Brazilian Journal of Biology®

ISSN 1519-6984 (Print)
ISSN 1678-4375 (Online)

Original Article

# Impact of the fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae) infestation on maize growth characteristics and yield loss

## Impacto da infestação da lagarta do cartucho *Spodoptera frugiperda* (Lepidoptera: Noctuidae) nas características de crescimento do milho e na perda de rendimento

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**Abstract**

The fall armyworm [FAW; *Spodoptera frugiperda* (J.E Smith, 1797)] is an invasive and polyphagous insect that infests cereal crops, causing economic losses, and may be led to pose a threat to future the global maize crop in the future. Field trials were conducted to study the negative impacts of *S. frugiperda* on vegetative growth measurements, yield, and the components of the maize cultivar (Single-Hybrid 168 Yellow) in Luxor Governorate, Egypt. *S. frugiperda* larvae infestation to maize plants was observed in the 3rd week of June and so continued till the harvest in both 2021 and 2022 seasons. *S. frugiperda* had three peaks of the seasonal activity/season in the untreated (pesticide-free, control) and in the treated main plots by pesticides. Maize vegetative growth attributes (averages of plant height, stem diameter, and the number of green leaves per plant) displayed higher rates of the treated maize plants by insecticides against *S. frugiperda*. Maize grain, straw, and biological yield (kg/ha) were decreased in the untreated maize plants (insecticides free) than in the treated by insecticides. Concerning maize yield components, the treated plants were to outperform in the average length of a plant stem (cm), stem diameter (cm), and weight of cob (g), as well as, number of rows/cob, number of grains/ cob, number of grains/cob, maize cob grain weight (g) and weight of 1000-grains (g)], in comparison with the untreated plants. Also, the FAW infestation to untreated maize plants was decreased well in all calculated maize growth attributes, i.e., grain yield, and components. Regarding the relationship between variations in a given variable and the changes in *S. frugiperda* larvae numbers and plant damage percentage, the simple correlation and regression coefficient revealed a highly significant negative relationship in all the parameters tested. The obtained information may help farmers and decision-makers in the management of FAW populations based on an effective plan related to control measures that should be implemented.

**Keywords:** maize plants, crop, yield, yield loss, fall armyworm, FAW, *Spodoptera frugiperda*, population density, agriculture, pesticides.

**Resumo**

A lagarta-do-cartucho [FAW; *Spodoptera frugiperda* (J.E Smith, 1797)] é um inseto invasor e polífago que infesta culturas de cereais, responsável por perdas econômicas, representando uma ameaça para a cultura mundial de milho no futuro. Ensaios de campo foram conduzidos para estudar os impactos negativos de *S. frugiperda* nas medidas de crescimento vegetativo, rendimento e os componentes da cultivar de milho (Single-Hybrid 168 Yellow) na província de Luxor, Egito. A infestação de larvas de *S. frugiperda* nas plantas de milho foi observada na terceira semana de junho e prosseguiu até a colheita nas temporadas de 2021 e 2022. A espécie *S. frugiperda* teve 3 picos da atividade sazonal nas parcelas não tratadas (sem agrotóxicos e controle) e nas tratadas com agrotóxicos. Os atributos de crescimento vegetativo do milho (médias de altura da planta, diâmetro do caule e número de folhas verdes por planta) apresentaram maiores taxas das plantas de milho tratadas com inseticidas contra *S. frugiperda*. O grão de milho, a palha e o rendimento biológico (kg/ha) diminuíram nas plantas de milho não tratadas (sem inseticidas) do que nas plantas tratadas com inseticidas. Com relação aos componentes de rendimento do milho, as plantas tratadas tiveram desempenho superior no comprimento médio do caule da planta (cm), diâmetro do caule (cm) e peso da espiga (g), bem como, número de fileiras/espiga, número de grãos/espiga, número de grãos/espiga, peso de grãos de espiga de milho (g) e peso de 1000 grãos (g), em comparação com as plantas não tratadas. Além disso, a infestação de LFM em plantas de milho não tratadas diminuiu consideravelmente em todos os atributos

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Received: May 8, 2023 – Accepted: May 24, 2023

de crescimento do milho calculados, ou seja, rendimento de grãos e componentes. Quanto à relação entre as variações de uma determinada variável e as mudanças no número de larvas de *S. frugiperda* e na porcentagem de danos às plantas, a correlação simples e o coeficiente de regressão revelaram uma relação negativa e altamente significativa em todos os parâmetros testados. A informação obtida pode ajudar os agricultores e gestores das populações da LFM com base num plano eficaz relacionado às medidas de controle que devem ser implementadas.

**Palavras-chave:** plantas de milho, colheita, rendimento, perda de rendimento, lagarta-do-cartucho, LFM, *Spodoptera frugiperda*, densidade populacional, agricultura, pesticidas.

## 1. Introduction

The Fall Armyworm (FAW), also known as *Spodoptera frugiperda* (J.E Smith, 1797) (Lepidoptera: Noctuidae) is a serious and destructive pest of maize. For this reason, maize production worldwide is still at risk. *S. frugiperda* is one of the polyphagous migratory pests in recent century that can cause significant economic losses in over 80 different crops in general (Bakry and Abdel-Baky, 2023; Anandhi et al., 2020; Caniço et al., 2020; Maruthadurai and Ramesh, 2020; Montezano et al., 2018; Goergen et al., 2016) and the most destructive maize pests in particular (Anjorin et al., 2022) and is quickly spreading in Africa (Goergen et al., 2016). Fall Armyworm is currently the most harmful crop pest affecting maize in Egypt and others in the world, as it has spread very widely (Bakry and Abdel-Baky, 2023). In Africa, FAW preferred maize to numerous other crops (Prasanna et al. 2018). The rapid spread of FAW is ascribed to its migratory potential (Meagher et al. 2004) and high dispersal ability (Kumela et al. 2018). FAW has several generations/year, and the adult can a flight up to 100 kilometers in a single night (FAO, 2017). It is a dangerous pest and an invasive, alien, nocturnal, and noxious pest that may pose a threat to the maize crop and food security in the future (Yigezu and Wakgari, 2020; Caniço et al., 2020; Sun et al., 2021).

FAWis difficult to control, manage, or eradicate because it is a polyphagous and transboundary pest, as well as, it has a high reproductive capacity and short life cycle, harbors a high migratory capacity through trade, and lacks diapause in its development (Rios et al., 2014).

FAW attacks maize plants at all developmental stages causing serious losses when maize leaves are damaged, lowering photosynthetic space, delaying plant growth, drawbacks to plant reproduction, and finally reducing the grain yield (Chimweta et al., 2020). FAW females laid their eggs on the upper and lower surfaces of leaves in groups, with 150-200 eggs per group covered in brownish fine hairs in either a single or multiple clusters (Tendeng et al., 2019). New hatch larvae attack maize leaves and scrape chlorophyll from the leaves, resulting in a silvery transparent film that eventually results in white elongated spots and pin and bulletholes. Young larvae initially consume leaf tissue from one side while leaving the obverse epidermal stratum intact. It resulted in the entire stem base of maize plantlets being sectioned, and heavily windowed whorls being loaded with feeding waste resulting from larvae. FAW larvae may damage maize plants over the vegetative and flowering stages. It also bores into the stems, ears, and cobs of maize. Later larvae instar makes a 'windowpane' on the plant leaves by depositing damp sawdust-like frass nearby the upper leaves and funnel. Adult larvae have four distinct black spots on the eighth segment of their abdominals and a white inverted 'Y' shaped cap on their heads (Shylesha et al., 2018). The adult caterpillar disrupts fertilization and pollination mechanisms, devastating tassels and bores into the maize cob, lowering harvest quality and leading to infection of the cob by secondary infection (Anjorin et al., 2022). It causes severe damage when the plant ages 42 to 56 days after planting (Dhar et al., 2019). FAW gravid females favor young maize plants with a height of 30 to 60 cm for oviposition. The caterpillars consume the leaves of young plants of maize, resulting in larval droppings and hollow leaves (Belay, 2011). Larger larvae can cause more damage and defoliation, leaving only the ribs and stalk of the corn plant with a ragged appearance. Overfeeding the larvae may lead to heart death and the tearing of young plants (Capinera, 2017). Adult moths can survive for up to 14 days under suitable environmental conditions and can invade new territories in tropical and subtropical regions (Du Plessis et al., 2020).

Maize yield losses as a result of the influencing FAW feeding and its biological activities have been estimated. Cruz et al. (1996) reported that when FAW infests 20% of maize plants in the mid-whorl stage of growth, the yield was reduced by about 17–18% or 34% and can be increased up to 58% (Cruz et al., 1999; Lima et al., 2010; García-Gutiérrez et al., 2012). The annual losses in Brazil are estimated to be $400 million (Figueiredo et al., 2005). In Latin America, FAW caused 73% of maize yield reduction (Murua et al., 2006). Day et al. (2017) and Rwomushana et al. (2018) estimated that FAW reduced maize yields by 22 to 67% in Ghana and Zambia, resulting in millions of dollars in losses. As mentioned, the FAW is expected to cause a loss of 21–53% in yearly maize production in the absence of control methods. Similarly, Croom (2018) mentioned that for each 1% increment in damaged plants, a yield reduction of 29.95 kg/ha. Kumela et al. (2018) revealed that FAW reduced 32% of the Ethiopian yield and 47% of the Kenyan yield. The impact of FAW damage on yield is about 57% in Namibia (FAO, 2018), 11.57% in Zimbabwe (Baudron et al., 2019), 33% in the Rangareddy district of Telangana, India (Balla et al., 2019), and between 26.5 and 56.8% in South Africa (Van den Berg et al., 2021). Heavy FAW infestations reduce maize crop yield by 50-80% (Adhikari et al., 2020; Chimweta et al., 2020). Data from smallholder maize-growing households in Zimbabwe revealed that FAW contributed 12% and more of people's hunger (Tambo et al., 2021) mentioned that households influenced by FAW were 12% more vulnerable to experiencing hunger. Furthermore, the severe infestation of FAW lowered each household's per capita pay by 44% and increased the odds of household hunger by 17%. As well the direct damage to FAW the maize, the insect can be destroying cobs resulting in fungal infection associated with larval feeding as indirect damage which may affect the grain quality (Bangale, 2019).

Thus, the purpose of this study is to evaluate *S. frugiperda* damage characteristics on vegetative growth, yield, and its components of the maize cultivar (Single-Hybrid 168 Yellow) in Luxor Governorate, Egypt. So it could assist farmers in increasing their knowledge regarding the detrimental effects resulting from infestation by this pest.

## 2. Materials and Methods

Field experiments were conducted over two successive growing seasons of maize (2021 and 2022) in the Esna district, Luxor Governorate, Egypt. Maize plants were cultivated in an area of half a hectare (One hectare= 10000 m$^2$).

The selected corn area (2100 m$^2$) was divided into two treatments (unsprayed and sprayed), and each treatment (four plots) was conducted by using a randomized complete block design. The maize cultivar (Single-Hybrid 168 Yellow) was used as a plant host, which was sowed with June 1$^{st}$ week of every season. All the standard agronomic practices (fertilization and irrigation) were carried out at the right time according to the maize agricultural operations schedule.

The unsprayed first four plots: to create a field infestation from FAW, four plots were left without any insecticide treatments (insecticide free) as a check during the study (from the sowing to harvest). The other four plots (replicates) were treated with pesticides according to the recommendations of the Egyptian Ministry of Agriculture (Agricultural Pesticide Committee). With the 1$^{st}$ infestation from FAW on maize plants, the plots were directly sprayed four times per season with pesticides according to the preventative schedule of the Egyptian Ministry of Agriculture, since it has a short life cycle (around 20 to 30 days), and could attack and repeat its infestation several times during the maize growing seasons. By the way, all adjacent fields around our experiment were planted with maize infested by the FAW colony.

The first spray of the chemical herbicide Dursban H 48% EC (Chlorpyrifos) was applied at a rate of (2.4 liter/ha) with the first infestation damage and/or presence of any small numbers of FAW larvae on maize plants. This technique is always carried out in the third week of June over two successive years (i.e., after two weeks of cultivation). The previous control treatments were carried out based on the recommendations of Silva (1999) who mentioned that insecticide control treatments against FAW should be applied within 2-3 weeks after the emergence of maize seedlings. Moreover, Ojumoola et al. (2022) recommended regular field investigations during the first three weeks of planting, to combat any FWA populations.

With the 1$^{st}$ week of July, FAW larvae populations increased up the two seasons, maize plants were sprayed with a Vanty 42% SC (Chlorfenapyr) at the rate of (360 cm$^3$/ha). Another pesticide treatment was done the first week of August over the two seasons and was sprayed with a Goldben 90% SP (Methomyl) pesticide at the rate of (720 g/ha), which the last pesticide treatment was applied the first week of September through the two seasons, by use a Speedo 5.7% WP (Emamectin benzoate) at the rate (360 g/ha).

All pesticide spraying treatments were carried out before sunset using a knapsack motorized sprayer (capacity 20 liters). The plants were covered from the outside with pesticides, in addition to directing the pesticide to the heart of the plant (the core of maize plants), where FAW larvae gather and live. In each pesticide treatment, maize plants were examined after 1, 3, and 5, days post-treatment, by choosing 10 plants at random. FAW live and dead larvae data were recorded (El-Gaby et al., 2022).

### *2.1. S. frugiperda Population studies*

Two biological parameters were used to express FAW biological activities in the maize fields, namely; larval population density and the number of damaged maize plants/fields.

A- Seasonal activity of *S. frugiperda* on maize plants:

To estimate the seasonal incidence of *S. frugiperda*, 40 maize plants (10 plants from each replicate) were randomly investigated per week from the initial infestation to the harvest. Since FAW larvae are affected by the day temperature and light, the larvae sneak into the midrib of maize leaves. The investigation was carried out in the morning (6–9 a.m.) and covered the four geographical directions of the tested maize field. Samples were selected in a "W" pattern to estimate the number of larvae of *S. frugiperda* as well as the damage to maize plants. The upper and lower surfaces of maize leaves, as well as the stalks, were examined according to Abd-Allah et al. (2018) and Caniço et al. (2020). By following Fernández's (2002) methodology, the number of larval individuals on 10 plants was counted and recorded to represent every inspection date ± standard error (SE), to express the population size of pests.

B–Maize plant damage percentage:

The number of maize plants as a result of FAW larvae feeding under natural infestation conditions was calculated using the Caniço et al. (2020) Formula 1:

$$\mathbf{PD} = (\mathbf{a} \ / \ \mathbf{b}) \times \mathbf{100} \tag{1}$$

Where, PD = Percentage of damaged maize plants.

a = the number of plants that displayed any visible symptoms of damage.

b = the total number of maize plants investigated surveyed (damaged and non-damaged ones)/sampling time. Maize plants were considered damaged if no apparent symptoms of larval feeding were observed in the case of visual diagnosis (symptoms), regardless of the presence or absence of larvae.

Data on the vegetative stage of maize plant growth that were taken into account were as follows:

At harvest, ten individual plants were chosen at random from each experimental plot to estimate the following characteristics:

Plant height (cm).

Stem diameter (cm).

No. of green leaves/plants.

Ear length (cm).

Ear diameter (cm).
Ear weight (g).
No. of rows/ear.
No. of grains/row.
No. of grains/ear.
Ear grain weight (g).
Weight of 1000- grains (g).
Grain yield (kg/ha): was calculated at harvest using the centric area of each plot (6 m × 7m = 42 $m^2$). Following shelling, the grains from each plot were weighed to determine the average grain yield (kg/ha) at 15.5 percent moisture.
Straw yield (kg/ha): For each plot, the biological yield (kg/ha) was subtracted from the grain weight (kg/ha).
Biological yield (kg/ha): was estimated by weighting all the plants at the centric area in each plot before shelling.

The amount of damage and losses caused by *S. frugiperda* infestation was estimated using Bakry et al. (2020) Formula 2:

$$\textbf{Loss \%} = \left[\left(\mathbf{A}-\mathbf{B}\right)/\,\mathbf{A}\right]\times\mathbf{100} \qquad (2)$$

**Where: A**= average of a given evaluation of the unsprayed plants, while **B**= averages the same attribute of the sprayed plants.

*2.2. Statistical analysis*

For each tested parameter, the averages for unsprayed and sprayed replicates were compared using a paired T-test at P < 0.05, which was performed by SPSS Program software (SPSS, 1999).

To estimate the relationship between the tested parameters for maize plants as the dependent variable and the two biological parameters of FAW, namely, the number of larvae and the percentage of damaged plants by S. frugiperda (as the independent variables) that were obtained during two growing seasons (2021 and 2022). The differences among the tested variables that could be produced by FAW were elucidated using the simple regression method. The linear regression equation was estimated using Fisher's (1950) and Hosny et al. (1972) formulas:

$$\mathbf{Y}_{=}\mathbf{a} \pm \mathbf{bx}$$

**Where:**

**Y** $_=$Prediction value (Dependent variable) **a** $_=$Constant (y-intercept)

**b** $_=$Regression coefficient **x** $_=$Independent variable

This method was useful for displaying fundamental information about the amount of variability in the estimated variables. Moreover, the collected data was evaluated by the Microsoft Excel 2010 program.

## 3. Results

The current work is the first field experiment in Egypt to shed some light on some undesirable effects caused by *S. frugiperda* infestation on vegetative growth and maize yield, as shown in Figures 1 and 2. These results were obtained through the study, which lasted for two consecutive seasons, 2021 and 2022. As for the weekly changes in the average numbers of *S. frugiperda* larvae that attacked maize plants and the percentage of damaged plants, the data are shown in Table 1.

*3.1. S. frugiperda Population and damage studies:*

*3.1.1. Seasonal dynamics of S. frugiperda larvae on maize plants:*

Results revealed that the larval stage of *S. frugiperda* was observed attacking maize plants from the third week of June till the harvest in each season. The larval stage recorded three peaks of seasonal activities /season, which appeared in the 1st week of July, the 1st week of August, and the 1st week of September in the untreated and treated plots over the two growing seasons.

In our study, the general average of *S. frugiperda* larvae /10 maize plants at treated and untreated plots varied considerably. Herein, the sprayed maize plants showed a general average of (3.40 ± 0.28 and 3.06 ± 0.28 larvae/10 plants) as compared with the unsprayed plants (13.41 ± 0.52 and 13.03 ± 0.46 larvae/10 plants) during the two seasons, respectively. Table 1 and Figure 3 reveal that the increase in *S. frugiperda* larval populations in untreated maize plants compared with the treated plants reached approximately 3.95 in 2021 and 4.25 times in 2022. The analysis of variance showed highly significant differences regarding FAW larvae numbers based on the inspected date. The L.S.D. values were 1.13 and 1.17 in the treated plants, while in the untreated plants, L.S.D. values were recorded 3.85 and 3.35 for the two seasons, respectively (Table 1). Statistically, the numbers of larvae in the sprayed and unsprayed plants revealed highly significant variances, where the L.S.D. values were 0.83 and 0.74 in 2020 and 24.08 and 22.62% in 2022 Table 1.

*3.1.2. Maize plant's damage percentages by S. frugiperda*

The damaged plants' percentages by *S. frugiperda* increased with increasing the periods of inspection during the maize's different growing stages in the untreated plots across the two seasons. This may be due to the availability of a larval population, the availability of foods, the short developmental times of insect life cycles, and its ability to move from one plant to another, so resulting in more severe damage to maize plants (Table 1, Figure 3). Moreover, some plants were observed to be infested well in advance of the time of examination (not recent infections). However, the percentage of affected plants in the treated plots fluctuated between increase and decrease during the different examination periods throughout the crop growth in the two years of the study.

The percentage of maize-damaged plants in the untreated plots recorded an average of 68.54 ± 2.71 and 60.42 ± 2.92%, while in the treated plots, there were 13.41 ± 0.52 and 13.03 ± 0.46% in the two successive seasons, respectively.

Maize-damaged percentage in the untreated plots increased by about 1.87 and 1.76 times that in the treated plots in 2021 and 2022, respectively (Table 1, Figure 3).


**Figure 1.** FAW, *Spodoptera frugiperda*, attacks maize plants at various phenological stages of maize. (A): egg mass. (B): larva with four black spots and an inverted Y-shaped head. (C): adult. (D): larvae attack the leaves, causing symptoms such as a silvery transparent film, white elongated spots, and pin and bullet holes. (E): Larvae feed on the growing region, on the plant heart with leaves defoliation, hollow leaves, and tearing of young plants, and they feed on the reproductive organ (tassel) of a flowering maize plant, leaving moist sawdust-like frass in the funnel and on flag leaves. (F): larvae damage maize plants over the flowering stage and disrupt fertilization and pollination mechanisms, resulting in devastating tassels.


**Figure 2.** Larvae of *S. frugiperda* on stems and cobs. (A) and (B): Larvae bore into maize stems, ears, and cobs, leaving behind wet, sawdust-like droppings. (C) and (D): Overfeeding the larvae may result in grain reduction and lower harvest quality, as well as a secondary infection of the cobs.

Statistically, maize-damaged plants percentages varied significantly according to the inspection dates (L.S.D. values were 10.95 and 11.00) in the treated plants and (L.S.D. values were 14.65 and 12.98) in the untreated plants over the two seasons, respectively, Table 1. Also, the maize-damaged plants' percentages varied significantly according to the treatments (treated and untreated plants). Values of L.S.D. were (3.67 and 3.75) and the coefficient of variation were (17.08 and 19.36%), respectively, across the two seasons. (LSD values were 10.95 and 11.00 in the treated plants

**Table 1.** Weekly mean numbers of *S. frugiperda* larvae and damaged plants percentage of maize plants at two rates (sprayed and unsprayed) at Esna district, Luxor Governorate during the two growing seasons (2021 and 2022).

| Sampling date | | 2021 season | | | | 2022 season | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Larvae count per 10 plants ± S.E. | | Damaged plants percentage (%) ± S.E. | | Larvae count per 10 plants ± S.E. | | Damaged plants percentage (%) ± S.E. | |
| | | Sprayed (Treated plants) | Unsprayed (Untreated plants) | Sprayed (Treated plants) | Unsprayed (Untreated plants) | Sprayed (Treated plants) | Unsprayed (Untreated plants) | Sprayed (Treated plants) | Unsprayed (Untreated plants) |
| June | 3rd | 7.75 ± 0.63 | 7.88 ± 2.32 | 37.50 ± 2.50 | 35.00 ± 2.89 | 7.50 ± 0.50 | 7.50 ± 0.87 | 35.00 ± 2.89 | 30.00 ± 2.04 |
| | 4th | 2.50 ± 0.29 | 12.38 ± 1.13 | 27.50 ± 4.79 | 45.00 ± 6.45 | 2.50 ± 0.29 | 10.88 ± 0.72 | 25.00 ± 5.00 | 35.00 ± 2.89 |
| July | 1st | 5.00 ± 0.41 | 14.25 ± 0.97 | 47.50 ± 2.50 | 52.50 ± 4.79 | 4.75 ± 0.48 | 14.25 ± 0.97 | 45.00 ± 2.89 | 40.00 ± 7.07 |
| | 2nd | 3.00 ± 0.41 | 10.50 ± 1.06 | 27.50 ± 4.79 | 62.50 ± 7.50 | 2.75 ± 0.25 | 11.25 ± 0.43 | 25.00 ± 6.45 | 50.00 ± 4.08 |
| | 3rd | 1.75 ± 0.25 | 11.63 ± 1.66 | 30.00 ± 4.08 | 65.00 ± 6.45 | 1.50 ± 0.29 | 12.38 ± 1.55 | 27.50 ± 4.79 | 52.50 ± 2.50 |
| | 4th | 1.25 ± 0.25 | 15.75 ± 2.49 | 27.50 ± 6.29 | 70.00 ± 4.08 | 1.00 ± 0.41 | 13.88 ± 1.42 | 25.00 ± 2.89 | 57.50 ± 4.79 |
| Aug. | 1st | 5.25 ± 0.63 | 17.63 ± 0.94 | 47.50 ± 2.50 | 75.00 ± 2.89 | 4.50 ± 0.29 | 14.99 ± 1.53 | 47.50 ± 2.50 | 67.50 ± 6.29 |
| | 2nd | 3.75 ± 0.25 | 15.00 ± 0.61 | 37.50 ± 2.50 | 77.50 ± 2.50 | 3.25 ± 0.48 | 12.75 ± 0.97 | 35.00 ± 2.89 | 70.00 ± 5.77 |
| | 3rd | 2.75 ±0.48 | 12.38 ± 1.28 | 42.50 ± 2.50 | 82.50 ± 4.79 | 2.75 ± 0.48 | 12.75 ± 1.30 | 40.00 ± 5.77 | 77.50 ± 4.79 |
| | 4th | 1.50 ± 0.29 | 14.63 ± 1.13 | 37.50 ± 6.29 | 82.50 ± 7.50 | 1.00 ± 0.41 | 15.00 ± 1.06 | 35.00 ± 5.00 | 80.00 ± 4.08 |
| Sept. | 1st | 4.00 ± 0.41 | 15.75 ± 0.97 | 42.50 ± 2.50 | 85.00 ± 2.89 | 3.25 ± 0.48 | 16.88 ± 1.28 | 40.00 ± 4.08 | 82.50 ± 7.50 |
| | 2nd | 2.25 ± 0.25 | 13.13 ± 1.13 | 35.00 ± 5.00 | 90.00 ± 4.08 | 2.00 ± 0.41 | 13.88 ± 2.07 | 32.50 ± 4.79 | 82.50 ± 2.50 |
| Total | | 40.75 | 160.88 | 440.00 | 822.50 | | 36.75 | | |
| General Average | | 3.40 ± 0.28 | 13.41 ± 0.52 | 36.67 ± 1.47 | 68.54 ± 2.71 | 3.06 ± 0.28 | 13.03 ± 0.46 | 34.38 ± 1.54 | 60.42 ± 2.92 |
| F value | | 23.03 | 3.98 | 3.82 | 11.40 | 20.46 | 4.35 | 4.15 | 17.79 |
| L.S.D. at 0.05 level | | 1.13 | 3.85 | 10.95 | 14.65 | 1.17 | 3.35 | 11.00 | 12.98 |
| L.S.D. at 0.05 level between the two treatments | | 0.83 | | 3.67 | | 0.74 | | 3.75 | |
| C.V.% between the two treatments | | 24.08 | | 17.08 | | 22.62 | | 19.36 | |

L.S.D. = Least significant difference; C.V = Coefficient of variation.

and 14.65 and 12.98 in the untreated plants over the two seasons, respectively, Table 1.

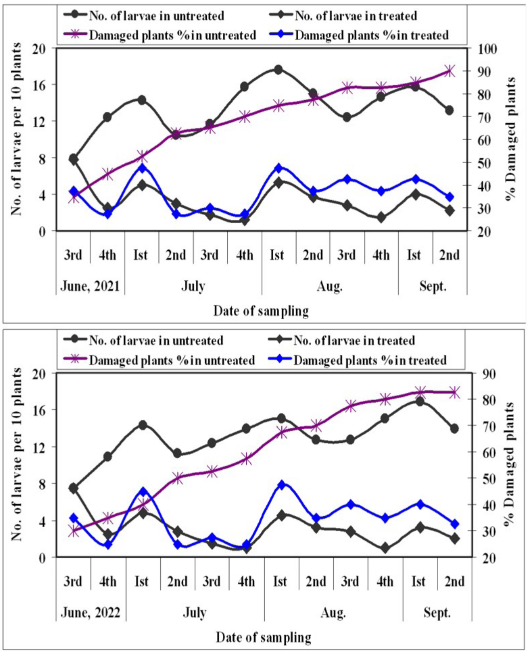


**Figure 3.** Weekly mean numbers of *S. frugiperda* larvae and damaged plants percentage of maize plants at two levels (sprayed and unsprayed) at Esna district, Luxor Governorate during the two growing seasons (2021 and 2022).

## 4. Influence of *S. frugiperda* Infestation on Maize Vegetative Growth, Yield, and Yield components

### *4.1. Maize Vegetative growth measurements*

Plant Growth can be expressed in many terms, i.e., length, leaf width, and area. But it can be used more expressions to explain plant growth like weight, volume, or mass (Moghazy, 2021). So, in this experiment, three growth characteristics were used to measure the growth of maize plants under FAW infestation, i.e., plant height, stem diameter, and the number of green leaves /plant.

### *4.1.2. Plant height (cm)*

Maize plant heights in the treated plots measured 259.45 ± 2.30 and 257.25 ± 1.11 cm as compared to 218.25 ± 3.57 and 219.25 ± 3.90 cm in untreated plots across the two growing seasons, respectively (Tables 2 and 3). Therefore, maize plant height was reduced by 15.88 and 14.77% in untreated plants as compared with the treated ones in 2021 and 2022, respectively. The variance in plant height in treated and untreated maize plants was very significant over the two successive seasons (paired T-test values were 8.10 and 9.65), respectively.

### *4.1.3. Maize stem diameter*

Measured on the above, the diameter of maize plant stems in treated plants was bigger and reached 3.70 ± 0.08 and 3.73 ± 0.09 cm than in untreated ones (3.35 ± 0.06 and 3.40 ± 0.04 cm) during 2021 and 2022, respectively. Consequentially, the maize stems diameters of the untreated maize plants were reduced by 9.46 and

**Table 2.** Measurements of vegetative growth, grain yield, and its components of the maize plants as affected by *S. frugiperda* larvae numbers at two blocks (Sprayed and unsprayed) during the first growing season (2021). (Each value is the mean of the four different replicates ± S.E.).

| Parameters | Sprayed plants (Treated) | Unsprayed plants (Untreated) | Average | % Reduction | Paired t-test |
|---|---|---|---|---|---|
| Plant height | 259.45 ± 2.30 | 218.25 ± 3.57 | 238.85 ± 8.03 | 15.88 | 8.10 ** |
| Stem diameter | 3.70 ± 0.08 | 3.35 ± 0.06 | 3.53 ± 0.08 | 9.46 | 5.42 ** |
| No. of green leaves/ plant | 15.53 ± 0.23 | 13.00 ± 0.11 | 14.26 ± 0.49 | 16.26 | 12.53 ** |
| Ear length | 22.98 ± 0.37 | 19.03 ± 0.54 | 21.00 ± 0.80 | 17.19 | 4.99 ** |
| Ear diameter | 5.95 ± 0.03 | 5.60 ± 0.08 | 5.78 ± 0.08 | 5.88 | 6.26 ** |
| Ear weight (g). | 290.21 ± 2.54 | 239.10 ± 6.92 | 264.66 ± 10.25 | 17.61 | 7.42 ** |
| No. of rows/ear | 14.48 ± 0.17 | 12.00 ± 0.41 | 13.24 ± 0.51 | 17.10 | 4.99 ** |
| No. of grains/row | 41.50 ± 0.96 | 30.50 ± 1.04 | 36.00 ± 2.18 | 26.51 | 11.00 ** |
| No. of grains/ear | 600.80 ± 16.53 | 367.25 ± 24.83 | 483.90 ± 46.25 | 38.87 | 10.14 ** |
| Ear grain weight (g). | 222.30 ± 1.27 | 177.75 ± 4.55 | 200.03 ± 8.70 | 20.04 | 12.66 ** |
| Weight of grains 1000 (g). | 341.75 ± 3.84 | 268.25 ± 7.98 | 305.00 ± 14.48 | 21.51 | 17.28 ** |
| Grain yield (kg/ha) | 6994.19 ± 51.78 | 5101.29 ± 140.32 | 6047.74 ± 364.36 | 27.06 | 20.03 ** |
| Straw yield (kg/ha) | 8273.98 ± 245.43 | 6547.75 ± 153.69 | 7410.86 ± 352.69 | 20.86 | 4.39 ** |
| Biological yield (kg/ha) | 15268.16 ± 240.70 | 11649.04 ± 198.24 | 13458.60 ± 701.87 | 23.59 | 8.21 ** |

**Highly significant at P ≤ 0.01.

**Table 3.** Measurements of vegetative growth, grain yield, and its components of the maize plants as affected by the damaged plants' percentage by *S. frugiperda* at two blocks (Sprayed and unsprayed) during the second growing season (2022). Each value is the mean of the four different replicates ± S.E.).

| Parameters | Sprayed plants (Treated) | Unsprayed plants (Untreated) | Average | % Reduction | Paired t-test |
|---|---|---|---|---|---|
| Plant height | 257.25 ± 1.11 | 219.25 ± 3.90 | 238.50 ± 7.42 | 14.77 | 9.65 ** |
| Stem diameter | 3.73 ± 0.09 | 3.40 ± 0.04 | 3.56 ± 0.08 | 8.72 | 5.17 ** |
| No. of green leaves/ plant | 15.33 ± 0.09 | 12.90 ± 0.21 | 14.11 ± 0.47 | 15.82 | 9.46 ** |
| Ear length | 23.56 ± 0.21 | 20.09 ± 0.75 | 21.83 ± 0.75 | 14.75 | 4.70 ** |
| Ear diameter | 5.92 ± 0.03 | 5.66 ± 0.03 | 5.79 ± 0.05 | 4.40 | 7.07 ** |
| Ear weight (g). | 290.70 ± 4.23 | 239.65 ± 3.94 | 265.18 ± 10.01 | 17.56 | 6.76 ** |
| No. of rows/ear | 14.50 ± 0.17 | 12.25 ± 0.32 | 13.38 ± 0.46 | 15.52 | 4.65 ** |
| No. of grains/row | 40.25 ± 0.63 | 29.75 ± 0.85 | 35.00 ± 2.04 | 26.09 | 8.82 ** |
| No. of grains/ear | 583.80 ± 14.03 | 364.13 ± 11.10 | 473.96 ± 42.33 | 37.63 | 9.96** |
| Ear grain weight (g). | 227.55 ± 3.11 | 182.73 ± 1.68 | 205.14 ± 8.63 | 19.70 | 12.60 ** |
| 1000-grains weight (g) | 339.25 ± 10.44 | 271.25 ± 4.27 | 305.25 ± 13.87 | 20.04 | 6.37 ** |
| Grain yield (kg/ha) | 7244.19 ± 159.24 | 5416.78 ± 313.10 | 6330.48 ± 381.71 | 25.23 | 7.41 ** |
| Straw yield (kg/ha) | 8333.50 ± 222.72 | 6607.28 ± 123.91 | 7470.39 ± 346.91 | 20.71 | 5.00 ** |
| Biological yield (kg/ha) | 15577.69 ± 307.90 | 12024.05 ± 243.01 | 13800.87 ± 695.69 | 22.81 | 14.04 ** |

**Highly significant at P ≤ 0.01.

8.72% as compared to the treated ones over the two seasons, respectively.

The statistical analysis showed highly significant differences in the stem diameter between the untreated and treated maize plants (paired T-test values were 5.42 and 5.17) through the two successive seasons, respectively.

*4.1.4. Number of green leaves per plant*

Results revealed that the untreated maize plants had fewer leaves/ plant with an average of13.00 ± 0.11 and 12.90 ± 0.21 leaves/plant, than the treated ones (15.53 ± 0.23 and 15.33 ± 0.09 leaves/plant) during the two seasons, respectively (Tables 2 and 3). As well, the number of leaves in the untreated plants was reduced by about 16.26 and 15.82% in comparison to the treated ones during the two seasons, respectively. Furthermore, the differences in the leaves number /plant, within the treated and untreated maize plants, were highly significant (paired T-test values of 12.53 in 2021 and 9.46 in 2022.

*4.2. Maize Yield components*

The average ear length (cm), diameter (cm), weight (g), number of rows/ear, number of grains/ ear, average ear grain weight (g), and weight of 1000 grains (g) were assessed. The mentioned-above criteria of maize yield components were used. To differentiate between FAW impacts in untreated and treated maize plants. Tables 2 and 3 represent the effects of FAW on eight maize yield components.

*4.2.1. Maize Ear length (cm)*

The mean length of maize ear were 19.03 ± 0.54 and 20.09 ± 0.75 cm as compared to 22.98 ± 0.37 and 23.56 ± 0.21 cm in the treated ones, through the two growing seasons, respectively. Consequently, maize ears in the untreated maize plants were lost by about 17.19 and 14.75% in its length as compared with those of the treated ones in 2021 and 2022, respectively (Tables 2 and 3). Data analysis showed highly significant differences in the ear length in the untreated and treated maize plants (paired T-test values were 4.99 and 4.70) during the two seasons, respectively.

*4.2.2. Maize Ear diameter (cm)*

Maize ear diameters in the untreated maize plants were smaller ear diameters (5.60 ± 0.08 and 5.66 ± 0.03 cm) than treated maize plants (5.95 ± 0.03 and 5.92 ± 0.03 cm) over the two seasons (Tables 2 and 3), respectively. So, the maize ear diameters in the untreated plants decreased by 5.88 in 2021 and 4.40% in 2022. The statistical analysis appeared highly important variances in the ear diameter among the untreated and treated maize plants (paired T-test values of 6.26 and 7.07) over the two successive seasons, respectively.

*4.2.3. Maize Ear weight (g)*

Results in Tables 2 and 3 showed that the ear weight in the treated maize plants was significantly higher, with an average of (290.21 ± 2.54 and 290.70 ± 4.23) than the untreated ones (239.10 ± 6.92 and 239.65 ± 3.94 g), through the two successive seasons, respectively. For the two seasons, there were highly significant differences in the weight of the ear among the untreated and treated ones (paired T-tests were 7.42 and 6.76), respectively. Also, the ear weight of the untreated maize plants lost about

17.61 and 17.56% of their weight as compared with the treated ones during the two growing seasons, respectively.

*4.2.4. No. of rows/ear*

Results appeared that the treated maize plants produced more rows per ear with an average of (14.48 ± 0.17 and 14.50 ± 0.17 rows/cob) than the untreated ones (12.00 ± 0.41 and 12.25 ± 0.32 rows/cob), during the two growing seasons, respectively (Tables 2 and 3). At the same time, the number of rows per ear in the untreated plants was reduced by 17.10 and 15.52% as compared to those in the treated ones during the two seasons, respectively. Also, the differences in the number of rows/single ears between treated and untreated maize plants were very significant (paired T-test values of 4.99 and 4.65, respectively) during the two seasons.

*4.2.5. No. of grains/row*

As seen in Tables 2 and 3, it was evident that the untreated maize plants produced the least number of grains per row/cob, with an average of (30.50 ± 1.04 and 29.75 ± 0.85 grains/row) as compared with the treated ones (41.50 ± 0.96 and 40.25 ± 0.63 grains/row) during the two growing seasons, respectively (Tables 2 and 3). As well, the number of grains per row in the untreated plants was lost by 26.51 and 26.09% as compared with the treated ones for the two seasons, respectively. Moreover, the variances in the number of grains per row among treated and untreated maize plants were very significant (paired T-test values of 11.00 and 8.82) during the two seasons, respectively.

*4.2.6. No. of grains/ear*

It is the product of the number of rows per ear multiplied by the number of grains per row. Data presented in Tables 2 and 3 showed that the number of grains/ear in the treated maize plants was higher with an average of (600.80 ± 16.53 and 583.80 ± 14.03 grains/ear) than (367.25 ± 24.83 and 364.13 ± 11.10 grains/ear) for the untreated plants over the two growing seasons, respectively (Tables 2 and 3). So, it was reduced by 38.87 and 37.63% as compared with the treated maize plants for the two seasons, respectively. Also, the differences in the number of grains/ear between treated and untreated maize plants were very significant over the two successive seasons (paired T-test values were 10.14 and 9.96, respectively).

*4.2.7. Ear grain weight (g)*

As shown in Tables 2 and 3, appeared that the ear grain weight in the untreated maize plants was significantly smaller, with an average of (177.75 ± 4.55 and 182.73 ± 1.68 g) compared to the treated ones (222.30 ± 1.27 and 227.55 ± 3.11 g) during the two successive seasons, respectively. Over the two seasons, there were very significant variances in the ear grain weight among the untreated and treated ones (paired T-tests were 12.66 and 12.60), respectively. Furthermore, the ear grain weight of the untreated maize plants lost about 20.04 and 19.70% of their weight as compared with the treated ones during the two growing seasons, respectively.

*4.2.8. 1000-grains weight (g)*

The data in Tables 2 and 3 showed that the average weights of 1000-grains in the untreated maize plants were lower at (268.25 ± 7.98 and 271.25 ± 4.27 g) as compared to (341.75 ± 3.84 and 339.25 ± 10.44 g) in the treated ones, over the two growing seasons, respectively. Analysis of the data revealed highly significant differences among the weights of 1000 grains from the treated and untreated maize plants (paired T-test values were 17.28 and 6.37), respectively. Also, the average weight of 1000grains from untreated maize plants was lost by (21.51 and 20.04%) in comparison to the treated ones during the two seasons, respectively.

*4.3. Yield characteristics*

The estimated three yield properties dealing with the average grain yield (kg/ha), straw yield (kg/ha), and biological yield (kg/ha) in the untreated and treated maize plants and their ability to suppress *S. frugiperda* infestation, during two experimental seasons are clearly shown in Tables 2 and 3.

*4.3.1. Grain Yield (kg/ha)*

Data obtained in Tables 2 and 3, proved that the treated maize plants had a higher grain yield with an average weight of (6994.19 ± 51.78 and 7244.19 ± 159.24 kg/ha) than the untreated ones (5101.29 ± 140.32 and 5416.78 ± 313.10 kg/ha) for the two seasons, respectively. There were very significant differences in the weight of grain yield per feddan between the untreated and treated ones (paired T-test of 20.03 and 7.41) for the two seasons, respectively. As well, the grain yield from the untreated plants lost about 27.06 and 25.23% of their weight as compared with the treated ones through the two growing seasons, respectively.

*4.3.2. Straw yield (kg/ha)*

The straw yield was acquired by subtracting the biological yield (kg/ha) from the grain weight (kg/ha) for each plot. As seen in Tables 2 and 3, it was evident that the untreated maize plants had a lower straw yield (average weight was 6547.75 ± 153.69 and 6607.28 ± 123.91 kg/ha) than the treated ones (8273.98 ± 245.43 and 8333.50 ± 222.72 kg/ha). The variance in straw yield among untreated and treated maize plants was very significant (paired T-test values were 4.39 and 5.00) for the two seasons, respectively. Also, the straw yield was reduced by (20.86 and 20.71%) from the untreated plants as compared with the treated plants during the two seasons, respectively.

*4.3.3. Maize biological yield (kg/ha)*

Biological yield (kg/ha): was estimated by weighting all the plants in the centric area in each plot before shelling. Data depicted in Tables 2 and 3 showed that the treated maize plants had a higher weight for biological yield with an average of (15268.16 ± 240.70 and 15577.69 ± 307.90 kg/ha) as compared to (11649.04 ± 198.24 and

12024.05 ± 243.01 kg/ha) for the untreated plants through the two growing seasons, respectively. The variances between untreated and treated maize plants were very significant (paired T-tests were 8.21 and 14.04) during the two seasons, respectively. Furthermore, the average weight of biological yield in the untreated maize plants was lost by 23.59 and 22.81% compared with the treated plants in the two growing seasons, respectively.

## 5. The Relationship Between the Changes in the Numbers of *S. frugiperda larvae*, Plant Damage Percentage, and Maize Yield Components

Data represented in Tables 4 and 5 showed the relationship between the measured parameters for maize plants as the dependent variable and the two insect expressions, namely, the number of larvae and the percentage of damaged plants caused by *S. frugiperda* as the independent variables, were obtained during two growing seasons (2021 and 2022).

### *5.1. S. frugiperda larvae numbers*

Results revealed a highly significant negative correlation between the mean numbers of *S. frugiperda* larvae and the vegetative growth characteristics, i.e., plant height, stem diameter, and number of green leaves/ plant (r values; -0.97, -0.84 and -0.98) for the first season and (-0.96, -0.85 and -0.97) during the second season, respectively. In conjunction with the calculated regression coefficient, it was indicated that an increase of one larva per 10 maize plants would decrease the vegetative growth properties, *i.e.*, plant height (4.08 and 3.75 cm), stem diameter (0.04 and 0.03 cm), and the number of green leaves per plant (0.25 and 0.24 leaves) for two seasons, respectively (Table 4).

Also, the calculated r values between the mean population of *S. frugiperda* larvae and the yield components, *i.e.*, ear length, diameter, and weight; number of rows/ear, number of grains/row, number of grains/ear, ear grain weight, and 1000-grains weight were highly significant negative; being (-0.94, -0.78, -0.97, -0.92, -0.94, -0.94, -0.96 and -0.98) and (-0.88, -0.94, -0.97, -0.88, -0.98, -0.97, -0.97 and -0.94), during the two seasons, respectively. The calculated regression coefficient mentioned that an increase of one larva per 10 plants, would decrease the ear length (0.40 and 0.35 cm), diameter (0.03 and 0.03 cm), and weight (5.22 and 5.11 g), number of rows/ear (0.24 and 0.21 rows), number of grains/row (1.07 and 1.05 grains), number of grains/ear (22.81 and 21.58 grains) weight of ear grain (4.37 and 4.40 g) and the weight of 1000-grains (7.45 and 6.83 g), for two seasons, respectively (Table 4).

Furthermore, the statistical analysis of simple correlation (Table 4) showed highly significant negative correlations between the numbers of larvae and the maize yield characteristics, namely, grain yield, straw yield, and biological yield (r values;-0.96, -0.94 and -0.97) and (-0.91, -0.91 and -0.96) during both seasons of study, respectively. As well, the simple regression pointed out that an increase of one larva per 10 plants, would decrease the grain yield (182.43 and 183.01 kg/ha), straw yield (172.80 and 166.54 kg/ha), and biological yield (355.24 and 349.56 kg/ha) for two seasons, respectively. The number of larvae of *S. frugiperda* per 10 plants was negatively correlated with all tested measurements of vegetative growth, grain yield, and its components.

### *5.2. Maize plant damage percentage*

Results showed a highly significant negative correlation between the damaged plants' percentage by *S. frugiperda* and the vegetative growth attributes, namely, plant height, stem diameter, and number of green leaves/ plant (r values; -0.96, -0.84, and -0.99) throughout the first season and (-0.97, -0.81, and -0.98) for the second season, respectively. Also, the calculated regression coefficient indicated that an increase of 1% in damaged plants percentage, would decrease the vegetative growth properties, i.e., plant height (1.25 and 1.39 cm), stem diameter (0.01 and 0.01 cm), and the number of green leaves per plant (0.08 and 0.09 leaves) for two seasons, respectively (Table 5).

Furthermore, the estimated correlation values between the pest-damaged plants' percentage and the maize yield components, namely, ear length, diameter, and weight; the number of rows/ear, number of grains/row, number of grains/ear, ear grain weight and 1000-grains weight were very significant negative; being (-0.91, -0.81, -0.96, -0.92, -0.92, -0.93, -0.96 and -0.97) and (-0.92, -0.83, -0.89, -0.89, -0.89, -0.91, -0.92 and -0.91), over the two seasons, respectively. The simple regression coefficient pointed out that an increase of 1% in damaged plants percentage, would decrease the ear length (0.12 and 0.13 cm), diameter (0.01 and 0.01 cm), and weight (1.61 and 1.72 g), number of rows/ear (0.08 and 0.08 rows), number of grains/row (0.33 and 0.35grains), number of grains/ear (7.03 and 7.52 grains), the weight of ear grain (1.36 and 1.54 g) and weight of 1000-grains (2.29 and 2.44 g), during the two seasons, respectively (Table 5).

As well, the simple correlation analysis as seen in (Table 5), showed highly significant negative correlations between the damaged plants' percentage and the maize yield characteristics, *i.e.*, grain yield, straw yield, and biological yield (r values; -0.96, -0.94, and -0.97) and (-0.80, -0.98 and -0.93) during both seasons of study, respectively. Likewise, the simple regression suggested that an increase of 1% in damaged plants percentage, would decrease the grain yield (57.03 and 59.18 kg/ha), straw yield (54.14 and 66.02 kg/ha), and biological yield (111.17 and 125.50 kg/ha) for two seasons, respectively. The results showed that the damaged plants' percentage was negatively correlated with all the tested parameters of vegetative growth, grain yield, and its components.

## 6. Discussion

The infestation of the fall armyworm [FAW; *Spodoptera frugiperda* (Lepidoptera: Noctuidae)] in maize is becoming a dangerous problem at present, and it may pose a threat to the future maize crop worldwide. There is little information in the literature about the assessment of the fall armyworm, *S. frugiperda*, damage on maize plant characteristics (growth characteristics and yield loss) in Egypt, therefore, this work is considered to be the first

**Table 4.** Simple correlation, regression coefficients, and explained variance estimates between the mean numbers of *S. frugiperda* larvae and the measurements of the vegetative growth, grain yield, and its components of the maize plants over the two growing seasons (2021 and 2022).

| Season / Parameters | | The first season (2021) | | | | | | The second season (2022) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | r | b | S.E | t-test value | Y = a ± bx | E.V.% | r | b | S.E | T-test value | Y = a ± bx | E.V.% |
| Vegetative growth | Plant height | -0.97 | -4.08 | 0.41 | 10.07 ** | 273.10 – 4.08 x | 94.41 | -0.96 | -3.75 | 0.44 | 8.61** | 268.43 – 3.75 x | 92.50 |
| | Stem diameter | -0.84 | -0.04 | 0.01 | 3.86 ** | 3.83 – 0.04 x | 71.30 | -0.85 | -0.03 | 0.01 | 3.91 ** | 3.83 – 0.03 x | 71.81 |
| | No. of green leaves/ plant | -0.98 | -0.25 | 0.02 | 12.06 ** | 16.38 – 0.25 x | 96.04 | -0.97 | -0.24 | 0.02 | 9.97 ** | 16.04 – 0.24 x | 94.31 |
| Yield components | Ear length | -0.94 | -0.40 | 0.06 | 6.73 ** | 24.32 – 0.40 x | 88.31 | -0.88 | -0.35 | 0.08 | 4.50 ** | 24.61 – 0.35 x | 77.15 |
| | Ear diameter | -0.78 | -0.03 | 0.01 | 3.08 ** | 6.04 – 0.03 x | 61.23 | -0.94 | -0.03 | 0.00 | 6.50 ** | 5.99 – 0.03 x | 87.57 |
| | Ear weight (g). | -0.97 | -5.22 | 0.49 | 10.74 ** | 308.50 – 5.22 x | 95.05 | -0.97 | -5.11 | 0.51 | 9.99 ** | 306.28 – 5.11 x | 94.31 |
| | No. of rows/ ear | -0.92 | -0.24 | 0.04 | 5.66 ** | 15.29 – 0.24 x | 84.23 | -0.88 | -0.21 | 0.05 | 4.62 ** | 15.08 – 0.21 x | 78.04 |
| | No. of grains/ row | -0.94 | -1.07 | 0.16 | 6.58 ** | 44.97 – 1.07 x | 87.84 | -0.98 | -1.05 | 0.09 | 12.34 ** | 43.48 – 1.05 x | 96.20 |
| | No. of grains/ ear | -0.94 | -22.81 | 3.26 | 6.99 ** | 675.64 – 22.81 x | 89.09 | -0.97 | -21.58 | 2.20 | 9.81 ** | 647.59–21.58 x | 94.12 |
| | Ear grain weight (g). | -0.96 | -4.37 | 0.52 | 8.45 ** | 236.70 – 4.37 x | 92.25 | -0.97 | -4.40 | 0.44 | 10.09 ** | 240.58 – 4.40 x | 94.42 |
| | 1000-grains weight (g) | -0.98 | -7.45 | 0.54 | 13.82 ** | 367.60 – 7.45 x | 96.95 | -0.94 | -6.83 | 1.04 | 6.60 ** | 360.23 – 6.83 x | 87.90 |
| Yield characteristics | Grain yield (kg/ha) | -0.96 | -182.43 | 0.01 | 8.20 ** | 7580.37 – 182.43 x | 91.82 | -0.91 | -183.01 | 0.01 | 5.47 ** | 7803.04 – 183.01 x | 83.27 |
| | Straw yield (kg/ha) | -0.94 | -172.80 | 0.01 | 6.61 ** | 8862.60 – 172.80 x | 87.92 | -0.91 | -166.54 | 0.01 | 5.50 ** | 8810.44 – 166.54 x | 83.49 |
| | Biological yield (kg/ha) | -0.97 | -355.24 | 0.02 | 9.54 ** | 16442.97 – 355.24x | 93.82 | -0.96 | -349.56 | 0.02 | 8.01 ** | 16613.48 – 349.56 x | 91.45 |

r = Simple correlation; b = Simple regression; S.E = Standard error; E.V% = Explained variance; **Highly significant at $P \leq 0.01$.

**Table 5.** Simple correlation, regression coefficients, and explained variance estimates between the damaged plants' percentage by *S. frugiperda* and the measurements of the vegetative growth, grain yield, and its components of the maize plants over the two growing seasons (2021 and 2022).

| Season / Parameters | | The first season (2021) | | | | | | The second season (2022) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | r | b | S.E | T-test value | Y = a ± bx | E.V.% | r | b | S.E | T-test value | Y = a ± bx | E.V.% |
| Vegetative growth | Plant height | -0.96 | -1.25 | 0.16 | 8.07 ** | 304.85-1.25 x | 91.56 | -0.97 | -1.39 | 0.15 | 9.35 ** | 304.36 – 1.39 x | 93.58 |
| | Stem diameter | -0.84 | -0.01 | 0.00 | 3.81 ** | 4.12 – 0.01 x | 70.73 | -0.81 | -0.01 | 0.00 | 3.40 ** | 4.13 – 0.01 x | 65.89 |
| | No. of green leaves/ plant | -0.99 | -0.08 | 0.00 | 17.94 ** | 18.44 – 0.08 x | 98.17 | -0.98 | -0.09 | 0.01 | 10.97 ** | 18.34 – 0.09 x | 95.25 |
| Yield components | Ear length | -0.91 | -0.12 | 0.02 | 5.34 ** | 27.28 – 0.12 x | 82.60 | -0.92 | -0.13 | 0.02 | 5.84 ** | 28.19 – 0.13 x | 85.06 |
| | Ear diameter | -0.81 | -0.01 | 0.00 | 3.37 ** | 6.32 – 0.01 x | 65.41 | -0.83 | -0.01 | 0.00 | 3.59 ** | 6.19 – 0.01 x | 68.27 |
| | Ear weight (g). | -0.96 | -1.61 | 0.19 | 8.45 ** | 349.17 –1.61 x | 92.25 | -0.89 | -1.72 | 0.37 | 4.69 ** | 346.86 – 1.72 x | 78.55 |
| | No. of rows/ ear | -0.92 | -0.08 | 0.01 | 5.73 ** | 17.27 – 0.08 x | 84.56 | -0.89 | -0.08 | 0.02 | 4.72 ** | 17.12 – 0.08 x | 78.79 |
| | No. of grains/ row | -0.92 | -0.33 | 0.06 | 5.61 ** | 53.15 – 0.33 x | 83.98 | -0.89 | -0.35 | 0.08 | 4.73 ** | 51.71 – 0.35 x | 78.85 |
| | No. of grains/ ear | -0.93 | -7.03 | 1.12 | 6.28 ** | 854.09 –7.03 x | 86.80 | -0.91 | -7.52 | 1.36 | 5.55 ** | 830.50 – 7.52 x | 83.70 |
| | Ear grain weight (g). | -0.96 | -1.36 | 0.16 | 8.39 ** | 271.74 –1.36 x | 92.14 | -0.92 | -1.54 | 0.27 | 5.63 ** | 277.96 – 1.54 x | 84.06 |
| | 1000-grains weight (g) | -0.97 | -2.29 | 0.24 | 9.75 ** | 425.64–2.29 x | 94.06 | -0.91 | -2.44 | 0.46 | 5.28 ** | 421.08 – 2.44 x | 82.28 |
| Yield characteristics | Grain yield (kg/ha) | -0.96 | -57.03 | 0.00 | 8.26 ** | 9047.91 – 57.03 x | 91.91 | -0.80 | -59.18 | 0.01 | 3.25 ** | 9135.41 – 59.18x | 63.71 |
| | Straw yield (kg/ha) | -0.94 | -54.14 | 0.00 | 6.76 ** | 10258.62 – 54.14 x | 88.37 | -0.98 | -66.02 | 0.00 | 12.00 ** | 10599.47 – 66.02x | 96.00 |
| | Biological yield (kg/ha) | -0.97 | -111.17 | 0.01 | 9.79 ** | 19306.53 – 111.17 x | 94.10 | -0.93 | -125.20 | 0.01 | 6.03 ** | 19734.88 – 125.20x | 85.85 |

r = Simple correlation; b = Simple regression; S.E = Standard error; E.V% = Explained variance; **Highly significant at P ≤ 0.01.

one to show the negative influences of *S. frugiperda* on growth characteristics, grain yield, and its components of maize plants in Luxor governorate, Upper Egypt. Consequently, our study provides the first estimates to could help farmers and decision-makers to manage FAW populations based on effective planning-related control measures that should be implemented to control this pest and reduce damage to the crop.

As we view from the present paper, the infestation by this pest maize plant was started in the third week of June until the last crop harvest of every season. As well, FAW larval stage recorded three peaks of seasonal activities /season. Supartha et al. (2021) noted that FAW adult populations and egg masses were found to be active two weeks after planting maize.

The damaged plants' percentages by *S. frugiperda* increased with increasing the periods of inspection during the maize's different growing stages in the untreated plots over the two seasons. In addition, some plants were noticed to be infested well in advance of the time of examination (not recent infestations) (Caniço et al. 2020). However, the percentage of affected plants in the treated plots fluctuated between increase and decrease during the different examination periods throughout the crop growth in the two years of the study.

The present results are going with Gross Junior et al. (1982) results, who mentioned that the sensitivity of maize growth stages to FAW attack was varied. Willink et al. (1993) stated that the maize vegetative stage suffered severe damage by FAW since the early stages of growth were more attractive and favorable to FAW larvae feeding. So, *S. frugiperda* could be caused more damage in these stages of maize life. Also, the dispersal of *S. frugiperda* larvae among maize plants can be changed depending on the phenological stage of maize (Beserra et al. 2002). Murúa et al. (2009) reported that the average number of *S. frugiperda* larvae depended on the age and growth of the plant. While Jaramillo-Barrios et al. (2019) mentioned that the FAW larval population was higher in the maize vegetative stage. Consequently, sowing maize crops at different times in the same season may create differential and overlapping vegetative stages, which provide a suitable environment for FAW to reproduce and spread, thus increasing its importance and damage (Supartha et al. 2021).

The methods used to assess the nutritional damage caused by FAW larvae varied, which made it difficult to compare studies that dealt with this criterion (Toepfer et al., 2021). Sparks (1979) reported that the first to third instar larvae of FAW were quite small and consumed only 2% of the overall foliage than they consumed during their life span. Whereas the 4$^{th}$, 5$^{th}$, and 6$^{th}$ instars ate 4.7, 16.3, and 77.2% of the overall foliage than they consumed in all life cycles, respectively. Lima et al. (2010) pointed out that FAW binge-feeding caused shorter plant growth in maize plants. Van den Berg et al. (2021), protecting maize plants from FAW damage during the early vegetative growth periods supplied the greatest yield gain.

Based on our data, it could be concluded that the vegetative growth measurements of the treated maize plants showed a significant increase in (plant height, diameter, and the number of green leaves/plant) during both (2021 and 2022) growing seasons. In addition, three yield parameters, namely, grain, straw, and biological yield, were decreased by *S. frugiperda* infestation in untreated plots as compared to those of the treated plants (sprayed). As for the influence on yield component attributes, the untreated maize plants by *S. frugiperda* exhibited a clear decrease in (average ear length, diameter, weight, number of rows/ear, number of grains/row, number of grains/ear, ear grain weight, and weight of 1000-grains. On the other hand, the untreated maize plants exhibited the greatest reductions in all studied growth attributes, grain yield, and its components. The impact of FAW damage on maize yield has been evaluated by several authors. Maize yield losses depended on the plant tissue type with infestations during the vegetative growth periods leading to wide foliar damage. Buntin (1986) reported that highly early infestations, mainly over the seedling periods, can lead to overall defoliation and crop damage. Lima et al. (2010) reported that the impact of controlling fall armyworm on maize plants increased grain yield, ear length, 100-grain weight, number of grain rows in an ear, number of grains per ear, and ear diameter as compared to untreated plants. Chimweta et al. (2020) mentioned that the FAW damage and yield reduction of a crop can be influenced by plant stage, level of weakness, and pest population density. The more pests there are, the more damage they cause. As well, the destructive ability of a pest also influences the severity of crop damage (Pathania et al., 2020). When compared to other corn leaf-eating pests, the capacity to harm the larvae of *S. frugiperda* is ten times stronger (CABI International, 2019). FAW causes more severe plant damage during the vegetative period (Suby et al., 2020). As seen by Supartha et al. (2021), an overall count of 0.2-0.8 larvae per plant reduces yield by 5–20%. Van den Berg et al. (2021) mentioned that the lowest yields were obtained from plots that received no insecticide application compared to the treated plots with insecticide applications (which had the highest yields). Maize yield losses reached 22, 67, 32%, and 47% in Ghana, Zambia, Ethiopia, and Kenya, respectively (Day et al., 2017; Kumela et al., 2018; FAO, 2018; Balla et al., 2019**).** Hence, in Africa alone, this invasive pest is considered responsible for causing financial losses of up to US$4.66 billion (Rwomushana et al., 2018). Maize infestation ranged from 26.4 to 55.9%, with a yield impact of 11.57% (Baudron et al., 2019). Damage levels on leaves, silk, and tassels ranged from 25 to 50%, with a grain yield decrease of 58% (Chimweta et al., 2020). Naganna et al. (2020) mentioned that there are numerous variables to consider when calculating the potential yield loss caused by fall armyworm infestation.

Some studies also indicated that this pest caused a decrease in the yield of peanuts, barley, and wheat by 78, 80%, and 90%, respectively (He et al., 2020; Yang et al., 2020). In addition, they harm tobacco crops as their numbers reach their peak (Xu et al., 2019).

Regarding the relationship between variations in a given preferred variable and the changes in the numbers of *S. frugiperda* larvae as well as damaged plants percentage, the simple correlation and regression coefficient estimates revealed a highly significant negative relationship presence. An increase of one insect per ten maize plants, or a 1%

increase in the percentage of damaged plants, would reduce all tested measurements of vegetative growth, resulting yield, and its components. Large differences occur in the infestation caused by a given level of FAW infestation as well as plant reaction to infestation. In this context, Lima et al. (2010) mentioned that plant biomass reduction for any insect activities resulted from reduced leaf area, stem diameter, and root growth. Thus, the plant height and stem diameter were decreased, as in our results. In Zimbabwe, Baudron et al. (2019) proposed that yield loss cannot be expected solely based on only infestation and leaf damage assessments. As well, the destroying cobs may result in fungal infection and loss of grain quality. Generally, maize crop reaction to fall armyworm infestation is extremely dependent on infestation level and timing. Overton et al. (2021) discovered great variations in the yield reductions caused by FAW damage and warned that crop losses revealed through farmer evaluations may be overestimated.

More research on the relationship between FAW damage and any cereal crop yield reduction within various agro-ecological regions is required to guide the control measures that should be implemented in the IPM approach of *S. frugiperda*.

## 6. Conclusion

Currently, The fall armyworm (FAW), *S. frugiperda* is one of the most destructive maize pests and poses a threat to the future maize crop in the world. We can point out here that the armyworm has devastating effects on the maize crop (cultivar "Single-Hybrid 168 Yellow") in Egypt if it is not controlled before the start of crop cultivation. From the current study, we found that the maize plant cultivar "Single-Hybrid 168 Yellow" in the treated plots with pesticides gave the highest vegetative growth characteristics and highest maize yield than those plots that were left without pesticide treatment (pesticide free- infested by FAW larvae). In the experimental plots, in which maize was not treated by pesticides, maize vegetative characteristics, total grain yield, and other maize yield components were greatly affected. Our results can improve our understanding of FAW infestation and control tactics and will provide knowledge for developing a management strategy to control this pest. Effective management strategies to control *S. frugiperda* populations, as well as improved biosecurity measures related to early detection and quarantine of commodity movements, may be required in unaffected countries to mitigate the expected march and rapid spread of *S. frugiperda* to and from other agricultural countries of the world.

## Acknowledgements

Researchers would like to thank the Deanship of Scientific Research, Qassim University for funding the publication costs of this project

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