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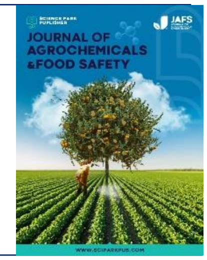

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Laboratory and field evaluation of some synthetic and bio-insecticides against the fall armyworm, *Spodoptera frugiperda* (J. E. Smith) on maize

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Abstract

Fall armyworm (FAW), *Spodoptera frugiperda* (Lepidoptera: Noctuidae), a maize pest from around the world, entered Africa in 2016 and caused harm. Maize is a vital crop for the global population. Insecticides are the most essential short-term strategy for managing FAW because of their high efficiency and cost-effectiveness. The goal of this study was to examine the efficiency of certain synthetic and bio-insecticides against three different FAW strains from Menufia, Sharkia, and Kalubia Governorates, which were collected from maize fields. A bioassay technique was used against 2nd instar larvae. Additionally, a field trial in Menufia Governorate was conducted. The laboratory results showed that chlorfenapyr (Challenger® 24% SC) was the most effective against the three field strains, followed by indoxacarb (Kangluda® 15% SC) and methomyl (Lannate® 90% SP). Emmamectin benzoate (EMB) (Aquaquim® 5.7% WG) was the most effective bio-insecticide against the Menufia strain, followed by spinetoram (Radiant®, 12% SC) against the Sharkia strain and *Bacillus thuringiensis* (*Bt*) (Dipel®, 6.4% DF) against Kalubia strain. The efficacy of Challenger®, Kangluda®, Lannate®, Dipel®, Aquaquim®, and Radiant® was evaluated in a field study, with mean values of 62.24, 59.13, 53.43, 46.33, 37.49, and 35.82%, respectively. Such insights could aid management decision-making in developing an effective control approach.

Keywords: Fall armyworm; Insecticides; Field strain; Laboratory strain; Egypt

1. Introduction

The autumn armyworm (FAW), *Spodoptera frugiperda* (J.E.Smith), and Lepidoptera: Noctuidae a polyphagous pest throughout tropical and subtropical America [1]. It has a large host range and is a major hazard to plants [2, 3]. It can cause 34% Maize yield losses [4]. It has been classified as an invasive insect pest in Africa [5], and it has undoubtedly become the most economically important insect in numerous crops, as well as a serious pest in maize, since its introduction into Egypt in 2019. It invaded Africa, parts of Asia, and Australia over the last six years, threatening the food security and income situation of most farmers, many of which are smallholders and depend on maize as the main crop [6].

Numerous studies have been conducted to better understand the biology and behavior of this pest under local contexts to build efficient management approaches. It causes serious damage to various crops, particularly maize [7]. In Africa, the intensity of FAW infestation caused farmers to spray insecticides repeatedly during the cropping season, typically relying on broad-spectrum active ingredients of highly hazardous pesticides (HHPs), especially in the initial years following the epidemic [8]. The regular appliance of wide-ranging insecticides may amplify product charges, hazard the growth of resistance, health risks to the growers and consumers, as well as impact biodiversity and the environment [9, 10]. However, several bio-pesticides are

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accessible to control FAW, for example, the oil extracted (seeds; neem tree) (*Azadirachta indica* L.) has just been revealed to be efficient [11]. Products based on *Bt* have also been revealed to be valuable and substantial bio-pesticides are obtainable in African countries [12]. Also, emamectin benzoate (EMB) was effective on FAW for 24 hr, and its sublethal concentrations were more effective on offspring larvae and oviposition period [13]. In Egypt according to the recommendation of the Ministry of Agriculture, the Agricultural Pesticides Committee (APC) initiated the special program in co-operating with the Food Agricultural Organization (FAO) authority to promote the use of all practices to eradicate FAW initially to Egypt in 2019. The program deals the information concerning the biology of pests, infestation signs, the role of agricultural practices, the main hosts, the most potent synthetic pesticides, and others to farmers, especially smallholders [14]. As a novel invasive in Egypt, there is limited information on whether it is vulnerable to synthetic and bio-insecticides, which have different mechanisms of action. The activity of such pesticides may be promoted in a program that explains the purpose of employing pesticides in sequencing mode to prevent the development of resistance phenomena. So, the current study intends to assess the efficiency of three of the bio-pesticides, concerning other synthetic commonly used in Egypt on FAW 2nd instar larvae under both laboratory and field settings.

2. Materials and method

2.1. Insecticides

The Three commonly used synthetic insecticides: Kangluda® 15% SC (indoxacarb), Lannate® 90% SP (methomyl), and Challenger® 24% SC (chlorfenapyr), and other 3 bio-agents: Dipel® 6.4% DF (*Bacillus thuringiensis*) (*B.t*), Radiant® 12% SC (spinetoram), and Aquaquim® 5.7% WG (emamectin benzoate) (EMB) were selected for the study and supplied by the Central Agricultural Pesticides Laboratory (CAPL), ARC, Egypt as cited in **Table 1**.

Table 1. Synthetic and bio-insecticides used their common, and trade names, the rates of application, and their mode of action.

Group	Common name	Trade name	Rate (ml or g/ hectare)	Mode of action
Synthetic	indoxacarb	Kangluda® 15% SC	63.5 ml	Blocks the sodium channel
	methomyl	Lannate® 90% SP	762.0 g	Inhibit the acetyl cholinesterase (AChE) in the nervous system disrupt the nerve impulses leading to paralysis and death.
	chlorfenapyr	Challenger® 24 % SC	610.0 ml	Disruption of ATP production and loss of energy leading to cell dysfunction and subsequent death
Bio	*Bacillus thuringiensis*	Dipel® 6.4 % DF	762.0 g	Proteneceous inclusions called endotoxins Microbial disrupters of insect midgut membranes
	spinetoram	Radiant® 12 % SC	254 ml	nACHR 4 allosteric modulator. Site 1
	emmamectin benzoate	Aquaquim® 5.7 % WG	152.5 g	(Glucl) allosteric modulators glutamated gate chloride channel agonist

2.2. Bioassay

2.2.1. Insect rearing

Representative samples of FAW constituting different instars of larvae were collected from three Egyptian Governorates: Menufia, Sharkia, and Kalubia. The samples were collected from field-grown maize plants, larvae carefully picked from leaf whorls of the plants for set up a colony and kept in tissue containers before being transported to the sectary. The larvae were fed in the laboratory with freshly castor oil leaves daily and kept individually in plastic ice box blocks and held till pupate to prevent cannibalism. The moisture of the castor oil leaves was sufficient to hydrate the larvae and the food was daily supplied. Upon pupate; the pupae were placed in pupal

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containers with a net covering the top until they emerged as adults. The pupal weight of the field samples were recorded and indicated no significant difference between Sharkia vs. Kalubia, while there was a significant difference between Menufia vs. Sharkia and Menufia vs. Kalubia as illustrated in **Figure 1**. Also, the mean weights of five 2nd instar larvae of the tested samples were recorded and showed no significant difference between Menufia vs. Kalubia and Sharkia vs. Kalubia, while there was a significant difference between Menufia vs. Sharkia as illustrated in **Figure 2**.

2.2.2. Bioassay

Under laboratory conditions, 2nd instar larvae of the chosen Governorates were used to evaluate the efficacy of three of both synthetic and bio-insecticides, a leaf dip bioassay method [15] with three replicates and five to seven concentrations for each pesticide was conducted. The results were undertaken after 24 hr for the insecticides used and 48 hr for the bio-insecticides. Abbott's formula [16] was used to correct the mortality on untreated leaves, where it was necessary. The data was statistically analyzed by Finney [17] probit analysis. The LC_{50} (ppm) slope of the curves and toxicity index were also recorded to differentiate the insecticides. Toxicity index was calculated using the following equation [18].

$$\mathbf{T.I} = \frac{LC50\ of\ the\ most\ effective\ comp.}{value\ of\ another\ one} \times \mathbf{100} \qquad (1)$$

2.3. Field trail

At maize fields in the Meunof district, Menufia Governorate, the experimental design used a randomized complete block design (RCBD) with four replicates each. The plots measuring 4.5 m×5 m were divided by 2 m alleys inside a block while blocks were 3 m apart. The maize variety used was Triple Hybrid 360 which is commonly planted in Menufia region. It was planted at a spacing of 60 cm between rows and 40 cm between plants within a row, within two seeds/holes. The sowing date was 30, May 2023. Treatments included all pesticides (**Table 1**). Treatment applications were carried out two weeks after crop emergence and were repeated at three-week intervals, therefore, with three applications in total. All treatments were performed in early on night, using CP-15 knapsack sprayers (capacity: 20 L). One sprayer was used for the synthetic pesticides spraying, and a new one for spraying bio-insecticides. The whole maize vegetation was covered during the treatment. To prevent product drift, a physical barrier made up of a plastic tarpaulin was positioned in the order of each given plot before insecticide practices. The volume of the spray solution was calculated according to each plot area. All agricultural practices were followed carefully during the experimental period. The observation was recorded on the number of live larvae before and on 2, 3, 5, 7, and 10 days after spraying. The field data was subjected to statistical analysis according to the Henderson and Tilton equation [19] for interpretation.

$$\%\ \mathbf{reduction} = \mathbf{1} - \frac{treatment\ after \times control\ before}{treatment\ before \times control\ after} \times \mathbf{100} \qquad (2)$$

2.4. Statistical analysis

Data of bioassay were analyzed for LC_{50} values according to Ldp line software program [17]. All data were analyzed using SPSS statistics 27 [20].

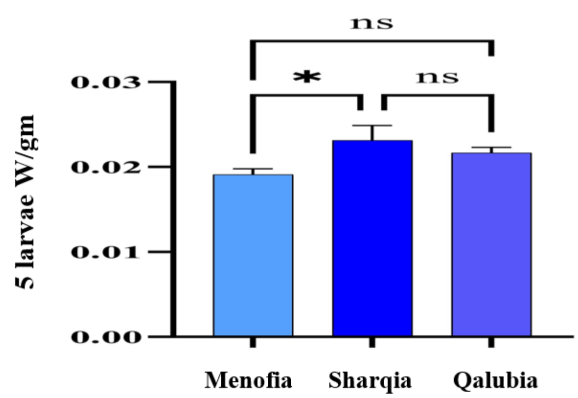

Figure 1. Representative samples of FAW constituting different instars of larvae which collected from three Egyptian Governorates. [ns= not significant; *=significant]

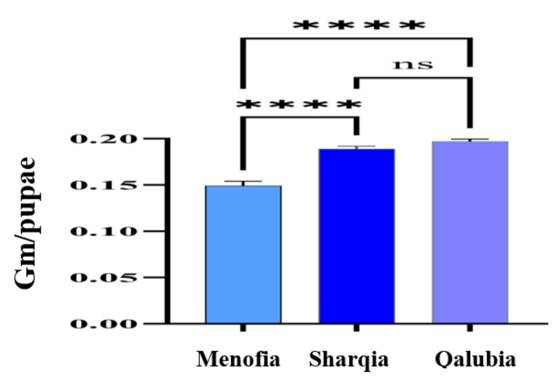

Figure 2. The mean weights (g) of five 2nd instar larvae of the tested samples.

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Table 2. Toxicity values of some synthetic insecticides against 2nd instar larvae of fall armyworm under laboratory conditions.

Insecticide	Kalubia			Sharkia			Menufia		
	LC_{50} (ppm) (95%confidence limits)	Slope ±S.E	T.I.	LC_{50} (ppm) (95% confidence limits)	Slope ±S.E	T.I.	LC_{50} (ppm) (95% confidence limits)	Slope ±S.E	T.I.
Kangluda® SC% 15	23.097 (12.41-49.62)	4.72	1.59±0.49	18.316 (7.31-35.47)	1.61 ±0.55	67.37	15.764 (27.82 -8.05)	1.88±0.53	86.89
Lannate® SP% 90	31.421 (16.90-74.35)	3.47	1.58±0.50	23.462 (9.84-48.85)	1.63 ±0.51	52.58	26.0157 (1.13-16.05)	1.08±0.53	52.65
Challenger® 24% SC	1.09 (0.39-236.68)	100	0.96 ±0.44	12.3397 (3.33-21.65)	1.37±0.41	100	13.697 (6.43-20.83)	2.08 ±0.54	100

3. Results and discussion

The efficacy of the insecticides against the 2nd instar of FAW strains was determined in the laboratory using the leaf dipping technique after 24 hr of treatment. Regarding the Menufia strain, Challenger® has the highest toxicity (LC50; 1.09 ppm) (T.I; 1.00), followed by Kangluda® (23.09 ppm) (4.72) and Lannate® (31.42 ppm) (3.47). In the instance of the Sharkia strain, the efficiency was calculated in the following order: Challenger®> Kangluda®> Lannate®, with mean values of 12.34, 18.32, and 23.46 ppm. The same procedure was performed for the Kalubia strain, with average readings of 13.69, 15.76, and 26.02 ppm for the above-mentioned chemicals. According to the data, Challenger® was the most potent, while Menufia strain was the most sensitive to it. However, the Kalubia strain was more sensitive to Kangluda® than the others (**Table 2**). In terms of bio-insecticides, the selected chemicals outperformed synthetic pesticides. Aquaquim® had the highest potency in the Menufia strain (LC_{50}; 0.0203 ppm) (1.00), followed by Dipel® (0.0627 ppm) (32.38) and Radiant® (0.136 ppm) (14.88). Radiant® was the most effective in the Sharkia strain (0.0157 ppm) (1.00), followed by Aquaquim® (0.0329 ppm) (47.72) and Dipel® (0.0382 ppm) (41.10). For the Kalubia strain, Dipel® was the most powerful (0.0364 ppm) (1.00), followed by Radiant® (0.0792 ppm) (45.96) and Aquaquim® (0.982 ppm) (3.71) (**Table 3**)

Table 3. The evaluation of the bio-insecticides against 2nd instar larvae of *Spodoptera frugiperda* under laboratory conditions.

Insecticide	Kalubia			Sharkia			Menufia		
	LC_{50} (ppm) (95%confidence limits)	Slope ±S.E	T.I.	LC_{50} (ppm) (95% confidence limits)	Slope ±S.E	T.I.	LC_{50} (ppm) (95% confidence limits)	Slope ±S.E	T.I.
Dipel® 6.4% DF	0.063 (0.017-0.444)	0.80±0.25	32.38	0.038 (0.005-0.232)	0.57±0.21	41.10	0.036 (0.006-0.175)	0.74±0.25	100
Radiant® 12% SC	0.1364 (0.045-0.586)	0.93±0.27	14.88	0.0157 (0.002-0.0648)	0.64±0.25	100	0.079 (0.0001-0.553)	0.75±0.36	45.96
Aquaquim® 5.7% WG	0.0203 (0.003-0.093)	0.76±0.26	100	0.0329 (0.0064-0.1218)	0.88±0.27	47.72	0.982 (0.237-2.824)	1.03±0.30	3.71

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As a highly polyphagous insect, its management tactics rely mostly on the use of synthetic pesticides, which has contributed to the development of resistance [21]. Hence, bio-pesticides are the most prominent method for controlling this pest due to their specificity and efficacy in the management of agricultural pests.

The present findings indicated that *Bt* efficacy was more efficient under laboratory conditions. This is by that obtained by Priyanka *et al.* [22], where Dipel® was not capable besides FAW larvae within 48.86% mortality. Also, Delanthabettu *et al.* [23] found that some strains were much more efficient than the reference strain (HDI) in killing FAW larvae. *Bt* isolates were showing mortality in the range of 6.9-65.52%. As indicated by Karshanal and Kalia [24], several *Bacillus* spp. Induced pathogenicity toward neonates of FAW. More investigations stated that *Bacillus* spp., which was isolated from soil, also had larvicidal effectiveness besides FAW [25]. Also, there are several studies indicating the susceptibility of *S. frugiperda* to Cry toxins and *Bt* strains [26]. According to work done by Hernandez (1988) [27], subspecies of *Bt kurstaki*, *Bt Aizawa*, and *Bt thuringiensis* induced mortalities percents of 80, 100, and 70% beside FAW neonates at (3×10^7 cells/ml), respectively. The variation in toxicity recently is attributed to the composition of the crystals [28].

On the other hand, combining multiple strains may increase the level of synergy between strain performances. Also, the rotation of strains application with some synthetic pesticides recently increases the efficiency and may minimize the development of resistance [29]. As a result, combining biorational pesticides with various mechanisms of action has been promoted as an important approach to insect resistance management [30].

In the field trial, synthetic and bio-insecticides were tested against FAW on maize plants in Menufia field conditions during crop season 2023 (**Table 4**). The decline rates were assessed after two, three, five, seven, and ten days of application. The data showed that all treatments reduced FAW larvae compared to the control. After two days of treatment, the highest reduction ranged between 70 and 72% for Kangluda®, Challenger®, and Lannate®, with percentages of 72.71, and 70.0%, respectively. Aquaquim® showed the smallest reduction (44%). After three days, Kangluda® and Challenger® produced the best efficiency (64%), followed by Lannate® (60%). Radiant® showed the lowest value (46%). Other times, efficiency decreased significantly to 59.00% after 5 days. The highest percentage was observed for Challenger® (59%), followed by Kangluda® (56.72%). The lowest value was observed for Aquaquim® (27.11%). The Challenger® induced the value (58.6%) after 7 and 10 days. The mean values of efficiency for the above periods are provided in the following order: Challenger® (62.24%), followed by Kangluda® (59.13%), Lannate® (53.43%), Dipel® (46.33%), Aquaquim® (37.49%), and Radiant® (35.82%). Similar findings were obtained by Shareef *et al.* [4], where insecticides assessed against 3rd instar larvae of *S. frugiperda* using topical application method, EMB proved to be highly toxic to the pest with the least LC_{50} (1.0 ppm), LC_{75} (2.7 ppm), and LC_{90} (6.7 ppm) values, followed by spinetoram, chlorantraniliprole, novaluron+EMB, novalron, novaluron+indoxacarb, flubendiamide, indoxacarb, lambda-cyhalothrin and chlorpyrifos. According to Sharanabasappa *et al.* [31], using 2nd instar of *S. frugiperda*, EMB was the most poisonous. The field efficacy results showed that the most effective insecticides were EMB, spinetoram, and indoxacarb in descending order. This conclusion is consistent with that obtained by Sharanabasappa *et al.* [32], who demonstrated that the LC_{50} values of EMB and spinetoram were extremely low when compared to indoxacarb in a toxicity investigation on the same pest. In India, field trials also demonstrated that spinetoram and EMB were significantly superior overall to other treatments, with larval reductions of 98.13 and 96.26% at 7 days of treatment [33]. A similar investigation was performed around the world, including China, Africa, Brazil, and India, to test the efficiency of pesticides through field and laboratory situations to control FAW, and reported that FAW is susceptible to synthetic pesticides; however, EMB caused the highest mortality [34]. The last concept was indicated by the percent standard, which was the greatest pesticide under laboratory conditions (0.0203 ppm) than other insecticides. Plant extracts: *Rhazya stricta* Decne., *Sophora mollis* (Royle) Baker, and *Withania somnifera* (L.) Dunal mixed with synthetic insecticide, chlorantraniliprole at half of the label-recommended dose induced major synergized toxicity (37.75% on 1st day to 99.25% on 7th-day post-treatment) against 3rd instar larvae of *S. frugiperda* under semi-field conditions [35]. In Pakistan, fipronil+EMB 0.35% G gave the best control when compared to other insecticides, with the lowest population of 2.00 larvae per plant found after fourteen days. Chlorantraniliprole 20% SC and EMB 5% WDG, followed by fipronil+EMB 0.35% G, regulated the larval population

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significantly better than the other insecticides, with the lowest population value of 3.25 larvae per plant [36]. Finally, our findings demonstrated that chlorfenapyr (Challenger®), indoxacarb (Kangluda®), and methomyl (Lannate®), both in field and laboratory studies, could serve as a useful reference point for future study on the FAW.

The information gathered would improve FAW management decision-making. The execution of an effective control strategy against this pest can only be accomplished through a constant survey of its susceptibility to insecticides that will be deployed in all maize-producing governorates across the country. Such monitoring is a critical component of any resistance prevention program; recognizing susceptibility evolution in the laboratory allows for the adaption of control techniques. Establishing a network of laboratories for monitoring the pesticide susceptibility of *S. frugiperda* is vital for creating integrated pest management (IPM) programs. FAW is a highly polyphagous pest whose management approaches have not yet been fully developed in Egypt. As stated in Africa, there have been several problems in developing and implementing a coordinated, evidence-based approach to control FAW in Africa. As a result, farming communities' ability to conduct FAW reconnaissance and effective monitoring at the national, regional, and continental levels is limited. In addition to delaying the discovery of the pest's progress in Africa, a lack of surveillance, monitoring, and scouting capacity has slowed efforts to uncover several crucial unknowns about FAW populations on the continent, as well as the dynamics of the pest's establishment and spread. The lessons acquired from the invasive FAW pest must be identified soon [37].

Table 4. Percents of reduction of pesticides used against FAW in fields of Menufia region.

Insecticide	Rate/hectare	% of reduction					Mean (%)
		2nd	3rd	5th	7th	10th	
Kangluda® SC% 15	63.5 ml	72.0	64.0	56.7	49.4	54.0	59.1
Lannate® SP% 90	762.0 g	70.0	60.0	52.2	48.3	36.8	53.4
Challenger® 24 % SC	610.0 ml	71.0	64.0	59.0	58.6	58.6	62.2
Dipel® 6.4 % DF	762.0 g	46.0	58.8	43.6	48.3	35.0	46.3
Radiant® 12 % SC	254.0 ml	50.5	46.0	34.4	31.0	17.2	35.8
Aquaquim® 5.7 % WG	152.5 g	44.0	46.7	27.1	46.3	23.3	37.5

4. Conclusion

The current findings presented a comparative pattern of synthetic and bio-insecticides' efficacy against FAW (2nd instar larva) in laboratory and field testing. The results suggested that Challenger®, Kangluda®, and Lannate® could be utilized as fast-acting insecticides against FAW. Furthermore, in the field trial, EMB may be more potent at higher doses. Further studies concern combination of synthetic and bio-insecticides are essential tool to eradicate this pest and minimize the development of resistance. From the present findings, field trials to suppress FAW necessitate the sequencing of pesti cides with several mechanisms of action to prevent such events. Increased investigations on pesticide toxicology may aid FAW decision-making.

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Declaration of interest

The authors have no relevant financial or non-financial interests to disclose.

Data availability

The data are available within the article. The authors confirm that the data supporting the findings of this study are available within the article.

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