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Laboratory Toxicity and field efficacy of selected insecticides against fall armyworm, *Spodoptera frugiperda* (Smith) in maize plants

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Abstract
Fall armyworm, *Spodoptera frugiperda* (J.E Smith) (*Lepidoptera: Noctuidae*, is one of the most important invasive destructive pests. It has a wide range of host plants, from which are maize, rice, sorghum, cotton and vegetables. A laboratory study was conducted to compute baseline dose-mortality responses of 4th instar larvae of *S. frugiperda* to methomyl, chlorantraniliprole + abamectin and indoxacarb using leaf-dipping technique. In addition, two field experiments were conducted at Sakha (Kafrelsheikh Governorate) and Quotor (Gharbia Governorate), Egypt during 2024 maize season to evaluate the efficacy of the three insecticides against the pest. Indoxacarb was the most toxic insecticide, with LC50 of 15.26 µg/ml, followed by chlorantraniliprole+ abamectin (LC50 32.45 µg/ml), while methomyl was the least toxic (LC50 287.34 µg/ml). Toxicity index values of the three compounds were 5.31, 47.02 and 100.00, respectively. On the other hand, the initial kill ranged from 88.20 to 94.23%. However, residual effects of indoxacarb, chlorantraniliprole+ abamectin and methomyl were 88.41, 85.18 and 73.65%, at maize fields of Gharbia Governorate, and 86.08, 81.76, and 69.01% at fields of Kafrelsheikh Governorate, respectively. These results could be promising against S. frugiperda, and the three insecticides may be efficient candidates against the pest within integrated pest management programs.

Keywords: *Spodoptera frugiperda*, insecticides, toxicity and field efficacy

Introduction
Maize, *Zea mays* (Lederer) is one of the most important cereal crops, in Egypt, used for feeding humanbeings and livestocks. Thus, policy of Ministry of Agriculture and Land Relamation emphasizes on expanding maize cultivated areas as well as increase the productivity of unit area to achieve self-sufficiency of this vital crop. Unfortunately, this crop is subject to attacks of several insect pests (Youssef 2018) [33], of which is *Spodoptera frugiperda* (J.E. Smith) (*Lepidoptera: Noctuidae*), that severely attacks maize plants throughout all growth stages (Wyckhuys *et al.* 2006 and Montezano *et al.* 2018) [19, 32]. This serious insect pest prefers feeding upon young maize leaves, ears and tassels (Falin *et al.* 2019) [11]. However, *S. frugiperda* was controlled using different pesticides in several countries in Americas (Tomquelski and Martins 2007 [28] Hardke *et al.* 2011[14]; Gutierrez-Moreno *et al.* 2019) and in Africa (Prasanna *et al.* 2018 and Sisay *et al.* 2019) [22, 25]. However, despite several negative impacts, pesticide applications may be necessary to achieve high crop yields (EPA, 2021). Methomyl, a carbamate insecticide, was firstly synthesized in 1968, and succeeded in suppressing populations of too many insect pest species, through inhibiting the acetylcholine (AchE) activity, ending with pest death (Van Scoy *et al.* 2013) [29]. This carbamate has high acute toxicity but is of weak stability accompanied by low bio-accumulative activity (Mortensen and Serex 2014) [20]. Chlorantraniliprole, anthranilicdiamide, was recorded as effective against *S. frugiperda*, with a minimal effect on both beneficial insects and environment when used wisely (Barrania 2013, Falin *et al.* 2019, Wang *et al.* 2022 [30] and Beuzelin *et al.*2022) [5, 6, 11]. Indoxacarb, belonging to oxadiazines, blocks sodium channel in insects, and, in most cases, is effective against pests that have developed resistance to insecticides. Thus, it is of a widespread use in managing pests (Mokbel *et al.* 2017, Khaled and Farag 2015 and Wu *et al.* 2022b) [17, 18, 31].

The objectives of this study were to determine the efficacy of three pesticides against larvae of *S. frugiperda*, in the laboratory, using leaf dipping method. Also, the initial kill and residual effect of these pesticides against this fall armyworm was investigated in field experiments.

Materials and Methods

Insect Culture: A laboratory strain of *Spodoptera frugiperda* was obtained from the insect rearing laboratoty, Cotton Leafworm Department, Plant Protection Research Institute, Sakha Branch, where the insect was reared for six generations under controlled conditions (25± 2º C, 65± 5% relative humidity and 16/8 h light/ dark period), according to El-Defrawi *et al.* (1964) [9].

Evaluated Insecticides

Three commonly applied insecticides, belonging to different chemical groups (Table 1) were evaluated, in lab and field tests, against *S. frugiperda*. The concentrations used were 1300, 650, 325 and 162.5 ppm for methany1, l, 25, 20, 15, 10 and 5 ppm for indoxacarb and 30, 25, 20 and 15 ppm for chlorantraniliprole + bamectin.

Table 1: Formulation, dosage, and commercial name of insecticides evaluated against *Spodoptera frugiperda* larvae

Chemical group	Active ingredient	Commercial name	Dosage/ L	Manufacturer
Carbamate	Methomyl	Pilarmate® 90% SP	1.5g	Pilarquim (Shanghai) Co., Ltd. China
Oxadiazine	Indoxacarb	Easo® 30% WG	0.3g	Nantong Shizhuang Chemical Co.,Ltd. China
Anthranilic diamide +Avermectin	Chlorantraniliprole+ Abamectin	Sparveiro plus® 6.3%SC	0.6 ml	Agri Sciences Tarim IlACUR. SAN. VE. LTIC. Turkey

Laboratory Bioassay

Castor bean leaves were dipped in the respective solutions of insecticides for 30 seconds, then air dried at room temperature, according to Shepared (1958) [24]. Fourth instar larvae were confined with the treated leaves in glass jars (15 cm diameter x 30 cm height) covered with muslin cloth for 24 h. Each treatment comprised 50 larvae (10 larvae/ jar, replicated five times). The control (untreated - check) had the same number of larvae, fed upon castor leaves, just immersed in distilled water. Mortality% was calculated 24 h post-treatment and data were corrected relatively to control mortality by Abbott's formula (1925) [1]:

$$\%\ \text{Corrected mortality} = \frac{\%\ \text{mortality in treatment} - \%\ \text{motality in control}}{100 - \%\ \text{motality in control}} \times 100$$

Slope and LC_{50} values were estimated for each compound, toxicity index was calculated according to Sun (1950) [26] formula:

$$\text{Toxicity index for } LC_{50} = \frac{LC_{50}\ \text{of the most effective compound}}{LC_{50}\ \text{of the least effective compound}} \times 100$$

Experimental Design

Two field experiments were conducted at Sakha (Kafrelsheikh) and at Quotor (Gharbia), during 2024 season to evaluate efficacy of methomyl, chlorantraniliprole+ abamectin and indoxacarb against *S. frugiperda* attacking maize plants. The experiments were laid out in a Completely Randomized Block Design. In both locations, the maize area was about 700 m^2 planted on August 5^{th}, 2024. The experimental area was divided into 16 plots (42 m^2 each), four treatments in four replicates. The insecticide fluids were directed to the plant whorl using Knapsack sprayer. Ten plants/ plot were dissected in the field and *S. frugiperda* larvae were counted just before application and 1, 3, 5, 7 and 10 days post-treatments. Reduction percentages in the larval numbers were corrected by the equation of Henderson and Tilton (1955) [16]:

% Reduction =1- (C1/C2 x T2/T1) x 100

Where:

C1: Population in control before application

T1: Population in treatment before application

C2: Population in control after application

T2: Population in treatment after application

Statistical Analysis

LC_{50} and slope were calculated using LDP line software (Baker, 2000) [4], according to Finney (1971) [12]. Results were statistically evaluated by one - way analysis of variance (ANOVA). The means of treatments were compared by Duncan's multiple range test (1955) [8], at 5% level of probability. CoStat Software Program (1995) [7] was used for all analysis.

Results and Discussion

Toxicity of Tested Insecticides on Basis of LC_{50}

Evaluated compounds (Table 2) had promising toxic effects on fourth instar of *S. frugiperda* larvae, with LC50 ranging between 15.26 and 287.34µg/mL. Based on LC50, toxicity of the compounds could be ascendingly ordered as methomy (287.34µg/mL), chlorantraniliprole+ abamectin (32.45) and indoxacarb (15.26 µg/mL). These findings are consistent with those of Ahmed *et al.* (2022) [3] who observed that there was a significant mortality of third instar larvae of *S. frugiperda* by chlorantraniliprole. Also, Shareef *et al* (2022) [23] concluded that chlorantraniliprole was more toxic than indoxacarb against third larval instar of *S. frugiperda*. This is in contrary with findings of Hardkke *et al* (2010) [15] who found that LC_{50} values of chlorantraniliprole and spinetoram were significantly lower than that of Indoxacarb against same insect on grain sorghum. However, Gutirrez - Moreno *et al* (2019) [13] reported that this fall armyworm had low resistance to Abamectin which is still effectively used for managing *S. frugiperda*.

Table 2: Lethal concentration (LC_{50}) of evaluated insecticides against the 4th instar larvae of *Spodoptera frugiperda*, 24 h post-treatments using leaf - dip method

Insecticide	LC_{50} (ppm)	Confidence limits		Toxicity Index	Slope ±S.E.
		Lower	Upper		
Methomyl	287.34	251.77	327.92	5.31	1.57 ±0.44
Chlorantraniliprole+ Abamectin	32.45	26.68	39.51	47.02	1.88±.82
Indoxacarb	15.26	9.37	25.06	100.00	1.24 ±0.33

Comparison on Basis of Toxicity Index

In order to calculate the efficiency of the evaluated compounds against 4th instar larvae of *S. frugiperda*, the toxicity index method developed by Sun (1950) [26] was used. Since indoxacarb was the most harmful to the treated larvae in this investigation, it was selected as the reference chemical and randomly assigned 100 units. According to the results shown in Table (2), the toxicity index values of chlorantraniliprole+ abamectin and methomyl, against the 4th instar larvae of *S. frugiperda* at the LC_{50} level were 47.02 and 5.31, respectively, as toxic as the toxicity of the indoxacarb compound.

Field Experiments: Efficacy of the tested chemicals against *Spodoptera frugiperda* larvae on maize plants

This study focused on the efficacy of three insecticides from different groups and formulations to control this pest on maize plants. At Gharbia Governorate, Table (3) represents the initial and residual effect of methomyl, chlorantraniliprole+ abamectin and indoxacarb against *S. frugiperda*. The obtained results showed that all tested compounds were effective against *S. frugiperda* larvae. The mean number of *S. frugiperda* before spray varied from 12.50 to 17.25 larvae / 10 plants. Based on the initial effect (reduction in population after one day of spray), the results indicated that all treatments gave the same efficiency of reduction without significant difference among them. The reduction in population ranged from 90.14 to 95.99%. With regard to the residual activity of tested insecticides, it was observed that the efficiency of indoxacarb and chlorantraniliprole+ abamectin was significantly higher (85.18 and 88.41% reduction) compared with methomyl which caused 73.65% reduction in the population.

The same trend of results was observed at the second region, at Kafrelsheikh Governorate (Table 4). All treatments recorded the reduction percentage ranging from 88.20 to 94.23% with the same effect due to non-significant difference between them in reduction. However,

Table 3: Field evaluation of insecticides against *Spodoptera frugiperda* larvae at Gharbia Governorate during 2024 season

Treatment	Mean No/10plants pre-spray	%Reduction of *S. frugiperda* larvae at the indicated days post treatment					
		Initial effect (1day)	3	5	7	10	%Residual effect
Methomyl	13.25	90.14±1.03ᵃ	91.28	79.05	68.12	56.14	73.65±3.25ᵇ
Chlorantraniliprole + Abamectin	17.25	93.40±2.44ᵃ	94.56	89.51	82.33	74.31	85.18±2.17 ᵃ
Indoxacarb	12.50	95.99±2.41ᵃ	94.95	94.27	87.04	77.41	88.41±1.18ᵃ
Control	16.50*	15.25*	14.50*	16.25*	18.50*	16.75*	—
L.S.D	—	7.26	—	—	—	—	7.28

*=Mean number of fall armyworm /10 maize plants in untreated control throughout the experimental period. Means within a column denoted by the same letter (s) are not significantly different at 5% level according to DMRT (1955).

However, indoxacarb and chlorantraniliprole+ abamectin and methomyl treatments recorded 88.20, 90.45, and 94.23% reduction, respectively, while the means of residual effect, from 3 to 10 days of spray, recorded 69.01, 81.76, and 86.08% for methomyl, chlorantraniliprole+ abamectin and indoxacarb, respectively. It was observed that indoxacarb and chlorantraniliprole+ abamectin treatments induced significantly highest increase of reduction, while the lowest increase occurred with methomyl treatment. The obtained results agree with the findings of Hardke *et al.*, (2011) [14] who found that, at 14 DAT of spray, chlorantraniliprole caused significantly higher mortality (85.90%) of *S. frugiperda* than the non-treated control (0.0%).

Table 4: Field evaluation of insecticides against *Spodoptera frugiperda* larvae at Kafrelsheikh Governorate during 2024 season

Treatment	Mean No/10plants pre-spray	%Reduction of *S. frugiperda* larvae at the indicated days post treatment					
		Initialeffect (1day)	3	5	7	10	%Residual effect
Methomyl	8.50	88.20±1.93ᵃ	89.09	78.27	60.67	48.02	69.01±5.64ᵇ
Chlorantraniliprole + Abamectin	10.00	90.45±3.94ᵃ	92.73	88.26	78.45	67.62	81.76±2.68ᵃ
Indoxacarb	10.25	94.23±4.08ᵃ	94.57	92.30	84.14	73.31	86.08±2.52ᵃ
Control	8.25*	12.50*	14.50*	16.25*	13.25*	18.25*	—
L.S. D	—	9.17	—	—	—	—	10.31

*= Mean number of fall armyworm /10 maize plants in untreated control throughout the experimental period, Means within a column denoted by the same letter (s) are not significantly different at 5% level according to DMRT (1955).

Also, Thrash *et al.* (2013) [27] found that the use of chlorantraniliprole and cyantraniliprole as seed treatments reduced the need for foliar sprays against FAW in soya. In support, Abd Elmageed *et al.* (2022) [2] reported that Indoxacarb was potent as initial kill (84% reduction) against FAW larvae infesting maize plants. Methomyl induced 61.91% reduction in case of residual effect. Residual efficacy provided by compounds may reduce repetitive insecticide application to achieve a satisfactory control. Further studies are required to determine the ecological effects of the persistent nature of these products in a row-crop ecosystem. Mourad *et al* (2022) [21] found that Neomyl 90% SP, Lamdathrin 5% EC, Dimeuron 10% EC and Match 5% EC, had intermediate effects of 79.05%, 72.12%, 70.59% and 70.11% on *S. frugiperda* larvae, respectively.

Conclusion

In our study, we evaluated the efficacy of different insecticides against *S. frugiperda* on maize plants in Egypt reveals important understandings for managing this pest. Effective *S. frugiperda* management requires a comprehensive approachs that integrates cultural, biological, and chemical control methods. By understanding *S. frugiperda* biology and ecology, growers can protect their crops from these pests and minimize the need for chemical interventions. These findings suggested that indoxacarb and chlorantraniliprole + abamectin significantly reduced larval populations, with reductions reaching up to 88%, proving their high effectiveness against *S. frugiperda* related to methomyl. The present study concluded that indoxacarb and chlorantraniliprole + abamectin and methomyl can be used in IPM programs of *S. frugiperda*.

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