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Insecticides' Performance against *Spodoptera frugiperda* (J.E. Smith) Larvae on the Sugar Beet Crop in Fayoum Governorate, Egypt

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ABSTRACT

Fall armyworm (FAW), *Spodoptera frugiperda* (J E. Smith), is among the most destructive, global, polyphagous pests that attack a variety of host plants. It was documented in Egypt in 2019, according to the Food and Agriculture Organisation of the United Nations (FAO, 2019). Among the insecticides currently applied, Indoxacarb and Emamectin benzoate are significant due to their selective toxicity to Lepidopteran larvae. Field tests demonstrated Indoxacarb and Emamectin benzoate caused up to 83-100% elimination of *Spodoptera frugiperda* (J.E. Smith) under outbreak conditions during the two experimental seasons (2020-2021 &2021-2022) with no significant difference in performance (p = 0.2191). On the other hand, the root yield of sugar beet crop improved from 8.5 to 12.0 t/fed. and from 7.5 to 12.6 t/fed. during the two successive seasons, with the Increase in Yield after Treatment (IYAT) being 29.2% and 40.5% respectively, demonstrating clear correlations between reduced pest density and improved yield performance. These findings confirm Indoxacarb and Emamectin benzoate as effective chemical options within an integrated pest management system.

INTRODUCTION

Sugar beet (*Beta vulgaris* L.) is the second most important crop used for sugar production in Egypt, following sugarcane. Sugar beet is also vulnerable to several foliar-feeding Lepidoptera species, including *S. frugiperda*, whose infestation on the crop was not reported earlier in Egypt. The record of this pest was first reported to infest Egyptian maize crops during 2018–2019 and spread rapidly throughout Upper and Middle Egypt. Adult movement from maize into subsequent crops and larval carryover have contributed to establishment within the local area; therefore, they represent a new host record and a potential danger to efficiency in sugar production and processing.

Although IPM strategies are essential for *S. frugiperda's long-term management, chemical control remains* a necessary measure under outbreak conditions. Among the insecticides currently applied, Indoxacarb and Emamectin benzoate are significant due to their selective toxicity to Lepidopteran larval and compatibility with IPM systems. Indoxacarb, an oxadiazine compound, acts on voltage-gated sodium channels, resulting in

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feeding interruption and paralysis (Wing *et al*., 2000), while Emamectin benzoate, a macrocyclic lactone from Streptomyces avermitilis, acts on GABA and glutamate-gated chloride channels, resulting in neuromuscular paralysis (Jansson *et al.*, 1997; Zhao *et al*., 2020; Liu *et al*., 2022; Amein & Abdelal, 2023). Both compounds are highly effective against S. frugiperda and sustainable for insect pest management. Accordingly, this study aimed to: 1- Evaluate the efficacy of both experimental compounds in reducing FAW damage on the sugar beet crop.2- Defining FAW impact on root yield of sugar beet and estimating its loss incidence in Egypt under the regional Agro ecosystem.

MATERIALS AND METHODS

1. Experimental Site and Design:

Field experiments were conducted at two successive sugar beet crop seasons (2020/2021 and 2021/2022) at a private farm in El-Fayoum Governorate, Egypt. The experiment aimed to control *Spodoptera frugiperda* on sugar beet (*Beta vulgaris* L.) using chemical insecticides. The experiments were conducted on a 4.5-feddan plot following maize cropping to simulate the natural crop rotation prevalent in the region.

A randomized complete block design (RCBD) was employed with plots of 0.5 feddan per treatment, each of three replicates, as well as an untreated control. Standard agronomic practices were uniformly applied to all plots according to local recommendations.

2. Insecticidal Treatments:

Chemical control trials were applied once the pest infestation exceeded the economic threshold (≥20% of plants showing shot-hole symptoms).

Two insecticidal treatments were tested:

•**Indoxacarb** (30% WG) applied at 60 g active ingredient per feddan.

•**Emamectin benzoate** (5.7% EC) applied at 80 g per feddan.

Application was made using a calibrated knapsack sprayer (20L) fitted with a hollow-cone nozzle and the recommended manufacturer's spray volume. The treatment was replicated three times in the first season (07 Oct, 04 Nov, and 02 Dec) and twice in the second season (14 Oct and 04 Nov). Larval counts were recorded before spraying and seven days after treatment (7 DAT).

3.Sampling Procedure and Larval Density Assessment:

Sampling was done weekly from the start of treatment up to 12 weeks after application. In each replicate, ten plants were randomly chosen along the diagonal transect; the number of live larvae per plant was counted. The identification of larvae was confirmed morphologically based on the diagnostic features described by Montezano *et al*. (2018). Data are expressed as the mean larval count per plant for each treatment and sampling date.

4. Modelling of Efficacy Decay:

An exponential decay model [$R(t) = R_0 e^{-kt}$] was fitted to the weekly reduction data for each treatment and season, where R_0 is the initial reduction (%) and k is the decay constant (week^{-1}), representing the rate at which suppression decreases over time.

Derived Parameters Included:

• Suppression half-life ($t_{1/2}$) = ln (2)/k; this approach follows standard first-order decay kinetics commonly applied in pesticide residue and pest suppression studies (Tang *et al*., 2013).

According to Trumper *et al*. (1998), two indices were defined for this study to quantify overall treatment efficacy over the observation period:

• Area Under Pest Suppression Curve (AUPSC) = $\int_0^{12} R(t)\,dt$, representing the cumulative pest reduction over 12 weeks.

• Residual Efficacy Index (REI) = (Mean reduction beyond week 3 / R_0) × 100, which reflects persistence of suppression beyond the initial three weeks of treatment.

5. Statistical Analysis:

All the data were subjected to analysis of variance (ANOVA). Comparison of means was conducted using Duncan's multiple range test at $p \leq 0.05$ (Duncan, 1955). Descriptive statistics (mean ± SE) were used to measure larval density, and Pearson correlation coefficients (r) were computed to examine the relationships between the density of pest populations and environmental factors (Snedecor & Cochran, 1989).

Independent-samples *t*-tests were employed to compare seasonally pest densities and treatment efficiency, whereas paired-samples *t*-tests were used to compare pre- and post-treatment larval reductions (Steel & Torrie, 1980). The percentage of reduction was obtained from corrected values of Reduction (%) using Abbott's formula Abbott, 1925 and Henderson and Tilton, 1955: [Reduction (%) = (C - T)/C × 100], where C is the mean pre-treatment larval count and T is the mean post-treatment count.

RESULTS

Field Observations:

Field experiments were conducted during the 2020–2021 and 2021–2022 crop seasons to monitor the infestation status, population dynamics, and feeding behaviour of *Spodoptera frugiperda* on sugar beet crops planted after a maize crop.

1.Efficiency of Indoxacarb and Emamectin Benzoate:

Data in Table 1, indicated larval densities before and after insecticide treatment. Chemical control was initiated once infestation levels crossed the economic threshold of 20 larvae per 10 plants. Indoxacarb effectively reduced the larvae from 18 to 3 larvae per 10 plants during 2020/2021 (83.3% reduction) and from 30 to 1 larva per 10 plants during 2021/2022 (96.7% reduction). Emamectin benzoate produced similar or slightly higher suppression rates (83% to 100%) (Fig.1& Table 1).

By the second season, natural population decline and residual impacts of the treatments maintained low infestation levels, reducing the need for further applications.

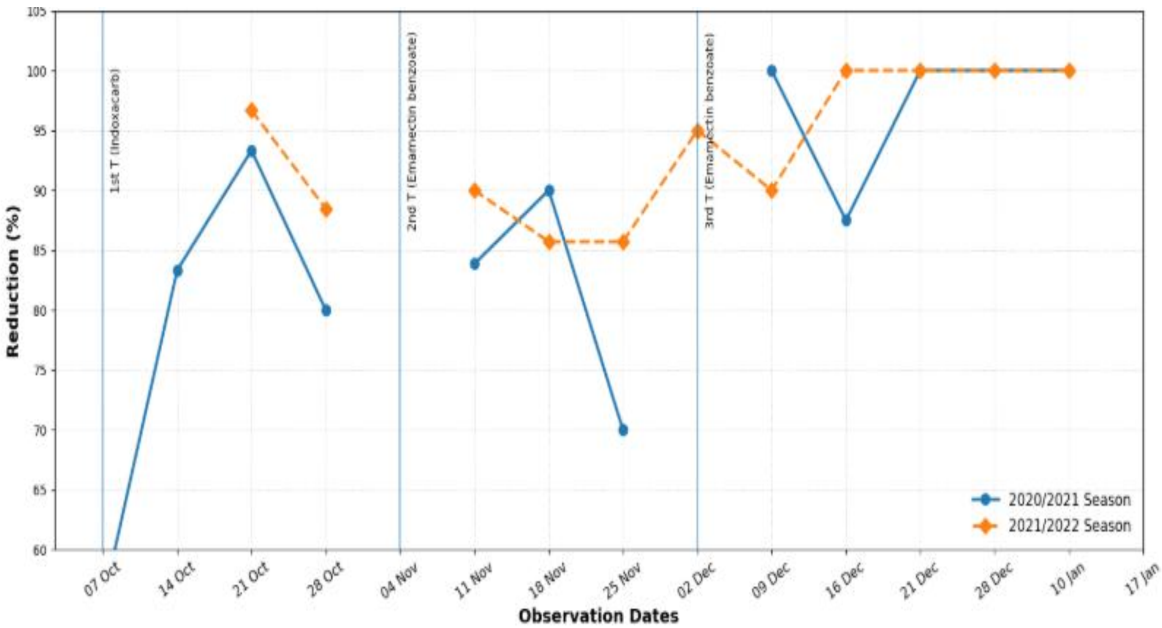

Fig.1: Population reduction of *Spodoptera frugiperda* on sugar beet crop across observation dates with insecticide application timeline during 2020/2021 and 2021/2022 seasons.

Table 1. *Spodoptera frugiperda* infestation on sugar beet crop before and after insecticide applications during the 2020/2021 and 2021/2022 seasons in El-Fayoum Governorate, Egypt.

Observation Dates	2020/2021 season			2021/2022 season		
	No. larvae /10 plants before treatment	No. larvae after treatment	Reduction%	No. larvae/10 plants before treatment	No. larvae after treatment	Reduction %
07 Oct	27	**1st T (Indoxacarb)**		12	11	
14 Oct	18	03	8.33×10^1	30	**1st T (Indoxacarb)**	
21 Oct	15	01	9.33×10^1	30	01	9.67×10^1
28 Oct	20	04	8.00×10^1	26	03	8.85×10^1
04 Nov	23	**2nd T (Emamectin benzoate)**		29	**2nd T (Emamectin benzoate)**	
11 Nov	31	05	8.38×10^1	20	02	9.00×10^1
18 Nov	30	03	9.00×10^1	21	03	8.50×10^1
25 Nov	10	03	7.00×10^1	21	03	8.57×10^1
02 Dec	26	**3rd T (Emamectin benzoate)**		20	01	9.50×10^1
09 Dec	25	0.0	10.0×10^1	10	01	9.00×10^1
16 Dec	08	01	8.75×10^1	09	0.0	10.0×10^1
21 Dec	03	0.0	1.00×10^2	03	0.0	1.00×10^2
28 Dec	02	0.0	1.00×10^2	03	0.0	1.00×10^2
10 Jan	01	0.0	1.00×10^2	01	0.0	1.00×10^2
17 Jan	0.0	-	-	0.0	-	-

2.Reduction in Larval Density and Yield Response:

As summarised in Table 2, both Indoxacarb and Emamectin benzoate achieved excellent post-treatment efficacy. The mean larval reduction after seven days of treatment ranged from 83.3–100% (2020/2021) to 90.0–96.7% (2021/2022), indicating high insecticidal performance. Root yield improved from 8.5 to 12.0 t/feddan and from 7.5 to 12.6 t/feddan during the two successive seasons, with the Increase in Yield after Treatment (IYAT) being 29.2% and 40.5% respectively, demonstrating clear correlations between reduced pest density and improved yield performance.

The post-treatment exponential decay analysis revealed a consistent reduction in *Spodoptera frugiperda* population following insecticidal application in both seasons. The estimated suppression half-lives were 5.82 weeks and 5.37 weeks in the 2020/2021 and 2021/2022 seasons, corresponding to the decay rate constants (k) of 0.119 week^{-1} and 0.129 week^{-1}, respectively. These indicate a fractionally greater suppression rate during the second season (Table 3).

Regression analyses also supported these findings with compelling negative trends between pre-treatment larval counts and post-treatment weeks of sampling in both years.

Regression slopes were −1.732 ($R^2 = 0.483$, $p = 0.0040$) for 2020/2021 and −1.996 ($R^2 = 0.668$, $p = 0.0002$) for 2021/2022, indicating a faster temporal decline in larval density in the second season (Fig. 2).

Table 2. Post-treatment Exponential Decay Model and Comparative Yield & Reduction Rates of Indoxacarb and Emamectin Benzoate Treatments During Two Seasons.

Season	Treatment	Observation Date	Larvae Before	Larvae After	Reduction (%)	Suppression Half-Life (weeks)	Decay Rate Constant (k, week^{-1})	YBT (t/feddan)	YAT (t/feddan)	IYAT (%)	Notes
2020/2021	**Indoxacarb**	14 Oct	18	3	-8.33×10^1 (≈ 83.3 %)	5.82	0.119				Strong suppression and yield gain
	E. benzoate	11 Nov	31	5	-8.39×10^1 (≈ 83.9 %)	5.82 †	0.119	8.5	12.0	2.92×10^1 (≈ 29.2 %)	Comparable reduction
	E. benzoate	09 Dec	25	0	-1.00×10^2 (100 %)	5.82 †	0.119 †				Complete suppression observed
2021/2022	**Indoxacarb**	14 Oct	30	1	-9.67×10^1 (≈ 96.7 %)	5.37	0.129	7.5	12.6	4.05×10^1 (≈ 40.5 %)	Faster decay, higher yield
	E. benzoate	11 Nov	20	2	-9.00×10^1 (≈ 90.0 %)	5.37	0.129				Sustained efficacy

IYAT: Increase in yield After Treatment (%), **YBT:** yield before treatment (t/feddan)**, YAT**: yield after treatment (t/feddan).

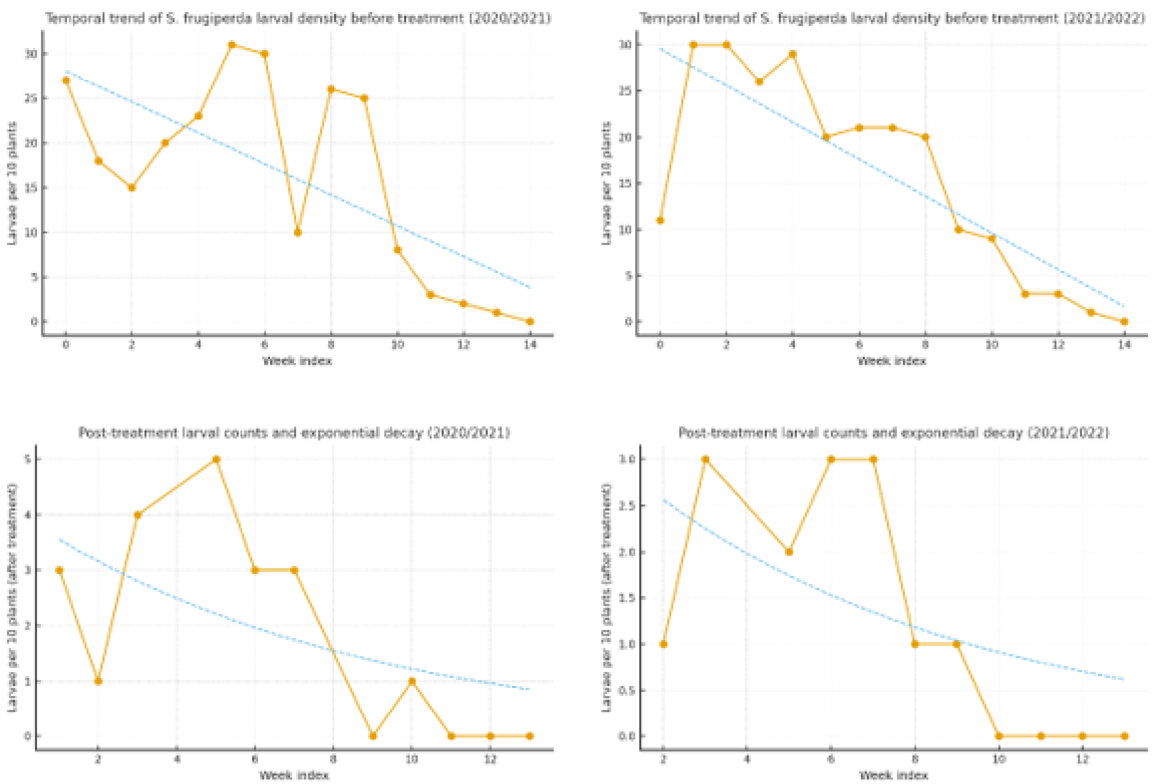

Fig. 2. Temporal patterns for 2020/2021 (left) and 2021/2022 (right) seasons' pre- and post-insecticidal application.

Statistical analyses (Table 3) confirmed that insecticide treatment drastically reduced infestation levels. Paired-sample t-tests confirmed the reduction in larval populations after treatments in both seasons (2020/2021: $t = 4.401$, $p = 0.0013$; 2021/2022: $t = 4.939$, $p = 0.0006$). However,

Table 3. Comparative and Inferential Assessment of Insecticide Control Effectiveness.

Test	Comparison	n	Statistic	p-value	Significance	Interpretation
Paired *t*-test	2020/2021 Before vs After	11	$t = 4.401$	0.0013	**Significant ($p < 0.01$)**	Infestation reduced
Paired t-test	2021/2022 Before vs After	11	$t = 4.939$	0.0006	**Highly significant ($p < 0.001$)**	Infestation reduced
Independent *t*-test	Reduction % (2020 vs 2021)	11 + 11	$t = -1.303$	0.2191	ns ($p > 0.05$)	Products comparable
Linear regression	Before counts vs week (2020)	15	slope = −1.732	0.0040	**Significant ($p < 0.01$)**	$R^2 = 0.483$; significant trend
Linear regression	Before counts vs week (2021)	15	slope = −1.996	0.0002	**Significant ($p < 0.01$)**	$R^2 = 0.668$; significant trend

ns = non-significant

Independent-sample *t*-tests for comparing percentage reductions between the seasons revealed no significant difference in the efficacy of seasons ($p = 0.2191$), confirming both insecticides to be statistically equivalent.

Substantively, both insecticide products maintained high and long-lasting levels of suppression, oftentimes well over 90% decline, indicating their excellent fit in integrated pest management (IPM) programs of sugar beet production under the same agronomic conditions.

3.Modelled Suppression Dynamics:

Both insecticides induced initial suppression of more than 80%, followed by a gradual exponential decay. Decay constants ranged from 0.119 to 0.129 week^{-1}, translating to a suppression half-life of approximately 5.37–5.82 weeks (Table 4).

4. Comparative Efficacy and Stability:

The Residual Efficacy Index (REI) average was 37–40% (~ one-third to two-fifths), indicating that approximately 40% suppression persisted beyond the third week.

Table 4. Comparative suppression dynamics of *Spodoptera frugiperda* on sugar beet under Indoxacarb and Emamectin benzoate treatments during two growing seasons.

Treatment	Season	Initial reduction, R_0 (%)	Decay constant, k(week^{-1})	Suppression half-life (weeks)	AUPSC %(week	Residual efficacy index (REI, %)	Interpretation
Emamectin benzoate	2020/2021	100.0	0.119	5.82	639.6	40.4	Strongest and most persistent efficacy
Indoxacarb	2020/2021	83.3	0.119	5.82	532.8	40.4	Slightly lower initial efficacy, similar persistence
Emamectin benzoate	2021/2022	90.0	0.129	5.37	~550	37.6	High initial suppression but faster decay
Indoxacarb	2021/2022	96.7	0.129	5.37	~520	37.6	Strong initial suppression, comparable decay to Emamectin

Emamectin benzoate had the highest cumulative suppression in 2020/2021, with an AUPSC of 639.6 %-weeks. Suppression levels remained around 70% for approximately three weeks post-treatment, gradually declining to about 63% by week four. Indoxacarb had a relatively lower AUPSC of 532.8 % weeks in the same season, but had a higher initial reduction of 96.7% in 2021/2022-2021/2022 (Fig. 3).

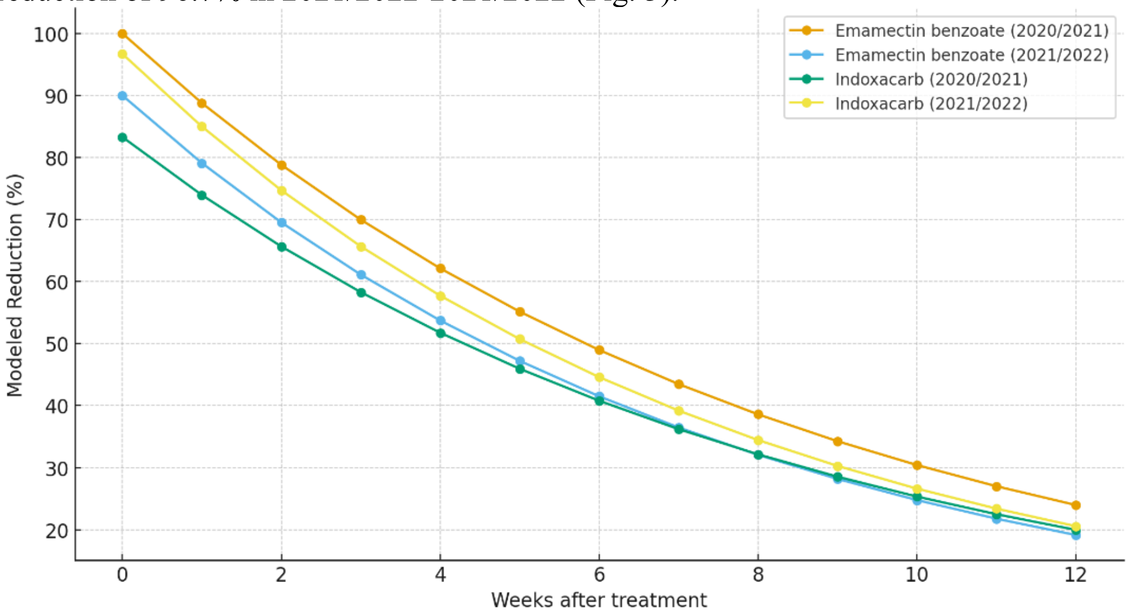

Fig. 3: Weekly percentage reduction in pest populations for each treatment across the 2020/2021 and 2021/2022 seasons.

DISCUSSION

Efficacy of Insecticidal Treatments:

Both Indoxacarb and Emamectin benzoate exhibited better larvicidal activity with reduction rates ranging from 83 % to 100 % through the two experimental seasons (2020-2021 & 2021-2022) with no significant difference in performance ($p = 0.2191$). The exponential decline model showed the ability of both compounds to attain sustained suppression of *Spodoptera frugiperda* populations on sugar beet. The slightly higher suppression observed in the second season most likely reflects improved synchronisation timing of application with pest-favourable climatic conditions for insecticides performance. Indoxacarb and Emamectin benzoate have very different biochemical modes of action. Indoxacarb acts on voltage-gated sodium channels, causing feeding cessation and paralysis (Wing *et al.,* 2000), while Emamectin benzoate, a semi-synthetic avermectin analogue, induces inhibitory neurotransmission enhancement through glutamate-gated chloride channels, leading to paralysis and death (Ishaaya *et al*., 2002). These divergent pathways not only ensure potent larvicidal action but also reduce the possibility of cross-resistance. Their selectivity toward Lepidopteran pests and relatively low toxicity to beneficial arthropods make them compatible with biological control agents and suitable for IPM programs with an emphasis on environmental sustainability.

The estimated suppression half-lives of 5.37–5.82 weeks for both insecticides denote moderate field persistence consistent with previous reports in maize and cotton systems (Thumar *et al.,* 2020; Mian *et al.,* 2022). The slightly accelerated decay during the 2021/2022 season might have been partly due to climatic influences such as higher temperatures, UV radiation, and rainfall, which accelerate photolytic and microbial degradation in open environments (Gutierrez-Moreno *et al.,* 2019 and Zhao *et al.,* 2020). Such environmental influences should be considered when considering spray intervals under Egyptian climatic conditions.

Comparative Efficacy and Residual Activity:

Both products yielded high suppression frequencies of over 90% more frequently, confirming their great residual activity, particularly for Emamectin benzoate towards the latter half of the 2020 season. The comparative analysis revealed that Emamectin benzoate exhibited slightly greater cumulative suppression (AUPSC = 639.6 %-weeks) and a slower decay rate than Indoxacarb (AUPSC = 532.8 %-weeks). These findings align with those of Wu *et al.* (2016) and Liu *et al.* (2022), who reported that the lipophilic nature and strong cuticular binding of Emamectin benzoate enhance its residual persistence on treated foliage. Conversely, Indoxacarb demonstrated a more rapid initial knockdown effect, achieving up to 96.7% larval reduction in the second season, but displayed faster decay ($k = 0.129$ week^{-1}). Such differences suggest that Emamectin benzoate provides longer-term protection, whereas Indoxacarb offers immediate and potent larvicidal activity.

Population Dynamics and Statistical Validation:

It was evident from the exponential decay model that the temporal reduction in larval density after insecticidal application confirmed the hypothesis that suppression of *S. frugiperda* follows a predictable, time-dependent decline. Regression analyses revealed significant negative correlations between sampling week and larval density ($p < 0.01$), reflecting constant decreases in populations over time. Furthermore, the non-significant differences in overall efficacy during the seasons ($p > 0.05$) imply high stability in the insecticidal performance under fluctuating climatic conditions. REI values of 37–40% showed that approximately 40% suppression was maintained beyond three weeks post-application, sustaining effective protection during important vegetative growth stages of the sugar beet crop.

These results are in agreement with those reported by Viana and Costa 1998 and Zhao *et al.* 2020, who concluded that a suppression level above 70%, maintained for three weeks, was an efficient threshold for the field-level control of *S. frugiperda*. The prolonged performance of these two insecticides further supports their use in field applications under moderate pest pressure conditions.

Yield Response and Agronomic Significance:

Yield responses were consistent with patterns of pest reduction, with the second season having the most advantage. The significant increases in sugar beet root yield that are linked to the reduced suppression half-life and higher decay constant after insecticide application (29.2% in the 2020/2021 and 40.5% in the 2021/2022 seasons) illustrate the economic and agronomic advantages of timely control of *S. frugiperda*. These yield increases are consistent with the respective calculated larval population reductions that agree with previous maize field trials (Mian *et al.,* 2022). The consistency in yield response and suppression half-life values for both compounds between seasons further highlights their reliability under Egyptian field conditions. Despite the non-significant differences among seasons, 2021/2022 reflects a more stable and predictable pest suppression dynamic. However, over-reliance on chemical control can foster resistance; therefore, rotation between insecticides of different modes of action and use of biological control agents is greatly encouraged. Such integrated methods not only ensure effectiveness but also minimize ecological disruption and the development of resistance.

Impact on Yield and Agronomic Implications:

S. frugiperda infestation resulted in extensive yield losses, revealing the economic importance of the pest to sugar beet production. The positive relationship between larval density and yield loss suggests early action and adherence to economic threshold levels; however, the rapid population reduction permitted more yield recovery. Indoxacarb and Emamectin benzoate effectively recovered yield potential, confirming the value of early chemical control in IPM schemes.

This infestation's feeding damage, ranging from windowpane lesions in seedlings to defoliation and whorl destruction, is congruent with that reported in maize and sorghum and indicates *S. frugiperda's* extensive host adaptability and polyphagous feeding habits (Hruska, 2019). The pest's presence in sugar beet systems is therefore not only a local agronomic problem but also a regional biosecurity threat with

Conclusion

The current study presents the first extensive evidence that *Spodoptera frugiperda* can complete its cycle on sugar beet in Egypt with measurable yield loss under field conditions. Indoxacarb and Emamectin benzoate proved to be highly and comparably effective in suppressing *S. frugiperda* infestation on sugar beet, confirming their potential inclusion into sugar beet IPM programs.

Declarations:

Ethical Approval: The research does not include human or animal subjects.

Competing interests: The authors declare that they have no duality of interest associated with this manuscript.

Authors' Contributions: Data Curation, Resources, figure, table, visual preparation, editing, and improvement of the final manuscript were performed by Rania M. El-Shennawy. Methodology and first Draft preparation of the manuscript by Mervat A.A. Kandel. Field surveys, sample collection, and monitoring of pest populations were conducted by Ibrahim M. Sabra.

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Availability of Data and Materials: All datasets analysed and described during the present study are available from the corresponding author upon reasonable request.

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ARABIC SUMMARY

أداء المبيدات الحشرية ضد يرقات دودة الحشد الخريفية على محصول البنجر السكري خلال موسمين زراعيين متتاليين في محافظة الفيوم، مصر.

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تُعد دودة الحشد الخريفية (*Spodoptera frugiperda*) من أكثر الآفات تدميرًا على مستوى العالم، وهي آفة متعددة العوائل، إذ تهاجم مجموعة متنوعة من النباتات المضيفة. وقد وُثِّقت في مصر عام ٢٠١٩، وفقًا لمنظمة الأغذية والزراعة للأمم المتحدة (الفاو). ومن بين المبيدات الحشرية المُستخدمة حاليًا، يُعدّ كلٌّ من إندوكساكارب و إيمامكتين بنزوات فعالين نظرًا لسميتهما الانتقائية ليرقات حرشفيات الأجنحة.

أدت الإصابات الشديدة إلى انخفاض في المحصول ليسجل 8.5-7.5 طن للفدان في الموسمين المتتالين على التوالي. وقد أظهرت الاختبارات الميدانية أن مركب الإندوكساكارب و إيمامكتين بنزوات أدى إلى القضاء على نسبة (83- 100%) من اجمالي اليرقات دون أي فرق معنوي في الأداء ($p = 0.2191$) لكلا المركبين. ووومن ناحية أخري ، تحسن إنتاج جذور بنجر السكر من 8،5 إلي 13،0 طن / فدان ومن 5.7 إلي 12،6 طن / فدان خلال الموسمين المتتاليين ، حيث بلغت الزيادة في الإنتاج بعد العلاج إلي 2،29% و 40،5 % علي التوالي مما يؤكد فعالية المركبين المختبرين كخيارين كيميائيين ضمن نظام المكافحة المتكاملة لهذه الآفة المستجدة علي البيئة المصرية ، وكذلك يدل علي وجود إرتباط واضح بين إنخفاض كثافة الآفة وتحسن كمية الإنتاج .