of 4th instar larvae to different insecticides. Methoxyfenozide resulted in the highest percentage of malformed adults (62.5%), followed by hexaflumuron (35.9%), tolfeprad (27.3%), and lufenuron (26.7%) relative to the control (2.1%).

Until now, and even in the foreseeable future, using chemical insecticides in managing *S. frugiperda* cannot be abandoned due to the high population densities at which the fall armyworm appears in the infested fields. The present

study highlighted the susceptibility of *S. frugiperda* to insecticides from different chemical groups, in addition to the latent effects on the biological aspects and development process of the fall armyworm.

Toxicity tests indicated that lufenuron, hexaflumuron, and methoxyfenozide were found to be very effective compared with profenofos, tolfenpyrad, and spinosad. Insecticides are important tools used for the control of *S. frugiperda* worldwide, notably in Africa (Sisay *et al.*, 2019). Belay *et al.* (2012) indicated that spinosad and indoxacarb caused 80% mortality 96 h after treatments. Spinosad indicated acute activity against *S. frugiperda* larvae in laboratory bioassay (Bajracharya and Binu, 2024). Similarly, Khanal *et al.* (2024) showed the highest toxicity of spinosad when conducting leaf dip on 3rd instar larvae against *S. frugiperda*.

Yet another study illustrated that LC₅₀ values, including indoxacarb, were significantly higher than the LC₅₀ of spintoram (Hardke *et al.*, 2011). In another study, indoxacarb showed the highest efficacy on *S. frugiperda* (Sharanabasappa *et al.*, 2024). Mallapur *et al.* (2019) reported that spinosad gave efficient control of *S. frugiperda*. The lowest

effective treatment against *S. frugiperda* was found to be profenofos (Sangle *et al.*, 2020). Mahmoud *et al.* (2024) showed that the exposure of *S. frugiperda* larvae to spinosad resulted in a significant decrease in the biological aspects of the pest. Abd El-Samei *et al.* (2019) showed that LC₂₅ of spinosad demonstrated a significant effect on the developmental aspects of *S. frugiperda* after 48 hrs. of exposure of the 3rd and the 5th instar larvae.

Recent studies in Indonesia indicated activities of spintoram as a chemical control tool against *S. frugiperda* and caused a significant increase in maize yield in treated plants (Nonci *et al.*, 2020). Meanwhile, Khamis *et al.* (2023) found that spintoram introduced good control, especially on first instar larvae of *S. frugiperda*, and indicated equipollent decreases in prolongation of % pupation of the second instar larvae. On the contrary, studies by Gao *et al.*, (2021) illustrated that spintoram had no impact on the pupation percentage of the fall armyworm. Chanadar and Tayde (2023) revealed that spinosad, profenofos, and indoxacarb were significantly superior to other insecticides in the control of *S. frugiperda*.

Table (2): Susceptibility of 2nd instar larvae of *Spodoptera frugiperda* to the tested insecticides.

Treatment	LC ₅₀ (mg a. i. L ⁻¹)	C. L. Lower –Upper	LC ₉₀ (mg a. i. L ⁻¹)	C. L. Lower –Upper	Slope ±SE	χ ²	P
Indoxacarb	23.37	19.31-27.46	132.22	98.70-203.56	1.70±0.187	0.622	0.892
Hexaflumuron	19.62	16.56-22.54	86.05	66.76-126.45	1.99±0.231	6.346	0.096
Profenofos	231.54	200.65-263.61	902.50	726.51-1215.98	2.16±0.202	4.505	0.211
Methoxyfenozide	21.25	16.44-25.25	70.58	59.30-91.49	2.45±0.322	2.110	0.348
Spinosad	48.56	38.72-68.32	371.24	196.11-533.14	1.45±0.233	2.420	0.298
Tolfenpyrad	59.37	50.24-69.44	332.95	240.86-541.13	1.71±0.190	3.900	0.272
Lufenuron	9.51	3.87-13.50	132.61	69.42-367.31	1.12±0.287	3.044	0.218

Table (3): Susceptibility of 4th instar larvae of *Spodoptera frugiperda* to the tested insecticides.

Treatment	LC ₅₀ (mg a.i. L ⁻¹)	C. L. Lower – Upper	LC ₉₀ (mg a.i. L ⁻¹)	C. L. Lower –Upper	Slope ±SE	χ ²	P
Indoxacarb	18.14	14.99-21.18	80.15	64.80-107.37	1.98±0.196	7.265	0.063
Hexaflumuron	28.27	25.00-31.98	105.87	81.94-154.82	2.23±0.240	4.270	0.233
Profenofos	284.24	250.88- 320.67	1188.08	932.66-1670.06	2.06±0.196	2.448	0.484
Methoxyfenozide	25.14	18.94-30.21	114.82	87.42-184.38	1.94±0.297	0.519	0.771
Spinosad	30.28	24.37-38.62	265.60	147.82-805.98	1.35±0.222	2.178	0.336
Tolfenpyrad	39.49	25.13-52.80	214.02	141.34-489.75	0.91±1.435	0.632	0.889
Lufenuron	24.39	19.82-30.90	190.62	101.81-781.14	1.43±0.288	4.521	0.104

Table (4): Sublethal effects of various insecticides on treated 4th instar larvae of *Spodoptera frugiperda*.

Treatment	% pupation	% normal pupae	% deformed pupae	% normal adults	% malformed adults
Indoxacarb	56.7±1.3 e	68.7±2.5 e	31.3±1.8 b	81.2±2.9 b	18.8±0.7 d
Hexaflumuron	21.5±2.1 g	71.4±1.7 e	28.6±2.6 b	64.1±2.7 d	35.9±1.8 b
Profenofos	76.8±2.5 b	82.3±3.3 c	17.7±0.7 c	86.3±1.9 b	13.7±0.6 de
Methoxyfenozide	62.9±3.4 d	72.7±2.8 e	27.3±1.2 b	37.5±1.6 e	62.5±3.2 a
Spinosad	71.3±2.6 c	79.9±1.4 cd	20.1±1.1 c	82.8±2.4 b	17.2±0.9 d
Tolfenpyrad	59.2±1.6 e	36.6±1.9 f	63.4±2.8 a	72.7±3.1 c	27.3±1.4 c
Lufenuron	30.6±1.9 f	89.2±2.7 b	10.8±0.7 d	73.3±2.5 c	26.7±1.8 c
Control	97.8±0.9 a	95.6±1.8 a	4.4±0.3 e	97.9±1.3 a	2.1±0.1 f

In the same column, the means followed by the same letter did not differ significantly based on 5% significant level by Duncan (1955).

In conclusion, chemical control remains an unavoidable procedure in the management of invasive pests such as *S. frugiperda*, especially in high population density or outbreak cases. In the current study, the degree of *S. frugiperda* susceptibility varied based on the insecticide used. The insect growth regulators lufenuron, methoxyfenozide, and hexaflumuron proved to be the most toxic to *S. frugiperda* larvae, followed by indoxacarb and spinosad. The tested insecticides possessed latent activity on the subsequent developmental stages of the pest. Percentages of deformed pupae and

malformed adults were significantly affected. Tolfenpyrad and methoxyfenozide resulted in the highest percentages of deformed pupae and malformed adults, whereas the organophosphorus compound profenofos resulted in the least activity in this direction. Finally, lufenuron, methoxyfenozide, hexaflumuron, and tolfenpyrad could be effectively used to face the menace of *S. frugiperda* on host plants.

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