Growth of *Spodoptera frugiperda* on four host plants and its sensitivity to some insecticides using various exposure methods

Abdel Salam A. Farag[1*] and Heba S. Abd El-Aty[1]

[1] Plant Protection Research Institute, Agricultural Research Center, Dokki, Giza, Egypt

Correspondence Author: Abdel Salam A. Farag

Received 18 May 2024; Accepted 23 June 2024; Published 12 July 2024

Abstract

In the maize fields, fall armyworm, *Spodoptera frugiperda* (FAW) Smith (Lepidoptera: Noctuidae) is a polyphagous lepidopteran pest, destroying maize crop, causes serious economic damage to corn plants worldwide in recent years especially Egypt. Three different insecticides were application with four exposure methods and four host plants in this research under laboratory conditions against *S. frugiperda*. Emamectin benzoate was the high efficacy insecticide (LC_{50} 1.90 mg $_{a.\ i.}$ / L and Toxicity index 100 %). Therefore, emamectin benzoate was observed the average highest larvae mortality in the larva-dip, leaf-dip, film and spray methods of 83.57, 81.87, 81.25 and 77.27 %, respectively. While, the other insecticides were least toxic with average mortality percentage 75.62 and 48.75 % with, indoxacarb and pyradelil, respectively when the film method was used. The moderate activity of indoxacab and pyradelil spray and leaf-dip methods comparing to that larva-dip method. Also, limited research has been conducted on biological aspects of FAW reared on different plants. Our findings demonstrated that there were various in larvae development period reared on maize had the shortest development duration 16.75 days and pupa period 9.25 days, the fecundity (1650.50 egg) and fertility (95.23 %) were highest, while the larvae (20.00 days) and pupa (14.25 days) duration were the longer fed on cotton, the fecundity (1110.25 egg) and Fertility (66.87%) were least. There were also moderate in the development survival, fecundity and Fertility to FAW reared on cowpea and potato plants. The preferred host of FAW in vitro was maize and other host plants were intermediate host.

Keywords: *Spodoptera frugiperda*, host plants, insecticides, exposure methods

Introduction

The fall armyworm, *Spodoptera frugiperda* Smith (Lepid.: Noct.) has the ability to fed on more 350 host plants (Montezano *et al*., 2018) [20]. It causes severe damage to crops spatially corn plant and can cause tremendous yield reduce and high economic decline (Baudron *et al*., 2019 and Wan *et al*., 2021) [7, 32]. Although, the fall armyworm can cause reduce yields in corn and invasion into Asia and Africa has high increased the application of pesticides in maize (Fallet *et al*., 2022) [13]. Host plants significantly activity the growth and development survival, play an important role in age stage and reproduction laboratory conditions (Chen *et al*., 2023) [9]. Insecticides have quickly become essential of FAW control in Africa and Asia (Abraham *et al*., 2017 and Tambo *et al*., 2020) [1, 30]. However, to reduce the effect of FAW, several control options are used biopesticides, such as viruses or bacterium, neem extracts and insecticides (Guo *et al*., 2020) [16]. *S. frugiperda* is polyphagous and causes severe damage to *zea mays*, tremendous yield, causing impacting millions of hectares of *zea mays* crops and differences in development duration, larvae fed on maize had the shortest development period (Chen *et al*., 2022) [10]. The best host plant of the fall armyworm was *zea mays*, while castor been, mung bean and groundnut were intermediate, cotton was worst (Bavisa *et al*., 2021) [8]. Host plants for FAW best on determinant of the establishment, survival, growth, fecundity of herbivorous pests and were calculated for armyworm. However, host plant does not support the armyworm in the same way. From the present studies the host plant is a key determinant the growth of *S. frugiperda* can be application for rearing of the armyworm and the information of the life cycle parameters of the fall armyworm on host plants will help to made IPM programs this economic pest. Development and duration of *S. frugiperda* larvae have been infested vary with host plants and significant influence in maintaining the continuity of the insect during the year (Sharanabasappa *et al*., 2018) [25]. FAW, growth indices were low by feeding on castor been leaves than on *zea mays* leaves. However, for rearing armyworm, on *zea mays* leaves many be used as preferred, while caster been can be also used in case of the absence of the maize (Rashed 2023) [23]. Corn is the preferred host plant for *S. frugiperda* then sorghum and wheat, duration stage was losses when rice plant was larvae as diet. Thus, fecundity, life expectancy, duration of the armyworm was increased on maize leaves then sorghum, wheat and rice (Altaf *et al*., 2022 and Idrees *et al*., 2021) [4, 17]. FAW larvae fed on all plant parts of their host plants (Midega *et al*., 2018) [19]. The shorter life cycle and higher survival rate of the fell armyworm fed on *zea mays* observed, is one of the preferred hosts (Guo *et al*., 2021) [15]. Insecticides used are one of the major *S. frugiperda* management practices in growth and developing countries. Insecticides activity has not been studies well post the used in field. Hence, a vitro tests were conducted to select the best pesticides that have a higher effect on *S. frugiperda*.

Material and methods

Insecticides

Commercial formulations of

- Emamectin-benzoate (Amazon® 5.7% SG), supplied by Kenza Co., was applied at the rate of 80 g/Feddan.
- Pyridalyl (Pleo® 50% EC), supplied by Sumitomo Chemical Co. Ltd, applied at the rate of 100 ml/Feddan.
- Indoxacarb (Indoxacarb (Peksi, 15% EC), supplied by Du Pont Co., applied at 60 g /Feddan., Du Pont Co.).

Fall armyworm rearing

The laboratory strain of *S. frugiperda* was reared in the laboratory at Sakha Agricultural Research Station, plant protection research institute Branch on maize plants. Larvae were fed on fresh plants of maize, without exposure to pesticides into a glass jar covered with muslin cloth while adults were reared into wire cages containing folded paper oviposition, fed on a 10 % sucrose solution under laboratory conditions of 27±2°C, 65±5 RH and a 16 h light, 8h dark photoperiod. The newly moulted fourth instar larval was used in this study in the laboratory experiment.

1. Exposure methods

1.1. Spray method

Fourth instar larval of *S. frugiperda* were transferred to maize plants of one month age into plastic boxes (10×6 cm diameter), the maize plants were fall sprayed with 10mL insecticides solution for each treatment, and sprayed by a hand sprayer with a capacity of half a liter. Five replicates were made for each compound and the control. 10 newly moulted fourth instar larval of *S. frugiperda* were into each replicate. After treatment and complete dryness of the maize leaves, the 4th instar larval was directly transferred to each clean plastic box with aid of a fine hair brush. Larvae were applied with immersed ultrapure water. The plastic boxes were covered to prevent the larvae evasion. Fresh maize plants were changed every day. Larvae death was calculated at 24, 48, 72 and 96 hours after treatments (Fig.1a).

1.2. Leaf- dip method

Three synthetic insecticides were application for bioassay against 4th instar larval of fall armyworm using a film method. Five replicated were performed for each treatment. Fifty fourth instar larval of *S. frugipirda* were considered one compound. Three used rates at 1.90, 11.62 and 7.76 mg were application for the study. The concentrations and plastic boxes were prepared from each compound, each replicate (plastic box) with volume 2ml insecticides solution. After dryness of the treated boxes, 10 fourth instar larvae of *S. frugipirda* were placed to each treated plastic box using a fine brush and the boxes are covered to prevent the pest escape. After 24 h post treatment all individually were fed in plastic boxes with fresh maize plants without any insecticides. The larvae that failed to move were considered dead, while those who responded to the gently touch of a brush were considered alive. Individuals mortality was assessed at 24, 48, 72, 96 hours exposure to the insecticides (Fig.1b).

1.3. Film method

Toxicity effect of emamectin benzoate, pyridalyl and indoxacarb against of *S. frugipirda* using leaf dipping method, insecticides was prepared from distilled water. Five fresh maize leaves were dipped in each treatment for 20 second, had dried before being offer to *S. frugipirda* a larvae. The treated maize leaves were transferred into the plastic boxes. Fifty fourth instar larval of *S. frugipirda* were transferred in a plastic boxes for each treatment using a camel hair brush. Five replications were performed for each compound, fourth instar larval of *S. frugipirda* were fed on the treated maize plants in a plastic boxes with performed lid with control (water). Fresh leafs of maize were transferred from the field to laboratory with replaced every day. Data of larval mortality were recorded after 24, 48, 72, 96 h after exposure (Fig. 1c).

1.4. Larvae dip method

Insecticides solutions with concentrations were prepared with destined water. Fourth instar larval was dipping into insecticides solutions for ten second times. After complete drying of the submerged larvae, 50 newly moulted 4th instar larval of *S. frugipirda* were prepared to each treatment into plastic boxes using aid of brush, untreated maize plants were transferred in all the plastic boxes with larvae immersed in solutions. Five replications were made for each compound and the control. For the control, untreated larvae were placed from clean plastic boxes. The boxes were covered their lid to prevent the larvae scape. The data were recorded after 24, 48, 72, 96 h of the treatment (Fig.1d).

2. Host plants

The laboratory trials were conducted carried out at cotton at Sakha Agricultural Research Station, Plant Protection Research Institute Branch, Cotton Pesticides Evaluation Department during season 2024. Four food plants were applied in the experiments, maize (*zea mays* L), cowpea (*vigna unguiculata*, sweet potato (*Ipomoea batatas* L) and cotton (*Gossypium barbadense* L.). These hosts were tested because they are preferred host plants of *S. frugipirda*. So, all host plants were grown in plastic pots under normal conditions, plants were watered every five days during the growing season. Each host plant was placed into clean plastic boxes. Ten fourth instar larvae were placed in each replicate additional of the control. Larval that had been fed on each of the four host plants. The plastic boxes covered with muslin cloth for aeration and ventilation. Larvae were starved for 12 h. The plants consumed were replaced every day with fresh and clean one. Five replicates were conducted per each host plant. The adults were monitored every day for oviposition and mortality, and number eggs laid, and were observed for the estimate hatch percent, and the duration of survival of the larval stage, and the duration of pupation and the role at evaluating the impacts of host plants on the various life cycle traits of FAW (Fig. 2).

(a) Spray-method (b) Leaf-dip method (c) Film-method (d) Larva-dip method

Fig 1: Sensitivity of *S. frugiperda* to some insecticides using four different exposure techniques

Fig 2: Development of *S. frugiperda* on some host plants (Maize- Cowpea- Sweet potato- Cotton)

Statistical analyses

The statistical data were analyzed by one- way (ANOVA) using SPSS 23.0 software (IPM), 2015), with mortality rate corrected by Abbott technique (Abbott, 1925) [3]. Duncan's Multiple Range test DMRT ($P < 0.05$) was used to compare the significant difference between the compounds. Toxicity index was determined according to Sun equation (Sun, 1950) [29] as follows:

$$\text{Toxicity index} = \frac{LC_{50}\ \text{most effective compound}}{LC_{50}\ \text{of tested compound}} \text{ X } 100$$

Results and discussion

The insecticidal toxicity of emamectin benzoate, pyradelil and indoxacab under laboratory conditions by four exposure methods against fourth instar larval of *Spodoptera frugiperda* are showed in Table (1) mentioned that the emamectin benzoate proved to be the high activity insecticide recording (LC_{50} 1.90 mg a.i. L and Toxicity index 100 %) against the fall armyworm using leaf-dip method, the LC_{50} values and Toxicity index of pyridalyl and indoxacarb 11.62, 7.76 values and 16.35, 24.48 at 48 h after application, respectively against the same pest. There was a significant various among the insecticides in the 4th larval instar of *S. frugipirda*. Accordingly, 24 h after application was least mortality percentage and increased gradually from 48 to 72 h until reached the highest mortality percentage after 96 h. Therefore, the higher mortality of emamectin benzoate and indoxacarb in the larva-dip method comparing to that in spray, film and leaf-dip methods.in the four exposure methods. On the other hand, emamectin benzoate observed the average highest larval mortality of 100.0, 97.5, 95.0 and 92.50 % at 96 h post treatment for larva –dip, leaf-dip method, film method and spray method, respectively. Indoxacarb showed to 97.50, 95.00, 95.00 and 87.50 % at 96 h after application for larva-dip method, leave-dip, film and spray methods, respectively. While pyridalyl 85.00, 78.00, 75.00 and 70.00 at 96 h after used for spray method, leave-dip, film method and larva-dip, respectively against of *S. frugipirda*. (Table 2 and 3). The fall armyworm, *S. frugipirda* was susceptibility to the application insecticides varied the larva-dip method. The findings of the present investigation suggest that direct spray and larva-dip on the fall armyworm in the case of emamectin benzoate a successful *S. frugipirda* control under laboratory conditions. The present results are similar with Sharma *et al*., (2022) [26] who showed emamectin benzoate was found efficiency for *S. frugiperda* dead in which > 90% mortality of the larvae was record in 24 h and no dead in control. Idrees *et al*., (2023) [18] indicated that emamectin-benzoate causes the increase mortality compared other pesticides. Similar data were reported by Bajracharya, Bhat and Sharma (2020) [6] showed that Emamectin-benzoate was more promising. Bakry and Gad (2023) [5] indicated that the emamectin benzoate caused the higher mortality then other insecticides. Thus, indoxacarb pesticide was the more rate harmful insecticide control this pest. EL-Zahi and Farag (2017) [12] demonstrated that the insect-spray was increased toxicity, whereas the effective of the others decreased compared leaf-dip for *Phenacoccus solenopsis*. Also, Tomlin (2003) [31], indicated that the higher toxicity in the insect-spray comparing to that in leaf-dip. Our studies, the development and growth of the immature stage different no significantly among the used hast plants. On the other hand, the development period on the same food plants differed not significantly at the all stages. Furthermore, the findings indicated that (fig. 2) the development and growth of the immature and adult stages (adult longevity, larvae duration, Pupa duration, fecundity and fertility percentage) were not significantly different among the four host plants. The development duration of each stage of the fall armyworm of four host plants is showed in Table 4. However, larvae duration fed on maize was development longer (16.75 days), compared to larvae fed on cowpea, potato and cotton (18.20, 19.75 and 20.00 days, respectively). The pupa period was longer on the three host plants (11.50, 13.25 and 14.25 days, respectively) compared the maize (9.25 days). The fecundity percentage was increase in larvae reared on corn (1650 eggs) compared to larvae fed on the other host plants (1257.25 eggs on cowpea, 1153.75 eggs fed on potato and 1110.25 eggs fed on cotton.

Table 1: Sensitivity of *Spodoptera frugiperda* 4th instar larval to some Emamectin benzoate, Pyridalyl and Indoxacarb under laboratory conditions

Treatment	LC_{50} 95% CL	Slope value	Toxicity index	X^2
Emamectin benzoate	1.90 (1.25-3.45)	3.01±0.67	100.0	0.56
Pyridalyl	11.62 (9.50-13.57)	1.23±0.34	16.35	1.78
Indoxacarb	7.76 (5.22-9.32)	2..54±0.36	24.48	1.30

Table 2: Susceptibility of *Spodoptera frugiperda* 4th instar larval after insecticides exposure using, spray, Film, Leaf-dip and Larva-dip techniques under laboratory conditions

Exposure methods (bioassay)	Compounds	LC_{50} (mg a. i./L)	Days after application				
			24h	48h	72h	96h	Average
Spray application	Emamectin benzoate	1.90	3.50±1.23	2.07±1.45	1.00±0.90	0.00±0.00	1.64±0.89
	Pyridalyl	11.62	7.50±1.90	4.25±1.54	4.00±1.09	1.50±1.81	4.31±1.58
	Indoxacarb	7.76	6.25±1.11	3.50±1.91	1.50±2.12	1.25±0.99	4.16±1.53
	Control	0.00	10.00 ±0.00	10.00±0.00	10.00±00	10.00±0.00	10.00±0.00
Leaf-dip method	Emamectin benzoate	1.90	3.75±1.91	2.50±1.77	0.75±1.85	0.25±0.99	1.81±1.63
	Pyridalyl	11.62	6.75±2.53	4.66±1.39	3.00±1.89	2.20±2.76	4.15±2.14
	Indoxacarb	7.76	4.75±0.90	2.25±0.98	1.25±0.90	0.50±0.99	2.18±0.94
	Control	0.00	10.00 ±0.00	10.00±0.00	10.00±00	10.00±0.00	10.00±0.00
Film method	Emamectin benzoate	1.90	10.00 ±0.00	10.00±0.00	10.00±00	10.00±0.00	10.00±0.00
	Pyridalyl	11.62	7.50±1.16	5.75±1.92	4.75±2.91	2.50±3.00	5.12±2.24
	Indoxacarb	7.76	5.50±2.21	2.09±1.04	1.00±1.08	0.50±0.90	2.27±1.30
	Control	0.00	4.75±0.00	3.00±0.00	1.50±0.90	0.50±0.99	2.43±0.47
Larva-dip method	Emamectin benzoate	1.90	3.50±1.91	2.00±0.98	1.25±1.98	0.75±1.09	1.87±1.49
	Pyridalyl	11.62	7.50±3.00	5.25±2.03	4.50±2.11	3.00±1.91	5.05±2.26
	Indoxacarb	7.76	4.00±2.02	2.75±2.47	0.75±2.08	0.25±0.98	1.93±1.88
	Control	0.00	10.00 ±0.00	10.00±0.00	10.00±00	10.00±0.00	10.00±0.00

The number eggs batch observed 6.75 batches were laid on maize, 5.50, 5.00 and 3.50 batches for cowpea, potato and cotton, respectively. The Fertility percentage of *S. frugipirda* was higher on maize (95.23 %) compared to cowpea (81.75 %), potato (75.25 %) and cotton (66.87 %).

Table 3: Percent mortality of *Spodoptera frugiperda* 4th instar larval after insecticides exposure using, spray, Film, Leaf-dip and Larva-dip techniques

Exposure methods (bioassay)	Compounds	LC_{50} (mg a. i./L)	Days after application				
			24h	48h	72h	96h	Average
Spray application	Emamectin benzoate	1.90	65.00 a	80.ooa	87.50 a	92.50 a	81.25 a
	Pyridalyl	11.62	25.0 c	57.5 c	60.0 c	85.0 b	56.87 c
	Indoxacarb	7.76	37.5 b	65.0 b	85.0 b	87.5 b	68.75 b
Leaf-dip method	Emamectin benzoate	1.90	62.5 a	75.0 a	92.5 a	97.5 a	81.87 a
	Pyridalyl	11.62	32.5 c	53.4 b	70.0 c	78.0 b	58.47 c
	Indoxacarb	7.76	52.5 b	77.5 a	87.5 b	95.0 a	78.12 b
Film method	Emamectin benzoate	1.90	45.0 b	79.1 a	90.0 a	95.0 a	77.27 a
	Pyridalyl	11.62	25.0 c	42.50 c	52.5 c	75.0 b	48.75 b
	Indoxacarb	7.76	52.5 a	70.0 b	85.0 b	95.0 a	75.62 a
Larva-dip	Emamectin benzoate	1.90	65.0 a	79.3 a	90.0a	100.0a	83.57 a
	Pyridalyl	11.62	25.0 c	47.5 c	55.0 c	70.0 c	49.37 c
	Indoxacarb	7.76	60.0 b	72.5 b	92.5 a	97.5 a	80.62 b
LSD at 5%			3.54	3.00	2.50	2.83	2.00

Thus, adult longevity was not significantly the longest when reared on maize and shortest when reared on potato and cotton, however, adult longevity on the same hosts was not significantly varicose (Table 4). The 4th larvae of *S. frugiperda* fed on maize had the longest development duration and growth compared with larvae reared on other three hosts. The present results are in parallel with Silva *et al*., 2017 [28] revealed that the soybean and cotton plants were observed to be low adequate hosts for the growth of the armyworm when compared to the grasses. *S. frugiperda* is polyphagous and more food plants have been attacked with preference such as maize, cotton, sorghum, wheat, cowpea, soybean and groundnut potato (Aguirre *et al*., 2016; Perez-Zubiri *et al*., 2016, Shylesha *et al*., 2018 and Rashed 2023) [2, 21, 27, 23]. Found that the higher host reduction of larvae was observed on wheat and corn seedling, he showed that the larval and pupa growth was higher when eating on corn leaves. Therefore, all host plants can contribute to the growth, development and outbreak of *S. frugiperda* in the absence of its best host, possibilities FAW development very depending on the host plant, this the impact of different host plants on the demographic aspects and life history of *S. frugiperda* in the laboratory (Chen *et al*., 2023) [9]. Ramos *et al*., (2022) [22] demonstrated that the pre, post oviposition and oviposition period and fecundity were higher for armyworm originated from larvae fed on *zea mays* plants than that fed on cotton, he reported the longer duration of the larval stage (25.18) after feeding on cotton comparing with maize (16.73 days). Also, Gamil (2020) [14] found that the mean duration of *S. frugiperda* were 13 and 11.22 days for male and female, productivity reached 1787.5 eggs, the larval stage duration was 21.4 days when feed on castor been, these data agree with those of Sharanabasappa *et al*., (2018) [25] revealed that the larval duration was 14 to 16 days after feeding on maize plants, Salem *et al*., (2021) mentioned that the larval stage period was 23.58 days after feeding on maize leaves and 23.36 days after feeding on castor been.

Table 4: Impact of the plant hosts on development period of *Spodoptera frugiperda* under laboratory conditions

Stages		Duration (days) of immature and adult stages				
		Maize	Cowpea	Potato	Cotton	LSD
Adult longevity		8.25±2.01 a	11.25±1.96 b	12.00±1.98 b	13.50±2.13 b	3.98
Egg duration		3.00±1.90 a	4.00±1.91 a	4.75±0.93 a	5.75±1.54 b	1.99
Larval duration		16.75±2.00 a	`18.20±1.98 b	19.75±1.08 b	20.00±0.98 b	1.56
Pupa duration		9.25±1.32 a	11.50±1.89 b	13.25±1.99 c	14.25±1.99 c	1.02
Life cycle		37.25±1.53 a	44.95±1.99 b	49.75±0.98 c	53.5±1.23 d	1.95
% of Pupation		95.75±1.54 a	85.75±1.99 b	72.20±0.98 c	69.50±2.91 d	11.50
% of emergence		90.50±3.04 a	80.50±1.94 b	70.50±0.1.09 c	62.75±3.00 d	13.96
N0. of eggs batch/ female		6.75±1.76 a	5. 50±0.91 a	5.00 ±2.00 a	3.50±1.93 b	2.95
Fecundity*		1650.50±1.96 a	1257.25±1.92 b	1153.75±1.23 c	1110.25±1.88 d	30.88
% of Fertility**		95.23±0.99 a	81.75±1.00 b	75.25±2.01 c	66.87±4.98 d	15.96
Life span	Female	35.25 a	39.95 b	41.00 b	44.00 c	2.90
	male	33.23 a	37.42 b	38.00 b	42.50 c	2.50

Conclusion

Spodoptera frugiperda is considered one the most important and dangerous insect pests currently in Egypt, especially maize. Fall armyworm infested corn plants from the seedling stage to the fruits, causing economic damage to the maize crop and leading to a decrease in yield. Thus, three different insecticides were applied using four exposure methods. Emamectin benzoate was the most effective. Therefore, the highest average larval mortality was observed for larval dip, leaf dip, film, and spray methods. The other insecticides were the least toxic and had average mortality when the method was used. Moreover, these insecticides may be used in an integrated pest management programs for control of the fall armyworm in the field. Also, this study concluded that life cycle of *S. frugiperda* for all stages were shorter when feed on maize plants than other host plants. Thus, the preferred host of FAW in vitro is maize plant, with the different host plants being intermediate hosts.

References

1. Abrahams P, Beale T, Cock M, Corniani N, Day R, Godwin J, et al. Fall armyworm status. Impact and control options in Africa. Outlooks on Pest Management. 2017;28(5):196-201.
2. Aguirre LA, Hernandez-Juarez A, Flores M Cerna E, Landeros J, Frias GA, Harris MK. Evaluation of foliar damage by Spodoptera frugiperda (Lepidoptera: Noctuidae) to genetically modified corn (Poalea:Poaceae) in Mexico. Florida Entomologist. 2016;99(2):276-280.
3. Abbott WS. A method of computing the effectiveness of an insecticide. J. Econ. of Eco. Entomol. 1925;18(2):265-267.
4. Altaf N, Idrees A, Ullah MI, Arshad M, Afzal A, Afzal M, et al. Biotic potential induced by different host plants in the Fall armyworm, Spodoptera frugiperda (Lepidoptera: Noctuidae). Insects. 2022;13(10):921.
5. Bakry MMS, Gad MA. Insecticidal efficiency of some pesticides against Spodoptera frugiperda (J. E. Smith) (Lepidoptera: Noctuidae) under laboratory conditions. Andalaian International Journal of Entomology (AIJENT). 2023;1(1):15-19.
6. Bybajracharya ASR, Bhat B, Sharma P. Field efficacy of selected insecticides against fall armyworm, Spodoptera frugiperda (J. E. Smith) (Lepidoptera: Noctuidae) in maize. Journal of the Plant Protection Society. 2020;6:127-133.
7. Baudron F, Zaman Allah MA, Chaipa I, Chari N, Chinwada P. Understanding the factors influencing fall armyworm (Spodoptera frugiperda J. E. Smith) damage in African smallholdwe maize fields and quantifying its impact on yield. A case study in Estern Zimbabwe. Crop Prot. 2019;120:141-150.
8. Bavisa RV, Jethva DM, Wadaskar PS. Host preference and digestibility indices of Spodoptera frugiperda (J. E. Smith) Lepidoptera: Noctuidae on different host plants. The Pharma Innovation Journal. 2021;10(7):1081-1083.
9. Chen WH, Itza B, Kafle L, Chang TY. Life Table study of Fall Armyworm (Spodoptera frugiperda) (Lepidoptera: Noctuidae) on Three Host Plants under Laboratory Condations. Journal Insects. 2023;14(4):329.
10. Chen YC, Chen DF, Yang MF, Liu JF. The Effect of Temperatures and Hosts on the Life Cycle of Spodoptera frugiperda (Lepidoptera: Noctuidae). Journal Insects. 2022;13(2):211.

11. Duncan DB. Multiple4 range and multiple F test. Biometrics. 1955;11:1-42.
12. El-Zahi SE, Farag AA. Population Dynamic of Phenacoccus solenopsis Teinsley on Cotton Plants and its Susceptibility to Some Insecticides in Relation to the Exposure Method. Alexandria Science Exchange Journal. 2017;38(2):231-237.
13. Fallet P, Bazagwira D, Guenat JM, Segura CB, Karangwa P, Mukundwa IP, et al. Laboratory and field trials reveal the potential of a gel formulation of entomopathogenic nematodes for the biological control of fall armyworm caterpillars (Spodoptera frugiperda). Biological control. 2022;176:1-10.
14. Gamil WE. Fall armyworm, caterpillars Spodoptera frugiperda (J. E. Smith) Biological Aspects as A New Alien Invasive Pest in Egypt. Egypt. Acad. J. Biology. Sci. 2020;13(3):189-196.
15. Guo JF, Zhang MD, Gao ZP, Wang DJ, He KL, Wang ZY. Comparison of larval preference and oviposition preference Spodoptera frugiperda among three host plants: potential risks to potato and tobacco crops. Insect Sci. 2021;28(3):602-610.
16. Guo J, Wu S, Zhang F, Huang C, He K, Babendreier D, et al. Prospects for microbial control of the fall armyworm Spodoptera frugiperda - a review. Biocontrol. 2020;65:647-662.
17. Idrees A, Qadir ZA, Akutse KS, Afzal A, Hussain M, Isalam W, et al. Effectiveness of Entomopathogenic Funge on Immature Stage and Feeding Performance of Fall Armyworm Spodoptera frugiperda (Lepidoptera: Noctuidae) Larvae. Insects. 2021;1(12):1044.
18. Idrees A, Afzal A, Chohan TA, Hayat S, Qadir ZA, Gaafar AZ, et al. Laboratory evaluation of selected botanicals and insecticides against invasive. Spodoptera frugiperda (Lepidoptera: Noctuidae). Journal of King Saud University, 2023, 35.
19. Midega CA, Pittchar JO, Pickett JA, Hailu GW, Khan ZP. A climate adapted push pull system effectively controls, of fall Armyworm, S. frugiperda (JE Smith), in maize in East Africa. Crop Prot. 2018;105:10-15.
20. Montezano DG, Specht A, Sosa-Gomez DR, Roque-Specht VF, Sousa-Silva JC, Paula-Moraes SV, et al. Host plants of Spodoptera frugiperda (Lepidoptera: Noctuidae) in the America. African Entomology. 2018;26(215):286-300.
21. Perez-Zubiri JR, Cerna-Chavez E, Aguirre-Uribe LA, Landeros-Flores J, Harris MK, Rodriguez-Herrera R. Population variability of Spodoptera cosmiodes (Lepidoptera: Noctuidae) in maize (Poalea: Poaceae) associated with the use of chemical insecticides. Florida Entomologist. 2016;99(2):329-331.
22. Ramos RH, Silva CAD, Lima TA, Junior PSA, Castellani MA, Serrao JE, et al. Development, Survival and Reproduction of Spodoptera frugiperda (Lepidoptera: Noctuidae) Fed an Artificial Diet or Cotton, Castor been and Cotton Leaves, Insects. 2022;13(5):428.
23. Rashed Hadeer S. Biology, Host Selection Behavior and Growth Indices of Invasive Fall Armyworm, Spodoptera frugiperda (J. E. Smith) (Lepidoptera: Noctuidae) on two Host Plants under Laboratory Conditions. Journal of Plant Protection and Pathology. 2023;14(6):181-186.
24. Salem SAR, Dahi HF, Mahmoud MAB. Development of the fall Armyworm, Spodoptera frugiperda (J. E. Smith) on three host plants. J. of Plant Protection and Pathology, Mansoura Univ. 2021;12(4):285-289.
25. Sharanabasappa D, Kalleshwara Swamy CM, Asokan R, Swamy HMM, Maruthi MS, Pavithra HB, et al. First report of the fall armyworm, Spodoptera frugiperda (JE Smith) (Lepidoptera: Noctuidae), an alien invasive pest on maize in India. Pest Manage Hortic Ecosyst. 2018;24:23-29.
26. Sharma S, Tiwari S, Thapa RB, Pokhrel S, Neupane S. Laboratory bioassay of fall armyworm (Spodoptera frugiperda) larva using various insecticides. Journal of Agriculture and Forestry University. 2022;5:133-138.
27. Shylesha AN, Jalal SK, Gupta A, Varshney R, Venkatesan T, Shetty P, et al. Studies on new invasive pest Spodoptera frugiperda (J. E. Smith) (Lepidoptera: Noctuidae) and its natural enemies. Journal of Biological Control. 2018;23(3):1-7. DOI: 10.18311\jbc\2018\21707.
28. Silva DM, Bueno AF, Stecca CS, Andrsde K, Neves PMOH, Oliveira MCN. Biology of Spodoptera eridania and Spodoptera cosmiodes (Lepidoptera: Noctuidae) on different host plants. Florida Entomologist. 2017;100(4):1657:1661.
29. Sun YP. Toxicity index an improved method of comparing the relative toxicity of insecticides. J. Econ. Entomol. 1950;43:45-53.
30. Tambo JA, Day RK, Lamontagne-Godwin J, Silvestri S, Beseh PK, Oppong-Mensah B, et al. Tacking Fall armyworm (Spodoptera frugiperda) outbreak in Africa: an analysis of farmers control actions. Ini. J. Pest Manage. 2020;66:298-310.
31. Tomlin CDS. The Pesticides Manual 13 Edition, British Crop Protection Council, UK, 2003.
32. Wan J, Huang C, Li CY, Zhou HX, Ren YL, ZY, et al. Biology, invasion and management of the agricultural invader: Fall armyworm, Spodoptera frugiperda (Lepidoptera: Noctuidae). J. Integrative Agriculture. 2021;20:646-663.