Brazilian Journal of Biology®

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

Original Article

Population density of the fall armyworm, *Spodoptera frugiperda* (Smith) (Lepidoptera: Noctuidae) and its response to some ecological phenomena in maize crop

Densidade populacional da lagarta-do-cartucho do outono, *Spodoptera frugiperda* (Smith e Lepidoptera: Noctuidae), e a sua resposta a alguns fenômenos ecológicos na cultura do milho

M. M. S. Bakry[a] and N. F. Abdel-Baky[b,c]*

[a]Agricultural Research Center, Plant Protection Research Institute, Department of Scale Insects and Mealybugs Research, Giza, Egypt
[b]Qassim University, College of Agriculture and Veterinary Medicine, Department of Plant Production and Protection, Buraydah 51452, Saudi Arabia
[c]Mansoura University, Faculty of Agriculture, Economic Entomology Department, Mansoura 35516, Egypt

Abstract

The fall armyworm [FAW; *Spodoptera frugiperda* (Smith) (Lepidoptera: Noctuidae)], is considered a serious invasive pest that poses a serious threat to world food security. It can completely devastate a whole country's cereal crops. Therefore, the present work is the 1st field trial in Egypt to elucidate some ecological aspects of *S. frugiperda* on maize plants (Single-Hybrid 168 Yellow Corn cultivar) at Esna district, Luxor Governorate, Egypt, throughout two sequential growing seasons of maize (2021-2022). Three insect parameters were used, i.e., egg masses, number of larvae, and percentage of damaged corn plants. Effects of certain climatic conditions and corn plant ages on *S. frugiperda* seasonal activity and damaged plants percentage were also estimated. *S. frugiperda* population initiated to attack maize plants from the 3rd week of June until the harvest in every season. *S. frugiperda* had two seasonal activity peaks in terms of egg masses numbers and three peaks regarding the larval population density/season. Its damage percentage increased with increasing plant age weekly. The mean of *S. frugiperda* egg masses were 2.83 ± 0.40 and 2.96 ± 0.45 mass /10 corn plants in 2021 and 2022, respectively. While, the overall mean larval populations were 13.41 ± 0.52 and 13.03 ± 0.46 larvae/10 plants, during the two growing seasons, respectively. Corn plant damage percentages reached 68.54 ± 2.71 and 60.42 ± 2.92% in 2021 and 2022, respectively. The combined effects of both the weather conditions and maize plant ages were highly significant on egg masses, larvae population density, and damage percentage, and varied from one season to another. The mean daily maximum temperature was the most effective variable on egg masses and the larval population. Maize plant age had a clear effect on the damage percentage caused by the larvae in the field during the two years of the study. The dramatic spread of FAW and the consequent damage (that appeared in different countries of America, Africa, and Asia) mean that different management approaches must be sought for the small and large-scale producers by using available technologies for smallholder farmers will eliminate pest damage without access to reach to an economic Injury level. This information may assist the decision maker when planning the *S. frugiperda* IPM program for maize plants and its surveillance.

Keywords: fall armyworm, FAW, *Spodoptera frugiperda*, seasonal abundance, maize crop (corn), *Zea* maize crop age, environmental conditions, incidence, climatic factors changes.

Resumo

A lagarta-do-cartucho [FAW; *Spodoptera frugiperda* (Smith) (Lepidoptera: Noctuidae)], é considerada uma séria praga invasora que representa uma séria ameaça à segurança alimentar mundial. Essa espécie pode devastar completamente as plantações de cereais de um país inteiro. Portanto, o presente trabalho é o primeiro ensaio de campo no Egito para elucidar alguns aspectos ecológicos de *S. frugiperda* em plantas de milho (Single-Hybrid 168 Yellow Corn cultivar) no distrito de Esna, Luxor Governorate, Egito, ao longo de duas estações de crescimento sequencial de milho (2021 a 2022). Três parâmetros de insetos foram utilizados, isto é, massas de ovos, número de larvas e porcentagem de plantas de milho danificadas. Também foram estimados os efeitos de certas condições climáticas e idades das plantas de milho na atividade sazonal de *S. frugiperda* e na porcentagem de plantas danificadas. A população de *S. frugiperda* começou a atacar as plantas de milho a partir da terceira semana de junho até a colheita em todas as estações. *S. frugiperda* apresentou dois picos sazonais de atividade como o número de massas de ovos e três picos em relação à densidade populacional larval/estação. Seu percentual de dano

*e-mail: nfaly@qu.edu.sa, nafabdel2005@yahoo.com
Received: January 11, 2023 – Accepted: February 18, 2023

aumentou semanalmente a partir do aumento da idade da planta. A média das massas de ovos de *S. frugiperda* foi de 2,83 ± 0,40 e 2,96 ± 0,45 massa/10 plantas de milho em 2021 e 2022, respectivamente. Enquanto, as populações larvais médias gerais foram de 13,41 ± 0,52 e 13,03 ± 0,46 larvas/10 plantas, durante as duas estações de crescimento, respectivamente. As porcentagens de danos às plantas de milho atingiram 68,54 ± 2,71 e 60,42 ± 2,92% em 2021 e 2022, respectivamente. Os efeitos combinados das condições climáticas e da idade das plantas de milho foram altamente significativos nas massas de ovos, densidade populacional de larvas e porcentagem de danos, e variaram de uma estação para outra. A temperatura média diária máxima foi a variável mais efetiva sobre as massas de ovos e a população larval. A idade da planta de milho influenciou visivelmente o percentual de dano causado pelas larvas no campo durante os dois anos de estudo. A propagação dramática da LFM e os danos consequentes (que apareceram em diferentes países da América, África e Ásia) significam que devem ser utilizadas diferentes abordagens de gestão para os pequenos e grandes produtores, a partir de tecnologias disponíveis para os pequenos agricultores eliminarem os danos causados pelas pragas sem acesso para chegar a um nível de dano econômico. Essas informações podem auxiliar o tomador de decisão no planejamento do programa MIP de *S. frugiperda* para plantas de milho e o seu monitoramento.

Palavras-chave: lagarta do cartucho, LFM, *Spodoptera frugiperda*, abundância sazonal, colheita (milho), tempo de colheita do milho *Zea*, condições ambientais, incidência, mudanças de fatores climáticos.

1. Introduction

Corn or Maize (*Zea mays* L.) is one of the most important cereal crops in Egypt and other parts of the world and ranks 3rd after rice and wheat. Maize is an annual plant, which forms the backbone of the world's food security since it is consumed by humans and cattle, as well as a source of industrial raw materials for the manufacturing of bioproducts like oil, alcohol, and starch. In 2020, the total cultivated area of maize in Egypt reached 871076.12 hectares (1 hectare = 10.000 m^2) with average productivity of 8154,48 tons/ha (El-Rasoul et al., 2020).

Many serious species of insect pests are attacking maize plants at different growth stages. The fall armyworm (FAW), *Spodoptera frugiperda* (Smith) is considered one of the most invasive, serious, and destructive insect species that invaded corn crops in Egypt and other world countries recently. *S. frugiperda* larvae feed voraciously on stems and leaves of over eighty plant species (i.e., maize, sorghum, sugarcane, as well as, other vegetables and crops) which induce great damage (Dahi et al., 2020). The first people to discover *S. frugiperda* in Africa were Goergen et al. (2016). The economic importance and damage have been determined as being the most destructive pest (Anjorin et al., 2022).

Females of FAW oviposit their eggs in groups (egg masses) on the adaxis and the abaxis surfaces of the leaves. Each egg mass had 150-200 eggs/group in either single or multiple masses (Tendeng et al., 2019). FAW larvae cause substantial leaf feeding as well as direct ear damage (Bessin, 2019). New hatching larvae feed on cereal crop leaves by scrapping chlorophyll, which leads to a silvery transparent membrane in the initial stage, ultimately resulting in white elongated patches. Leaf-feeding causes extensive "window pane" damage to the plant. The larvae in the early stage consume the leaf epidermis from both sides (Smith et al., 1997), causing holes as a result of their feeding (Sisay et al., 2019). While the older larvae make deeper holes in the leaves because of their greedy feeding, resulting in huge masses of sawdust-like droppings with the destruction of a leaf to be like a window hollow. Generally, feed of FAW larvae on a young maize plant led to a dead heart (dead and rending hearts), while the larger larvae could inflict more damage and leaf defoliation, leaving only the corn plant's ribs and stalk with a ragged aspect (Capinera, 2020). The larvae of this insect hide deeply throughout the day (sunlight periods) inside the maize plant stem, feeding on the heart, and destroying silks and tassels, which hinders the plant reproduction process. Damage to cobs leads to a fungal infection, aflatoxins, and loss of grain quality (Bangale, 2019).

Fall Armyworm is a migratory insect pest, with females migrating before laying eggs (Rwomushana, 2020), which causes yield loss in maize up to 57.6% to 58% (Cruz et al., 1999). FAW has no diapause but it can overwinter in warmer climates (Rwomushana, 2020). To develop an efficient IPM program for *S. frugiperda*, it is necessary to understand insect bio-ecology, including population dynamics in various climatic conditions, which may affect the insect life cycles and its damage. From an ecological point, determining the factors that affect insect biodiversity is a fundamental topic and necessary, as well as, from a practical view, forming a base to estimate the economic injury levels (Baskauf, 2003).

Since all insects are poikilothermic, environmental temperatures and other factors have a clear impact on insect development and infestation rates (Lamb, 1992). Therefore, an occurrence of any climate fluctuations may have a substantial impact on FAW population dynamics and status (Woiwod, 1997). There is always an interactive relationship that may be positive or negative between any insect and its plant hosts. Since maize plant age have a substantial influence on FAW development and damage, so maize plant age can determine the infestation levels and explain why the damage rates changed with the change in maize plant development (Williams and Dixon, 2007).

In May 2019, the Egyptian Ministry of Agriculture represented by the National Pesticides Committee recorded the 1st FAW presence and occurrence within corn fields in Kom Ombo district, Aswan Governorate, South Egypt (Dahi et al., 2020). Since this study is considered the first field trial in Egypt to clarify some FAW ecological aspects, therefore, the purposes of this study are to estimate *S. frugiperda* seasonal populations and fluctuations and determine the role of certain weather factors. As well as, maize plant ages and their influence on egg mass, larvae, and damage percentage over two successive growing seasons 2021 and 2022.

2. Materials and Methods

In this study, three indicators were used to express their effects on the *S. frugiperda* population, i.e., egg mass numbers, larval stage population, and corn plant damage percentage.

2.1. Population studies of S. frugiperda

2.1.1. S. frugiperda seasonal activity and plant damage

The field experiments were carried out in one of the maize fields in Esna district, Luxor Governorate, Egypt, through two successive growing seasons of corn in 2021 and 2022. About half a hectare (One hectare= 10000 m^2) was cultivated with maize plants (Single-Hybrid 168 Yellow Corn cultivar). The selected corn area (2100 m^2) was divided into four replicates. Corn seeds were sown in the first week of June in both 2021 and 2022. All regular conventional agricultural practices, which are normally carried out in any corn fields, were applied except the chemical control by pesticides.

The fall armyworm damage was observed and recorded 15 days after corn sowing (15 days of corn seedling age). 40 maize plants (10 plants/replicate) were selected randomly, inspected weekly, and the inspection procedures were continued until the harvest. Due to the larval feeding behavior, the inspection was done in the morning from 6 to 9 a.m. since the larvae tend to be concealed in the midrib of maize leaves after 9 a.m. as a result of the air temperature beginning to rise gradually.

FAW samples were taken, by applying a "**W**" pattern to represent all the experiment area directions, to estimate egg masses numbers, the population density of larvae, and the number of damaged plants.

The examination techniques involved the adaxis and the abaxis surfaces of the leaves, as well as, corn stems (Abd-Allah et al., 2018; Caniço et al., 2020). Following the Fernández (2002) methodology, to estimate FAW population size, the numbers of egg masses and larvae /10 plants were counted and recorded/inspection date ± standard error (SE). The following Formula 1 of Caniço et al. (2020) was applied to calculate, the egg mass numbers, larval population density, and the percentage of damaged plants:

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

Where:
PD = damaged plant percentages.
a = plant numbers that have FAW visual infestation signs.
b = the total number of examined maize plants (infested and non-infested) / sampling time.
Note: plants were regarded as damaged whenever visual symptoms of larvae feeding were observed, regardless of the presence or non-presence of the larvae.

2.1.2. Calculate the accumulated larval population

To predict the overall trend in larval population growth and to compare corn growth seasons, the seasonal activity of the larvae, and the overall accumulated larval stage populations were estimated. As well as, the percentage of the accumulated larval population was calculated by dividing the total accumulated larval population by the sum of the larval stage counted up to that time/ sampling date (Bakry, 2018).

2.1.3. Estimate the weekly variation rate in FAW population

According to Bakry et al. (2020) and Mohamed et al. (2021), the weekly variation rate within FAW population was estimated as follows (Formula 2):

$$R = (w / W) \tag{2}$$

Where:
R = Rate of FAW weekly variation
w = Average FAW numbers /week
W = Average FAW numbers given in the previous week

2.2. Simultaneous effects of both climatic factors and plant ages on S. frugiperda seasonal activity within maize plants

The weather parameters of Luxor Governorate were obtained weekly from the Central Laboratory for Agricultural Climate (CLAC), Agricultural Research Center (ARC), Ministry of Agriculture at Giza through the two consecutive growing seasons (2021 and 2022). These parameters were:
$\mathbf{X_1}$: mean daily maximum temperature,
$\mathbf{X_2}$: mean daily minimum temperature, and
$\mathbf{X_3}$: mean percentage of relative humidity.

By the way, the Luxor area is 99 meters above sea level, with a longitude of 32.71 degrees east and an altitude of 25.67 degrees north.

Concerning the parameters of the corn plant phenology, plant age is indicated as a symbol ($\mathbf{X_4}$) during 2021 and 2022. A third-degree polynomial equation was established to represent these relationships (i.e., age, age^2, and age^3 according to the sampling dates). The following formula was applied: $Y = a \pm b_1X_4 \pm b_2X_4^2 \pm b_3X_4^3$ (Bakry et al., 2020; Mohamed et al., 2021). According to Fisher (1950), data were statistically analyzed, by using different models of correlation and regression, to find out the relationships between the main weather factors and plant ages (independent variables), the numbers of egg masses, the larval population density, and percentages of damaged plants (as dependent variables). In addition, the explained variance percentage was also calculated to provide important information regarding the amount of variation in the population size under these investigated circumstances. SPSS Program Software (1999) was used to perform all the statistical analyses of the data. All of the data was estimated and graphically described using Microsoft Excel.

3. Results

In Egypt, this study is the 1st ecological study dealing with the fall armyworm (*S. frugiperda*) population density, insect fluctuations, and its damage, as well as, the effectiveness of certain weather factors on FAW under field conditions (Figure 1).

Weekly numbers of FAW egg masses/ mass and larval populations, as well as the percentage of damage, were recorded throughout the two successive growing seasons (2021 and 2022) and represented in Tables 1-2) and Figure 2.

The weekly average of the effect of the climatic weather and plant ages of maize on FAW seasonal populations is also shown. The influences of climatic factors and plant ages on FAW seasonal abundance were estimated based on a count of the average number of egg masses and larvae /10 plants/ sampling date.

Our observation declared that *S. frugiperda* infested maize plants from the 3rd week of June until the corn harvest.

3.1. Population studies

3.1.1. Seasonal incidence of S. frugiperda

A) *S. frugiperda* egg mass

The average FAW egg mass numbers were 2.83 ± 0.40 and 2.96 ± 0.45 egg mass/10 plants in 2021 and 2022, respectively (Tables 1-2 and Figure 2), and recorded two peaks in each season. In 2021, the 1st peak of FAW egg mass number was in the 1st week of July and reached 6.00 ± 1.41 egg mass /10 plants, while the 2nd was in 1st week of August and recorded 6.50 ± 0.96 egg mass /10 plants. While in 2022, the two FAW egg mass peaks occurred in the 1st week of July and August which listed 8.50 ± 1.50 and 5.50 ± 0.96 and egg mass/10 plants, respectively. The analysis of variance (LSD) revealed highly significant differences in the number of egg masses with sampling dates.

B) *S. frugiperda* larval stage

The average population densities of the larval stage were 13.41 ± 0.52 and 13.03 ± 0.46 larvae / 10 plants in 2021 and 2022, respectively (Tables 1-2, Figure 2). The larvae seasonal abundance recorded three peaks of its activity, within the 1st week of July, the 1st week of August, and the 1st week of September over the two growing seasons.

In 2021, the larval stage population density values were 14.25 ± 0.97, 17.63 ± 0.94, and 15.75 ± 0.97 larvae / 10 plants, respectively. While in 2022 listed 14.25 ± 0.97, 14.99 ± 1.53, and 16.88 ± 1.28 larvae / 10 plants, respectively. It could be noticed that the larval stage reached its maximum numbers during the 1st week of August 2021 (17.63 ± 0.94 larvae /10 plants) and in the 1st week of September 2022 (16.88 ± 1.28 larvae / 10 plants).

Figure 1. (a-f): *Spodoptera frugiperda* damage maize plants at different development stages. (a): egg mass, (b): larvae with an inverted Y-form head and four black pinacula, (c): adult, (d): damage symptoms on maize leave caused by larvae such as a silvery transparent film, white elongated spots, pinholes, windowing, and hollow leaves, (e): larvae feed on the plant heart with leaves rending, causing death within young plants, as well as, attacking maize tassel, leaving feces in the funnel and on the flag leaves. Deactivate pollination and fertilization mechanisms and devastate tassels, (f): the larvae attack the stems and ears, and as a result of their excessive feeding, they cause holes and cavities in the cobs, resulting in grain loss, lower quality, and cobs infection by fungi.

Table 1. Weekly Average counts of the egg masses, larvae populations, % cumulative no. of *S. frugiperda*, and its damage percentages on maize plants, as well as the effect of climatic factors, at Esna district, Luxor Governorate, Egypt (2021).

Sampling dates		Plant age (in days)	Count /10 plants ± SE		% No. larvae from the overall seasonal	Cumulative larval numbers / 10 plants	% Cumulative	Plants damage (%)	Climatic factors		
			Egg masses	Larvae					Max. temp.	Min temp.	% R.H.
June 2021	3rd	16	3.00 ± 0.58	7.88 ± 2.32	4.90	7.88	4.90	35.00 ± 2.89	40.34	27.39	22.73
	4th	23	6.50 ± 0.50	12.38 ± 1.13	7.69	20.25	12.59	45.00 ± 6.45	39.82	28.57	19.87
July	1st	30	6.00 ± 1.41	14.25 ± 0.97	8.86	34.50	21.45	52.50 ± 4.79	39.20	29.95	24.99
	2nd	37	4.00 ± 0.82	10.50 ± 1.06	6.53	45.00	27.97	62.50 ± 7.50	40.06	29.01	23.72
	3rd	44	0.00 ± 0.00	11.63 ± 1.66	7.23	56.63	35.20	65.00 ± 6.45	41.27	31.89	26.17
	4th	51	4.50 ± 0.50	15.75 ± 2.49	9.79	72.38	44.99	70.00 ± 4.08	41.38	30.98	22.33
Aug.	1st	58	6.50 ± 0.96	17.63 ± 0.94	10.96	90.00	55.94	75.00 ± 2.89	38.91	30.20	23.96
	2nd	65	3.50 ± 0.50	15.00 ± 0.61	9.32	105.00	65.27	77.50 ± 2.50	39.40	29.06	24.48
	3rd	72	0.00 ± 0.00	12.38 ± 1.28	7.69	117.38	72.96	82.50 ± 4.79	39.08	28.56	25.55
	4th	79	0.00 ± 0.00	14.63 ± 1.13	9.09	132.00	82.05	82.50 ± 7.50	42.38	30.63	22.77
Sept.	1st	86	0.00 ± 0.00	15.75 ± 0.97	9.79	147.75	91.84	85.00 ± 2.89	40.52	29.77	27.43
	2nd	93	0.00 ± 0.00	13.13 ± 1.13	8.16	160.88	100.00	90.00 ± 4.08	41.46	30.12	27.83
	Total		34.00	160.88	100.00						
	Average		2.83 ± 0.40	13.41 ± 0.52				68.54 ± 2.71	40.32	29.68	24.32
	F-value		35.85	3.98				11.40			
	LSD at 0.05 level		1.31*	3.85*				14.65*			

F-value refers to analysis of variance; %R.H. = the percentage of relative humidity. *Highly significant at $P \leq 0.01$.

Table 2. Weekly average counts of the egg masses, larvae populations, % cumulative no. of *S. frugiperda*, and its damage percentages on maize plants, as well as the effect of climatic factors, at Esna district, Luxor Governorate, Egypt (2022).

Sampling dates		Plant age (in days)	Count / 10 plants ± SE		% No. larvae from the overall seasonal	Cumulative larval numbers / 10 plants	% Cumulative	Plants damage (%)	Climatic factors		
			Egg masses	Larvae					Max. temp.	Min temp.	% R.H.
June 2022	3rd	16	3.00 ± 0.58	7.50 ± 0.87	4.80	7.50	4.80	30.00 ± 2.04	41.17	25.33	27.59
	4th	23	6.50 ± 0.96	10.88 ± 0.72	6.95	18.38	11.75	35.00 ± 2.89	40.63	26.43	24.11
July	1st	30	8.50 ± 1.50	14.25 ± 0.97	9.11	32.63	20.86	40.00 ± 7.07	40.00	27.70	30.33
	2nd	37	4.00 ± 0.82	11.25 ± 0.43	7.19	43.88	28.06	50.00 ± 4.08	40.87	26.62	28.79
	3rd	44	0.00 ± 0.00	12.38 ± 1.55	7.91	56.25	35.97	52.50 ± 2.50	43.11	28.50	31.77
	4th	51	4.50 ± 0.50	13.88 ± 1.42	8.87	70.13	44.85	57.50 ± 4.79	42.22	28.65	27.10
Aug.	1st	58	5.50 ± 0.96	14.99 ± 1.53	9.59	85.12	54.43	67.50 ± 6.29	41.75	27.94	29.09
	2nd	65	3.50 ± 0.50	12.75 ± 0.97	8.15	97.87	62.59	70.00 ± 5.77	40.21	26.88	29.71
	3rd	72	0.00 ± 0.00	12.75 ± 1.30	8.15	110.62	70.74	77.50 ± 4.79	39.88	26.42	31.01
	4th	79	0.00 ± 0.00	15.00 ± 1.06	9.59	125.62	80.33	80.00 ± 4.08	42.38	28.33	27.64
Sept.	1st	86	0.00 ± 0.00	16.88 ± 1.28	10.79	142.49	91.13	82.50 ± 7.50	41.35	27.54	33.30
	2nd	93	0.00 ± 0.00	13.88 ± 2.07	8.87	156.37	100.00	82.50 ± 2.50	42.30	27.86	33.79
Total			35.50	156.37	100.00						
Average			2.96 ± 0.45	13.03 ± 0.46				60.42 ± 2.92	41.32	27.35	29.52
F-value			20.56	4.35				17.79			
LSD at 0.05 level			1.89 *	3.35 *				12.98 *			

F-value refers to analysis of variance; %R.H. = the percentage of relative humidity. *Highly significant at $P \leq 0.01$.

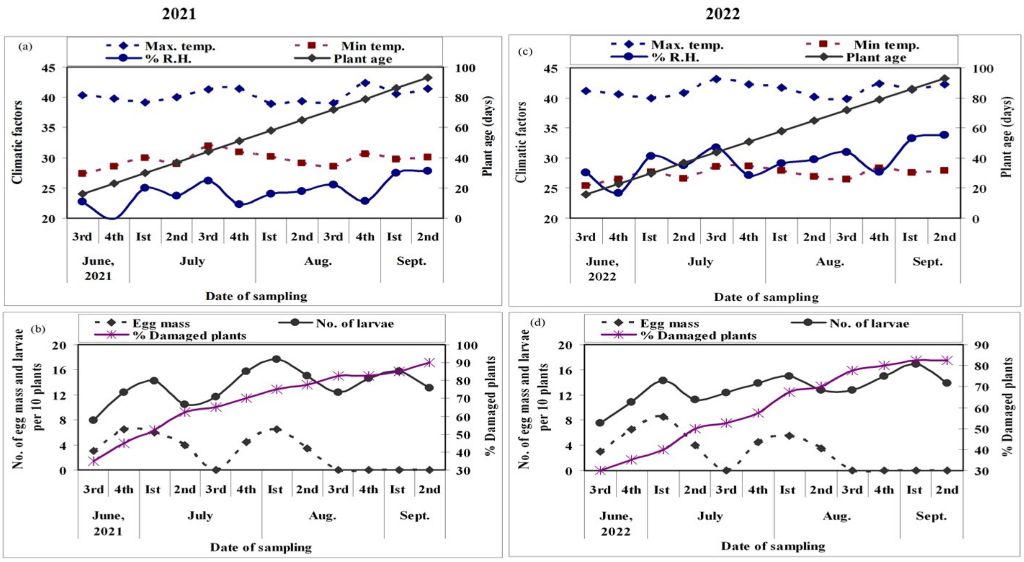

Figure 2. Effect of the climatic factors on the weekly average counts of *S. frugiperda* and its damage on maize plants at Esna district, Luxor, Egypt (2021) during the two growing seasons [2021 (a-b) and 2022 (c-d)].

Statistically, the larvae numbers varied with high significance, where LSD values were 3.85 and 3.35 in the two successive seasons, respectively (Tables 1-2).

C) Damage rates by *S. frugiperda*

Maize plant damage percentages increased with increasing examination periods of the maize crops within the two successive seasons of study (Tables 1-2, Figure 2). There was a significant difference in the percentages of damage (LSD values were 14.65 and 12.98) throughout the two seasons, respectively, (Tables 1-2). In comparison between the two growing seasons, the statistical analysis revealed that there were no significant differences between the mean numbers of egg masses and the mean numbers of the larval population.

In contrast, highly significant differences among the percentages of damaged plants in the two seasons were recorded (LSD value was 4.10). As well, the study showed that the vegetative stage of maize plants was a more favorable one for FAW to built-up a higher population density of larvae. Consequently, the percentage of damaged plants increased gradually towards the flowering and reproductive stages of corn plants which caused severe damage over the two growing seasons.

3.1.2. Population peaks and cumulative numbers of S. frugiperda larvae

There are three peaks of FAW larval population densities, these peaks occurred in the 1st week of July, August, and September/ growing season, which listed 8.86, 10.96, and 9.79% of the total larval populations in 2021 and 9.11, 9.59, and 10.79% in 2022, respectively (Tables 1-2). So, the accumulated *S. frugiperda* larvae percentage increased gradually with the length of the investigation intervals through the maize growing season.

3.1.3. Weekly variation rate in S. frugiperda eggs and larvae population

The rate of weekly variation in FAW populations and damage percentage is considered an indicator to determine the most favorable week for FAW activity, which can be expressed as the time (week) that supports the higher population densities throughout the season. Therefore, the weekly variation rates in FAW egg masses, larvae population densities, and the percentages of damage were calculated (Table 3).

The huge increase in FAW egg masses occurred in the 4th week of June and the 1st week of August in 2021 (Table 3) which the variation rates being 2.17 in the 1st week of June and 1.44 in the 1st week of August. While in 2022, the most favorable times to increase FAW egg masses were in the 4th week of June, the 1st week of July, and the 1st week of August, with 2.17, 1.31, and 1.22 variation rates/ weekly, respectively.

The rates of weekly variation (RWVP) of FAW larval population (the suitable times to build up higher larval population densities) were in the 4th week of June, the 1st, 3rd, and 4th weeks of July, the 1st and 4th weeks of August, and the 1st week of September in 2021. These rates listed 1.57, 1.15, 1.11, 1.35, 1.12, 1.18, and 1.08, respectively. Similarly, in 2022, the favorable periods for FAW larvae to increase their populations were in the 4th week of June, the 1st, 3rd, and 4th weeks of July, the 1st, 3rd and 4th weeks of August, and the 1st week of September, with an average of 1.45, 1.31, 1.10, 1.12, 1.08, 1.00, 1.18, and 1.13, respectively (Table 3). As for FAW percentages of damage during 2021 and 2022, the rates of weekly variation were greater which recorded more than one in all investigation periods.

Generally, the RWVP for egg masses, larvae population density, and damage of corn plants were greater than 1 (>1)

Table 3. The rate of weekly variation (R.W.V.P) in the mean number of egg mass, larvae, and damage plant percentages by *S. frugiperda* on maize plants at Esna district, Luxor Governorate during the two growing seasons (2021 and 2022).

1st growing season (2021)					2nd growing season (2022)				
Sampling date		R.W.V.P			Sampling date		R.W.V.P		
		Egg masses	Larvae	Plants Damage %			Egg masses	Larvae	Plants Damage %
June 2021	3rd	—	—	—	June 2022	3rd	—	—	—
	4th	2.17	1.57	1.29		4th	2.17	1.45	1.17
July	1st	0.92	1.15	1.17	July	1st	1.31	1.31	1.14
	2nd	0.67	0.74	1.19		2nd	0.47	0.79	1.25
	3rd	0.00	1.11	1.04		3rd	0.00	1.10	1.05
	4th	0.00	1.35	1.08		4th	0.00	1.12	1.10
Aug.	1st	1.44	1.12	1.07	Aug.	1st	1.22	1.08	1.17
	2nd	0.54	0.85	1.03		2nd	0.64	0.85	1.04
	3rd	0.00	0.83	1.06		3rd	0.00	1.00	1.11
	4th	0.00	1.18	1.00		4th	0.00	1.18	1.03
Sept.	1st	0.00	1.08	1.03	Sept.	1st	0.00	1.13	1.03
	2nd	0.00	0.83	1.06		2nd	0.00	0.82	1.00

which means that climatic circumstances were preferable for FAW feeding and reproduction activities. In addition, the optimum times for FAW activity were similar during the two seasons of study.

3.2. Effect of certain climatic factors and corn plant age on S. frugiperda seasonal activity

3.2.1. Influence of independent variables on egg masses and larvae population size

A) Impact of the daily maximum temperature (X_1)
FAW egg masses (Y_1)

The statistical analysis of simple correlation showed weak negative insignificant correlations between the daily mean maximum temperature and the numbers of *S. frugiperda* egg masses for the two growing seasons (r-value; -0.56 and -0.45), respectively (Table 4). While, the simple regression coefficient revealed that an increase of 1 °C in the daily mean maximum temperature, decreased FAW egg mass numbers by 1.37 and 1.29 egg masses/10 plants in the two seasons of study, respectively. The partial regression (P. reg.) values emphasized a significant negative effect of the daily mean maximum temperature on the numbers of egg masses in the two seasons (-1.56 and -1.29), respectively. In addition, the partial correlation accounts were -0.75 and -0.75 and the estimated t-test values were -2.86 and -1.61 in 2021 and 2022, respectively (Table 4). Data revealed that the daily mean maximum temperature was the most effective climatic variable in changing the numbers of FAW egg masses by 26.74% in the 1st season and 27.12%, in the 2nd one (Table 4).

Larval population density (Y_2)

The simple correlation coefficient (*r*) between the daily mean maximum temperature and *S. frugiperda* larvae populations was non-significantly negative (-0.08) in 2021 and had a non-significantly positive relation (+0.19) in 2022. Also, the simple regression indicated a 1 °C increase in the daily maximum temperature, a decrease in the larval population by 0.18 /10 plants in 2021, and an increase of 0.47 /10 plants in 2022 (Table 5). This factor was accountable for the changes in the larval population by 32.38 and 12.46% for the two successive growing seasons, respectively (Table 5).

B) Effect of the daily minimum temperature (X_2)
FAW egg masses (Y_1)

The simple correlations (*r*) between the daily mean minimum temperature (DMMT) and FAW egg masses numbers were negative and non-significant negative (-0.22 and -0.14) during the two seasons, respectively. Likewise, the simple regression indicated that every 1 °C increase in the daily mean minimum temperature, increased the egg masses numbers by 0.48 and 0.40 egg masses/10 plants in 2021 and 2022, respectively (Table, 4). The accurate effect of the daily mean minimum temperature on the egg masses numbers was positive but non-significant (P. reg. Value = +0.77) through 2021 and slightly negative in 2022 (P. reg. Value = -0.40). In addition, the partial correlation values were (+0.56 and -0.71), while the *t*-test values were +1.58 and -0.44) through the two successive seasons, respectively.

The average daily minimum temperature was within the optimum range for the insect's egg-laying activity in the first season and above the optimum range during the second one. This climatic factor was responsible for changes in egg mass numbers by 8.18 and 21.94% in 2021 and 2022, respectively (Table, 4).

Larval population density (Y_2)

The simple correlation between the daily mean minimum temperature and the larvae *S. frugiperda* density

Table 4. Correlation and regression analysis model for the relationship between the effect of certain weather factors, and corn age, on *S. frugiperda* egg masses during the two growing seasons (2021 and 2022).

Season	Tested variables	Simple correlation and regression values				Partial correlation and regression values				Efficiency %	Rank	Analysis variance			
		r	*b*	S.E	*t*-test	P. cor.	P. reg.	S.E	*t*-test			*F*	*MR*	R^2	E.V.%
2021	Max. temp (X_1)	-0.56	-1.37	0.65	-2.12	-0.75	-1.56	0.54	-2.86 *	26.74	1	5.93 *	0.88	0.77	77.21
	Min. temp (X_2)	-0.22	-0.48	0.68	-0.71	0.56	0.77	0.49	1.58	8.18	3				
	R.H.% (X_3)	-0.63	-0.76	0.29	-2.56 *	-0.67	-0.68	0.29	-2.31*	17.29	2				
	Plant age (X_4)	-0.65	-0.07	0.03	-2.72 *	-0.62	-0.02	0.03	-0.85	2.38	4				
	Plant ages (X_4, X_4^2, X_4^3)											2.52	0.70	0.49	48.57
	Combined effect (X_1 to X_4^3)											5.58 *	0.93	0.87	87.00
2022	Max. temp (X_1)	-0.45	-1.29	0.80	-1.61	-0.75	-1.29	0.80	-1.61 *	27.12	1	6.38 *	0.89	0.78	78.47
	Min. temp (X_2)	-0.14	-0.40	0.92	-0.44	-0.71	-0.40	0.92	-0.44 *	21.94	3				
	R.H.% (X_3)	-0.55	-0.59	0.28	-2.08	-0.32	-0.59	0.28	-2.08	2.50	4				
	Plant age (X_4)	-0.68	-0.08	0.03	-2.90 *	-0.72	-0.08	0.03	-2.90 *	22.89	2				
	Plant ages (X_4, X_4^2, X_4^3)											2.86	0.72	0.52	51.77
	Combined effect (X_1 to X_4^3)											4.01*	0.91	0.83	82.78

r = simple correlation; *b* = simple regression; P. cor. = partial correlation; P. reg.= partial regression; *MR* = multiple correlation; R^2 = coefficient of determination; E.V% = explained variance; S.E = standard error.
*Significant at $P \leq 0.05$.

Table 5. Correlation and regression analysis model for the relationship between the effect of certain weather factors, and corn age, on *S. frugiperda* larval populations during the two growing seasons (2021 and 2022).

Season	Tested variables	Simple correlation and regression values				Partial correlation and regression values				Efficiency %	Rank	Analysis variance			
		r	*b*	S.E	*t*-test	P. cor.	P. reg.	S.E	*t*-test			*F*	*MR*	R^2	E.V.%
2021	Max. temp (X_1)	-0.08	-0.18	0.76	-0.24	-0.80	-1.67	0.47	-3.52 **	32.38	3	7.84 **	0.90	0.82	81.74
	Min. temp (X_2)	0.52	1.13	0.59	1.93	0.82	1.62	0.43	3.79 **	37.60	2				
	R.H.% (X_3)	0.14	0.17	0.37	0.46	-0.72	-0.70	0.26	-2.73 *	19.46	4				
	Plant age (X_4)	0.53	0.06	0.03	1.98	0.83	0.09	0.02	3.87 **	39.10	1				
	Plant ages (X_4, X_4^2, X_4^3)											2.60	0.70	0.49	49.32
	Combined effect (X_1 to X_4^3)											5.07 *	0.93	0.86	85.88
2022	Max. temp (X_1)	0.19	0.47	0.72	0.66	-0.72	-1.09	0.43	-2.55 *	12.46	2	11.24 **	0.93	0.87	86.53
	Min. temp (X_2)	0.73	1.76	0.51	3.44 **	0.86	2.00	0.48	4.20 **	33.92	1				
	R.H.% (X_3)	0.49	0.41	0.25	1.67	0.06	0.01	0.16	0.06	0.01	4				
	Plant ages (X_4)	0.74	0.07	0.02	3.33 **	0.70	0.04	0.02	2.42 *	11.32	3				
	Plant ages (X_4, X_4^2, X_4^3)											4.99 *	0.81	0.65	65.16
	Combined effect (X_1 to X_4^3)											6.01*	0.94	0.88	87.83

r = simple correlation; *b* = simple regression; P. cor. = partial correlation; P. reg.= partial regression; *MR* = multiple correlation; R^2 = coefficient of determination; E.V% = explained variance; S.E = standard error.
*Significant at $P \leq 0.05$; **Highly significant at $P \leq 0.01$.

had a non-significantly positive correlation (*r*-value = +0.52) in 1st season and a highly significant positive relation (*r*-value = +0.73) in the second one (Table 5). The simple regression model declared that each 1°C increase in the mean daily minimum temperature increases the larvae numbers by 1.13 and 1.76 / 10 plants during the two seasons of study, respectively (Table 5). Likewise, the partial correlation coefficients recorded 0.82 and 0.86, and the *t*-test values were 3.79 and 4.20 during the two seasons, respectively. The mean daily minimum temperature caused changes in larval populations by 37.60 and 33.92% in the first and second growing seasons, respectively (Table 5).

C) Effect of the relative humidity (X_3)

FAW egg masses (Y_1)

The relative humidity (%RH) effect on FAW egg masses numbers had a significantly negative relation (*r*-value = -0.63) in the first season and a non-significantly negative relation (*r*-value = -0.55) in the second one. The simple regression coefficient indicates that an increase of 1% in the mean relative humidity, decreased the egg mass numbers by 0.76 and 0.59 / 10 plants in 2021 and 2022, respectively (Table 4). The partial regression values of this relation showed a significant negative effect (P. reg. value = -0.68) in 2021 and a negative relationship (-0.59) in 2022. While the values of the partial correlations were -0.67 and -0.32, meanwhile, *t*-test values were -2.31 and -2.08 for the 1st and 2nd seasons, respectively. The relative humidity factor had responsible for certain changes in the egg mass numbers by about 17.29% in 2021 and 2.50% in 2022 (Table 4).

Larval population density (Y_2)

The correlation coefficient between RH and the larval population was non-significantly positive (*r*= +0.14 and +0.49) during the two seasons, respectively. So, the simple regression indicated that an increase of 1% in the mean RH, increase the larval population by 0.17 and 0.41 /10 plants during the two seasons, respectively (Table 5). The partial regression values were also calculated and were significantly negative (P. reg.= -0.70) in 2021, and non-significantly positive (P. reg.= +0.01) in 2022. As well, the partial correlation values recorded -0.72 and 0.06 in 2021 and 2022, respectively. Meanwhile, the *t*-test values were -2.73 and 0.06 during both seasons, respectively. The results revealed that the %RH caused changes by 19.46 and 0.01% in both growing seasons, respectively (Table 5).

D) Effect of the plant's age (X_4)

FAW egg masses (Y_1)

Through this study, it was found that the maize plant age had a clear effect on both the number of eggs and larvae of *S. frugiperda* (Table, 4). Statistically regarding its effect on egg mass numbers, the simple correlation coefficients (*r*) had significantly negative effects (*r*-values= -0.65 and -0.68) during the two seasons, respectively. The calculated regression coefficient (*b*) indicated that with a daily increase in the plant age of maize, the egg masses numbers decreased by about 0.07 and 0.08 mass /10 plants in 2021 and 2022, respectively.

The partial regression showed a non-significant negative relationship (-0.02) in 2021 and significant negative relation (-0.08) in 2022. Whereas, the partial correlation coefficients listed -0.62 and -0.72, the *t*-test values were -0.85 and -2.90 for the two seasons, respectively. Moreover, the maize age affected *S. frugiperda* egg mass numbers by 2.38% in the first season, and by 22.89% during the second one.

Larval population density (Y_2)

The simple correlation coefficient (*r*) between the maize plant age and *S. frugiperda* larvae numbers was non-significantly positive (*r*= +0.53) in 2021, and had a highly positive relationship (*r*= +0.74) in 2022. Also, the partial correlation values were listed as 0.83 and 0.70, where the *t*-test values were 3.87 and 2.42 for the two growing seasons, respectively. Maize plant age had an effect and cause changes in the larval population by 39.10% during the first season, and by 11.32% during the second (Table 5).

E) The combined effect of the three climatic factors as well as plant ages

S. frugiperda egg mass numbers

The combined effects of these examined factors on *S. frugiperda* egg mass numbers were highly significant, where the "*F*" values listed 5.93 and 6.38, in the two growing seasons, respectively (Table 4). Moreover, the degrees of variability were 77.21% in 2021 and 78.47% in 2022.

S. frugiperda larval density

The collective effect of three climate factors and plant age on the larvae density of *S. frugiperda* was highly significant where the "*F*" values were 7.84 and 11.24, respectively (Table 5).

3.2.1.1. Effect of the plant ages (X_4) on S. frugiperda egg mass numbers

The maize plant's age (X_4) (applying a three-degree polynomial equation $Y_1 = a \pm b_1X_4 \pm b_2X_4^2 \pm b_3X_4^3$) revealed a high relation of variation on FAW populations. The explained variance (E.V.) values were listed 48.57 in 2021 and 51.77% in 2022 (Table, 4). Based on this model, the numbers of *S. frugiperda* egg masses can be predicted based on the maize plant age. The following regression model equations were presented in Figure 3:
The first season (2021) (Formula 3):

$$Y_1 = -5^2 X_4{}^3 - 0.0052\,X_4{}^2 + 0.2484\,X_4 + 1.364 \quad \left(R^2 = 0.4857\right) \quad (3)$$

The second season (2022) (Formula 4):

$$Y_1 = -5^5 X_4{}^3 - 0.0087\,X_4{}^2 + 0.3952\,X_4 + 0.0871 \quad \left(R^2 = 0.5177\right) (4)$$

In addition, the combined influence of these factors on the egg mass numbers was very low, and the calculated "*F*" values were 2.52 and 2.86 during the two seasons, respectively (Table 4).

3.2.1.2. Effect of the plant ages (X_4) on S. frugiperda larval density:

The effects of plant age (calculated using a three-degree nonlinear function $Y_2 = a \pm b_1X_4 \pm b_2X_4^2 \pm b_3X_4^3$) had a strong relationship with the larval population. The E.V. values were 49.32 and 65.16% for two successive seasons, respectively (Table 5). The equations for regression models (Figure 3):

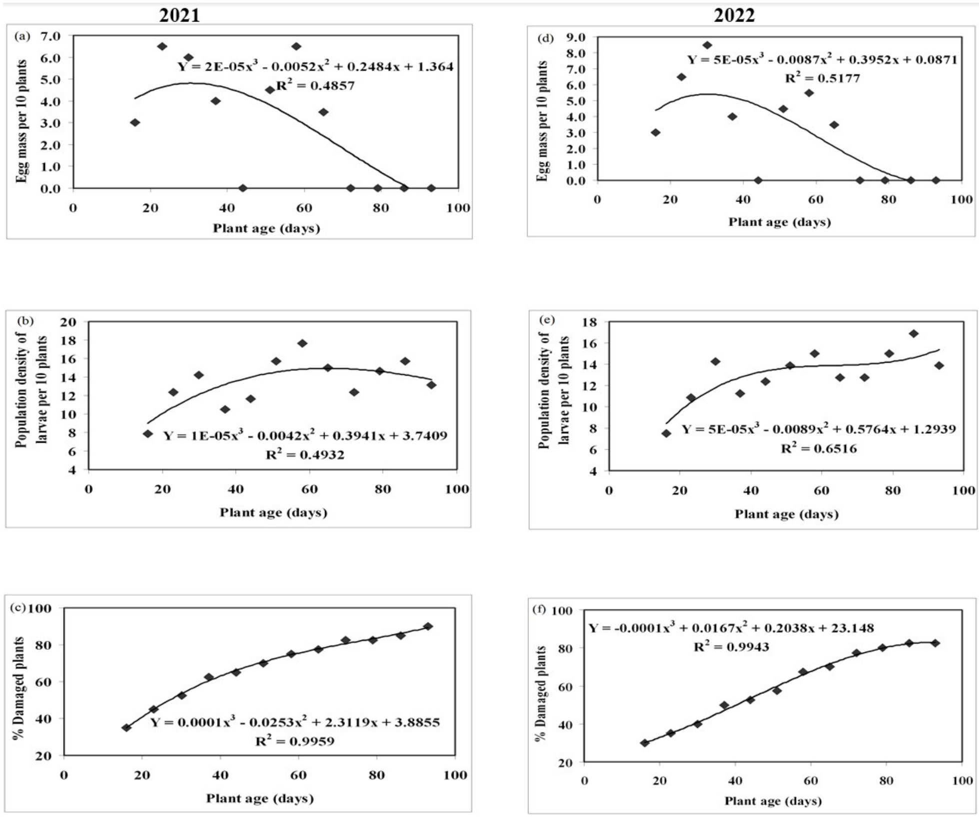

Figure 3. The polynomial relationship between corn age and *S. frugiperda* populations (egg masses, larval population) and corn damage percentages during the two growing seasons [2021 (a-c) and 2022 (d-f)].

The first season (2021) (Formula 5):

$$Y_2 = -5^1 X_4^3 - 0.0042\, X_4^2 + 0.3941\, X_4 + 3.7409 \quad R^2 = 0.4932 \tag{5}$$

The second season (2022) (Formula 6):

$$Y_2 = -5^5 X_4^3 - 0.0089\, X_4^2 + 0.5764\, X_4 + 1.2939 \quad R^2 = 0.6516 \tag{6}$$

The combined effect of these examined factors on larval density was non-significant and the "*F*" value was recorded 2.60 in 2021 and significant in 2022 and recorded 4.99 during the second season (Table 5)

The effect of independent variables (X_1, X_2, X_3, X_4, X_4^2, and X_4^3)

S. frugiperda egg masses (Y_1) (as a dependent variable)

The combined effects of three abiotic factors (climatic factors) and plant age (in days) on the egg mass numbers were studied and illustrated in Table 4. The degree of variation was significant and the "*F*" value was listed as 5.58 in 2021 and 4.01 in 2022 (Table 4). The explained variance percentages (E.V.%) were 87.00 in 2021 and 82.78% in 2022. As a result, the numbers of egg masses were mathematically influenced by the meteorological conditions and maize ages.

Larvae population of *S. frugiperda* (Y_2) (as dependent variable)

The data displayed the pooled effect of the three weather factors and plant ages (in days) on the variation in the larvae density of *S. frugiperda* (Table 5). The values of the multiple regression analysis demonstrated that changes in the larval density were caused by an effect of all variables tested.

3.2.1.3. Effect on damage rates (Y_3) caused by S. frugiperda

3.2.1.4. Effect of three climatic parameters (X_1, X_2, and X_3) and plant age (X_4) on the occurrence of damaged plants

A) Effect of daily maximum temperature (X_1)

Statistically, the simple correlation (Table 6) showed a non-significant positive relationship between the daily mean maximum temperature and the damage percentage caused by *S. frugiperda* larvae (r = +0.24 and +0.22) in the two seasons, respectively. Moreover, the simple regression model showed that any increase in the daily mean maximum temperature by 1°C led to an increase in the damage percentage by 3.73 and 3.96% in 2021 and 2022, respectively (Table 6). Details on the daily mean maximum temperature effects on the damage percentage are shown in Table 6.

B) Effect of the daily mean minimum temperature (X_2)

The statistical analysis of the relationship between the simple correlation (r) between the daily mean minimum temperature and the damage percentage revealed a non-

Table 6. Correlation and regression analysis model for the relationship between the effect of certain weather factors, and corn age, on *S. frugiperda* damage percentage during the two growing seasons (2021 and 2022).

Season	Tested variables	Simple correlation and regression values				Partial correlation and regression values				Efficiency %	Rank	Analysis variance			
		r	b	S.E	t-test	P. cor.	P. reg.	S.E	t-test			F	MR	R^2	E.V.%
2021	Max. temp (X_1)	0.24	3.73	4.74	0.79	-0.65	-2.70	1.18	-2.29	2.03	3	62.51 **	0.99	0.97	97.28
	Min. temp (X_2)	0.45	6.22	3.95	1.57	0.71	2.88	1.06	2.71 *	2.84	2				
	R.H.% (X_3)	0.61	4.64	1.88	2.46 *	-0.31	-0.56	0.64	-0.88	0.30	4				
	Plant age (X_4)	0.97	0.66	0.05	12.44 **	0.98	0.68	0.06	11.51 **	51.54	1				
	Plant ages (X_4, X_4^2, X_4^3)											640.91 **	0.99	0.99	99.59
	Combined effect (X_1 to X_4^3)											579.79 **	0.99	0.99	99.86
2022	Max. temp (X_1)	0.22	3.96	0.99	0.99	-0.29	-1.00	1.38	-0.72	0.17	3	74.70 **	0.99	0.98	97.71
	Min. temp (X_2)	0.43	8.04	0.99	0.99	0.13	0.50	1.54	0.32	0.03	4				
	R.H.% (X_3)	0.59	4.09	0.99	0.99	-0.35	-0.39	0.51	-0.76	0.19	2				
	Plant ages (X_4)	0.99	0.74	0.99	0.99	0.98	0.77	0.06	12.89 **	54.33	1				
	Plant ages (X_4, X_4^2, X_4^3)											466.20 **	0.99	0.99	99.43
	Combined effect (X_1 to X_4^3)											227.99**	0.99	0.99	99.64

r = simple correlation; b = simple regression; P. cor. = partial correlation; P. reg.= partial regression; MR = multiple correlation; R^2 = coefficient of determination; E.V% = explained variance; S.E = standard error.
*Significant at $P \leq 0.05$; **Highly significant at $P \leq 0.01$.

significant positive relationship (+0.45 and +0.43) for the two seasons, respectively. Likewise, the simple regression coefficient showed that an increase of the daily mean minimum temperature by 1°C led to increasing the damage percentages by 6.22% in 2021 and 8.04% in 2022 (Table 6). As well as, the partial regression values for the influence of daily mean minimum temperature on damage percentage are shown in Table 6.

The *t*-test values were 1.06 and 1.54 in both seasons, respectively (Table 6). The daily mean minimum temperature seems to be responsible for certain changes in the damage percentage, which listed as 2.84 in 2021, and 0.03% in 2022 (Table 6).

C) Effect of the mean relative humidity (X_3)

The correlation coefficient relationships between relative humidity and the damage percentages were significant (r = 0.61 and 0.59) during the two seasons, respectively. Data analysis indicated that any increase in the mean relative humidity by 1%, increases the corn damage percentage by 4.64 and 4.09% through the two seasons, respectively (Table 6). In this context, the partial regression of RH had a slightly negative (P. reg. = -0.56 and -0.39) during the two seasons, respectively, on damage percentage. While, the partial correlation values were -0.31 and -0.35, and the calculated *t*-test values were -0.88 and -0.76 for both growing seasons, respectively (Table 6).

D) Effect of plant ages (X_4)

Maize plant age had a significant effect on FAW larval infestation (+0.97 and +0.99) during the two seasons, respectively. The simple regression coefficient showed a higher relationship between the daily growth rate of the maize plants and, the damage rates which listed 0.66 and 0.74% in the two seasons, respectively (Table 6). This relation was expressed as highly positive (P. reg. = 0.68 and 0.77) in both seasons, respectively (Table 6).

E) The combined effects of independent parameters on the corn damage occurrence

The combined effects of these variables on the *S. frugiperda* infestation are represented in Table 6 and Figure 3.

4. Discussion

Fall armyworm (FAW), *Spodoptera frugiperda* is now a pest of global economic importance. *S. frugiperda* was restricted to America, but recently reported from various countries in Africa, posing a serious challenge to agricultural sustainability. Since FAW invaded Africa for the 1st time in 2016. FAW had rapidly outspread in Africa and had entered, invaded, and spread in Asia and Australia (Cruz et al., 1999; Dahi et al., 2020). Subsequentially, FAW has put various million maize farmers and food producers in the danger. Accordingly, some countries of the world may encounter a shortage of human and animal foods.

Currently, global agriculture often faces new threats from some serious insect pests, which requires immediate attention and collaborative action to manage these invasive insect pests. In this regard, the fall armyworm, *S. frugiperda*, is a notorious invasive insect pest in many world countries. It has a high dispersal capacity, wide diversity in the number of plant hosts, as well as its high fertility, which makes it one of the most economically dangerous pests (Cruz et al., 1999; Goergen et al., 2016; Tendeng et al., 2019; Rwomushana, 2020). This species causes massive damage to maize and some other crops, posing major socioeconomic challenges. There is scanty information in the literature about the pest population density in Egypt, consequently, this study is considered to be the 1st one to deal with FAW populations and the effects of certain weather factors in Upper Egypt. Therefore, our study provides the first estimates to guide decision-making for how to benefit from the effectiveness of FAW biotic factors (population estimation), an estimate of plant damage, and their links with abiotic factors like some climate variables under field conditions in upper Egypt. As we see from the current paper, the presence of larvae, increased food availability, the interval of larvae growth being short, and movement from one plant to the next, resulted in severe foliar damage. Furthermore, some of the maize plants that were noticed to be damaged were not attacked (free of larvae) at the examination time (Fernández, 2002). The infestation by this pest maize plant was initiated in the third week of June until the last crop harvest of every season. These findings were in agreement with Supartha et al. (2021) data, who mentioned that FAW adult populations and egg masses were discovered to be active after two weeks of maize planting.

Based on our data, the seasonal activity of *S. frugiperda*, on maize plants, was observed to be initiated from the third week of June until the harvest. As well, the first stages of the maize vegetative stage were more susceptible to infestation by *S. frugiperda*, where the greatest amount of damage was observed during this stage of maize development. The aforementioned findings are consistent with earlier findings by Gross Junior et al. (1982) who mentioned that the sensitivity of maize growth stages to FAW attack varied based on the plant growth and development. In the maize vegetative growth stages, *S. frugiperda* larvae mainly consume a large leaf mass area, which indirectly affects the yield by reducing the area of photosynthetic leaves. Willink et al. (1993) stated that the vegetative stage is more vulnerable to larval *S. frugiperda* attack.

Furthermore, during the study, some of the damaged corn plants were not infested at the time of the examination but were damaged in the later developmental stages of the corn (Caniço et al., 2020).

According to Supartha et al. (2021), the reason for the increase in insect population density is the availability of overlapping maize crops throughout the growing season. Moreover, based on the feeding performance of FAW, the prevalence, and diversity of cover crops may be among the reasons FAW increases among pests in successive crops. On the other hand, Valdez-Torres et al. (2012) reported that the fall armyworm could have at least two generations during the maize season growing. This is in line with the results Abd-Allah et al. (2018) who mentioned that *S. littoralis* larvae recorded only two peaks/season. Sisay et al. (2019) mentioned that the generation time of FAW was shorter which was spent about 20 to 30 days, which may be led to re-infestation by the pest (repeated generations) more than one time during the maize growing season. When rearing FAW larvae on a suitable plant host, the rate of adult reproduction will be similar to the results obtained in this study on maize (which is one of the favorite hosts of FAW). Consequently, it results in higher reproduction rates and a shorter generation period, which may help in a disaster phenomenon for corn farmers.

Its spread is ascribed to its high ability to adapt to various environmental conditions (Dent, 1991). FAW may invade other areas of the world, and thus may help in increasing the damage to major economic crops, based on the expected changes in climate weather. Our results are matching with Dent's (Dent, 1991) results, which indicate that the seasonal occurrence of any insect in an area may be due to environmental variables. While the average number of *S. frugiperda* larvae population density was related to the maize age and their growth (Murúa et al., 2009).

The same finding was reached that the dispersal of *S. frugiperda* eggs and larvae changed based on the maize phenological phase, and the larvae population was higher in the maize vegetative stage. Therefore, if the management actions weren't applied in this stage properly, the maize plants may suffer economic damage that can be ranging from 52 to 72% (Beserra et al.. 2002; Jaramillo-Barrios et al., 2019; Ma et al., 2019). In China, a comparative study of the behavior of FAW larvae fed on different host plants, using three biological parameters: 1) life table, 2) biological characteristics, and 3) egg-laying preference experiments. The results indicated that FAW raised on maize showed the highest activity in all biological traits (Guo et al., 2021).

Worldwide, FAW could be established under any changes in climate scenarios in the future. So, under African climatic conditions, FAW can infest and spread to unsuitable habitats, across migration from nearby areas of a multi-generational permanent habitat convenience condition, which should be checked regularly (Tepa-Yotto et al., 2021).

It is obvious that the effect of both the climate variables and maize age on any insect pest such as *S. frugiperda* regarding its population density and damage percentage was extremely important over the two seasons tested, and as we know that these climatic variables are changeable from one season to another. Therefore, through analyzing data on climatic factors in the growing two seasons, the mean daily maximum temperature was the most accurate variable responsible to cause differences in the FAW egg masses numbers. While the mean daily minimum temperature was more effects on the larval population densities. Contrarily, relative humidity was the least effective variable on the measured independent variables during the two seasons.

The maize plants and their relation to FAW damage were affected by various biotic and abiotic variables (Buntin, 1986). The biotic variables included plant growth and vigor periods, FAW infestation occurrence, the severity of damage symptoms, as well as, larval feeding time. They summarized that the physical and biological factors were very important in causing big differences in insect population density (Buntin, 1986). Also, climate change had a significant impact on insect pest growth, development, dispersion, and population dynamics (Naeem, 1996). FAW infestation can be influenced by plant age and morphological characteristics. For example, it could be identified as the best time of plant age that can FAW attack and infest the maize plants, which may cause severe damage (Williams and Dixon, 2007). Since *S. frugiperda* is considered a migratory pest, it can be expected to arrive in huge numbers very quickly if the weather factors were suitable, and that may explain its wide distribution. Therefore, FAW could pose a danger to several crops in a region. These biotic potentials of FAW could provide an ability to invade a wide range of host plants and to be adapted with appropriate climatic factors to reproduce with a higher reproductive rate in many world regions (Chang et al., 2008).

The environmental conditions (on the growth of maize, maize genotype, agricultural techniques, plant phenology, and plant maturity) are playing a crucial role in the system's dynamics in a particular location (Goergen et al., 2016; Montezano et al., 2018). Abiotic variables have a significant impact on eggs and the mortality of early larval stages of *S. frugiperda* (Simmons, 1993; Riggin et al., 1993). Furthermore, climate change is expected to affect the geographic range of many species, allowing invasive species to spread further (Perrings et al., 2005; Watson and Mifsud, 2017). Suitable weather factors play the main role in FAW spread and infestation (Varella et al., 2015).

Simulation studies indicate that dramatic climate changes may aid the species' spread, which could cause a potential increase of 12-44% in the future. Such conditions may contribute to the rapid spread and unexpected increase in their numbers, due to the possibility of interactions and rapid adaptation between FAW and the main host plants, which will cause an expected increase in the potential damage to crops worldwide (Balla et al., 2019). Daily temperature in the open field had a great influence on the *S. frugiperda* feeding and its performance (Caniço et al., 2020).

Parameshwari et al. (2021) mentioned that *S. frugiperda* seasonal occurrence during the spring was a significantly positive association with maximum temperature (0.232, 0.253, and 0.031) and minimum temperature (0.232, 0.253, and 0.031) displayed a non-significant positive association and relative humidity (-0.241,-0.049, and -0.130) reported non-significant negative linked with the number of egg masses, larvae population, and damaged plants percentages by *S. frugiperda*, respectively. The autumn season revealed that maximum temperature (0.310, 0.391, and 0.490) showed non-important positive associations, while minimum temperature degrees (0.560, 0.421, and 0.723) reported important, non-important, and highly important positive correlation relations and relative humidity (-0.430, -0.223, and -0.347) displayed non-significant negative correlations were observed in the number of egg masses, larvae population, and damaged plants ratio by *S. frugiperda*, respectively.

When knowing that FAW attacks about 350 host plant species belonging to 76 plant families (Montezano et al., 2018). So, the economic effects of *S. frugiperda* on crops can be assorted into four categories: (i) direct and indirect yield loss, (ii) management costs, (iii) loss of quality, and (iv) effects on trade arising from the agricultural quarantine measures required by countries imported (Overton et al., 2021). According to our research, the numbers of *S. frugiperda* egg masses, larvae, and damaged plants percentage are influenced by biotic and abiotic variables. As a result, the early discovery of invasive species in the Luxor region, of Egypt is crucial for eradication efforts to be successful and effective. This study is one of the components of integrated pest management that should be applied to reduce the damage by *S. frugiperda* to maize crops. Finally, the climatologic conditions prevailing in the maize growing season decide the fluctuation and abundance of FAW. So, abiotic factors as well abiotic factors must be taken into account by the decision-maker in consideration when planning an IPM control strategy for the control FAW.

5. Conclusions and Recommendations

Data gathered in this paper will be used as an indicator to decision-makers who will be planning effective pest control based upon environmentally sound management. These data included: a) pest behavior; b) egg mass quantity to determine the pest's reproductive capacity; and c) registration of biotic and abiotic factors to determine the best time to conduct pest control operations.

Right now, The fall armyworm (FAW) (*Spodoptera frugiperda*) is one of the most serious invasive pests against cereal plant hosts, threatening the world's food security. FAW is a cereal pest species that become global and spread from its Native home of America to invade Africa and Asia in 2016. The present work is the 1st field trial in Egypt to point out some ecological aspects of *S. frugiperda* on maize plants throughout two sequential growing seasons of maize (2021-2022).

Three biological parameters of FAW were studied (egg masses, number of larvae, and damage to corn plants). *S. frugiperda* population initiated to infest maize plants from the 3rd week of June until the harvest. *S. frugiperda* had two seasonal peaks of its activity concerning egg masses numbers and three peaks regarding the larval population numbers/season. FAW damage increased with the increase of the corn age. Egg mass numbers listed 2.83 ± 0.40 and 2.96 ± 0.45 mass /10 corn plants in 2021 and 2022, respectively. While, the larval populations were 13.41 ± 0.52 and 13.03 ± 0.46 larvae/10 plants, during the two growing seasons, respectively. Corn plant damage reached 68.54 ± 2.71 and 60.42 ± 2.92% in 2021 and 2029, respectively. The combined effects of both the weather conditions and maize plant ages were highly significant on egg masses, larvae population density, and damage percentage, and varied from one season to another. Most cereal farmers affected by FAW in America had large-scale farm operations, while the overwhelming majority of farmers in Africa and Asia are smallholders. The dramatic spread of FAW and the consequent damage (that appeared in different countries of America, Africa, and Asia) mean that different management approaches must be sought for the small and large-scale producers by using available technologies for smallholder farmers will eliminate pest damage without access to reach to an economic injury level (EIL). This information may assist the decision maker when planning the *S. frugiperda* IPM program for maize plants and its surveillance.

Acknowledgements

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

References

ABD-ALLAH, R., SHARKAWY, H.E., MEHANA, A.H., and HASHEM, M., 2018. Ecological and control studies on *Spodoptera littoralis* (Boisd.) infesting cowpea crop. *Journal of Productivity and Development*, vol. 23, no. 1, pp. 97-109. http://dx.doi.org/10.21608/jpd.2018.41858.

ANJORIN, F.B., ODEYEMI, O.O., AKINBODE, O.A. and KAREEM, K.T., 2022. Fall armyworm (Spodoptera frugiperda) (J. E. Smith) (Lepidoptera: Noctuidae) infestation: maize yield depression and physiological basis of tolerance. *Journal of Plant Protection Research*, vol. 62, no. 1, pp. 12-21.

BAKRY, M.M.S., 2018. Abundance, generation determination and spatial distribution pattern of the sunt wax scale insect, *Waxiella mimosae* (Signoret) (Hemiptera: Coccidae) infesting sunt trees in Luxor Governorate, Egypt. *Current Investigations in Agriculture and Current Research*, vol. 4, no. 3, pp. 523-538. http://dx.doi.org/10.32474/CIACR.2018.04.000187.

BAKRY, M.M.S., ARBABTAFTI, R. and MOHAMED, L.Y., 2020. Effect of certain climatic factors and plant phenology on population density of *Schizaphis graminum* on wheat plants in Luxor Governorate, Egypt. *International Journal of Agriculture Innovation and Research*, vol. 8, no. 5, pp. 401-414.

BALLA, A., BHASKAR, M., BAGADE, P. and RAWAL, N., 2019. Yield losses in maize (*Zea mays)* due to fall armyworm infestation and potential IoT-based interventions for its control. *Journal of Entomology and Zoology Studies*, vol. 7, no. 5, pp. 920-927.

BANGALE, S.A., 2019. Fall armyworm (*Spodoptera frugiperda*): a serious problem for maize cultivation in India. *Biomolecule Reports*, vol. BR/10/19/28, pp. 1-5.

BASKAUF, S.J., 2003. Factors influencing population dynamics of the southwestern corn borer (Lepidoptera: Crambidae): a reassessment. *Environmental Entomology*, vol. 32, no. 5, pp. 915-928. http://dx.doi.org/10.1603/0046-225X-32.5.915.

BESERRA, E.B., DIAS, C.T.D.S. and PARRA, J.R., 2002. Distribution and natural parasitism of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) eggs at different phenological stages of corn. *The Florida Entomologist*, vol. 85, no. 4, pp. 588-593. http://dx.doi.org/10.1653/0015-4040(2002)085[0588:DANPOS]2.0.CO;2.

BESSIN, R., 2019 [viewed 18 February 2023]. *Fall armyworm in corn* [online]. College of Agriculture, Food and Environment. Available from: https://entomology.ca.uky.edu/ef110

BUNTIN, G.D., 1986. A review of plant response to fall armyworm, *Spodoptera frugiperda* (J.E. Smith), injury in selected field and forage crops. *The Florida Entomologist*, vol. 69, no. 3, pp. 549-559. http://dx.doi.org/10.2307/3495389.

CANIÇO, A., MEXIA, A. and SANTOS, L., 2020. Seasonal dynamics of the alien invasive insect pest *Spodoptera frugiperda* Smith (Lepidoptera: Noctuidae) in Manica Province, Central Mozambique. *Insects*, vol. 11, no. 8, p. 512. http://dx.doi.org/10.3390/insects11080512. PMid:32784750.

CAPINERA, J.L., 2020. Fall armyworm, *Spodoptera frugiperda* (JE Smith) (Insecta: Lepidoptera: Noctuidae). *Electronic Data Information Source*, no. EENY098, pp. 1-6.

CHANG, X.N., GAO, H.J., CHEN, F.J. and ZHAI, B.P., 2008. Effects of environmental moisture and precipitation on insects: a review. *Shengtaixue Zazhi*, vol. 27, pp. 619-625.

CRUZ, I., FIGUEIREDO, M.L.C., OLIVEIRA, A.C. and VASCONCELOS, A., 1999. Damage of *Spodoptera frugiperda* (Smith) in different maize genotypes cultivated in soil under three level of aluminium saturation. *International Journal of Pest Management*, vol. 45, no. 4, pp. 293-296. http://dx.doi.org/10.1080/096708799227707.

DAHI, H.F., SALEM, S.A.R., GAMIL, W.E. and MOHAMED, H.O., 2020. Heat requirements for the fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) as a new invasive pest in Egypt. *Egyptian Academic Journal of Biological Sciences*, vol. 13, no. 4, pp. 73-85. http://dx.doi.org/10.21608/eajbsa.2020.120603.

DENT, D., 1991. *Insect pest management*. Wallingford: CAB International. Natural enemies, pp. 295-372.

EL-RASOUL, A.A.E.Y., SHEHAB, S.M.H. and MAGHRABY, H.E.S., 2020. Trends and decomposition growth analysis of the most important cereal crops in Egypt. *Munich Personal RePEc Archive*, no. 100231, pp. 1-10.

FERNÁNDEZ, J.L., 2002. Estimación de umbrales económicos para *Spodoptera frugiperda* (JE Smith) (Lep.: Noctuidae) en el cultivo del maíz. *Investigaciones Agrarias: Producción y Protección Vegetales*, vol. 17, pp. 467-474.

FISHER, R.A., 1950. *Statistical methods for research workers*. 12th ed. Edinburgh: Oliver and Boyd Ltd., 518 p.

GOERGEN, G., KUMAR, P.L., SANKUNG, S.B., TOGOLA, A. and TAMO, M., 2016. First report of outbreaks of the fall armyworm *Spodoptera frugiperda* (JE Smith) (Lepidoptera, Noctuidae), a new alien invasive pest in west and central Africa. *PLoS One*, vol. 11, no. 10, e0165632. http://dx.doi.org/10.1371/journal.pone.0165632. PMid:27788251.

GROSS JUNIOR, H.R., YOUNG, J.R. and WISEMAN, B.R., 1982. Relative susceptibility of a summer planted dent and tropical flint corn variety to whorl stage damage by the fall armyworm (Lepidoptera: noctuidae). *Journal of Economic Entomology*, vol. 75, no. 6, pp. 1153-1156. http://dx.doi.org/10.1093/jee/75.6.1153.

GUO, J.F., ZHANG, M.D., GAO, Z.P., WANG, D.J., HE, K.L. and WANG, Z.Y., 2021. Comparison of larval performance and oviposition preference of *Spodoptera frugiperda* among three host plants: potential risks to potato and tobacco crops. *Insect Science*, vol. 28, no. 3, pp. 602-610. http://dx.doi.org/10.1111/1744-7917.12830. PMid:32515103.

JARAMILLO-BARRIOS, C.I., BARRAGÁN-QUIJANO, E. and MONJE-ANDRADE, B., 2019. Populations of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) cause significant damage to genetically modified corn crops. *Revista Facultad Nacional de Agronomía*, vol. 72, no. 3, pp. 8953-8962. http://dx.doi.org/10.15446/rfnam.v72n3.75730.

LAMB, R.J., 1992. Developmental rate of *Acyrthosiphon pisum* (Homoptera: Aphididae) at low temperatures: implications for estimating rate parameters for insects. *Environmental Entomology*, vol. 21, no. 1, pp. 10-19. http://dx.doi.org/10.1093/ee/21.1.10.

MA, J., WANG, Y.P., WU, M.F., GAO, B., LIU, J., LEE, G.S., OTUKA, A. and HU, G., 2019. High risk of the fall armyworm invading Japan and the Korean Peninsula via overseas migration. *Journal of Applied Entomology*, vol. 143, no. 9, pp. 911-920. http://dx.doi.org/10.1111/jen.12679.

MOHAMED, G.S., ALLAM, R.O.H., MOHAMED, H.A. and BAKRY, M.M.S., 2021. Impact of certain weather factors and plant ages on population density of Aphis craccivora (Koch) on faba bean plants in Luxor Governorate, Egypt. *International Journal of Agricultural Sciences*, vol. 3, no. 4, pp. 84-104.

MONTEZANO, D.G., SPECHT, A., SOSA-GOMEZ, D.R., ROQUE-SPECHT, V.F., SOUSA-SILVA, J.C., PAULA-MORAES, S.V., PETERSON, J.A. and HUNT, T.E., 2018. Host plants of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in the Americas. *African Entomology*, vol. 26, no. 2, pp. 286-300. http://dx.doi.org/10.4001/003.026.0286.

MURÚA, M.G., JUÁREZ, M.L., PRIETO, S., GASTAMINZA, G. and WILLINK, E., 2009. Distribución temporal y espacial de poblaciones larvarias de *Spodoptera frugiperda* (Smith) (Lepidóptera: Noctuidae) en diferentes hospederos en provincias del norte de la Argentina. *Revista Industrial y Agrícola de Tucumán*, vol. 86, no. 1, pp. 25-36.

NAEEM, M., 1996. *Responses of aphids and their natural enemies to a silvorable agroforestry environment*. Leeds: Leeds University, 272 p. Ph. D. Thesis.

OVERTON, K., MAINO, J.L., DAY, R., UMINA, P.A., BETT, B., CARNOVALE, D., EKESI, S., MEAGHER, R. and REYNOLDS, O.L., 2021. Global crop impacts, yield losses and action thresholds for fall armyworm (*Spodoptera frugiperda*): a review. *Crop Protection*, vol. 145, p. 105641. http://dx.doi.org/10.1016/j.cropro.2021.105641.

PARAMESHWARI, D., PAZHANISAMY, M. and MURALIKRISHNAN, L., 2021. Influence of weather parameters on population dynamics of fall armyworm *Spodoptera frugiperda* (J. E. Smith) on maize. *International Journal of Entomological Research*, vol. 6, no. 6, pp. 87-90.

PERRINGS, C., DEHNEN-SCHMUTZ, K., TOUZA, J. and WILLIAMSON, M., 2005. How to manage biological invasions under globalization. *Trends in Ecology & Evolution*, vol. 20, no. 5, pp. 212-215. http://dx.doi.org/10.1016/j.tree.2005.02.011. PMid:16701371.

RWOMUSHANA, I., 2020 [viewed October 2020]. *Spodoptera frugiperda (invasive species compendium)*. CAB International. Available from: http://www.cabi.org/isc

SISAY, B., TEFERA, T., WAKGARI, M., AYALEW, G. and MENDESIL, E., 2019. The efficacy of selected synthetic insecticides and botanicals against fall armyworm, *Spodoptera frugiperda*, in maize. *Insects*, vol. 10, no. 2, p. 45. http://dx.doi.org/10.3390/insects10020045. PMid:30717302.

SMITH, I.M., MCNAMARA, D.G., SCOTT, P.R. and HOLDERNESS, M., 1997. *Quarantine pests for Europe*. 2nd ed. Wallingford: CABI/EPPO. Spodoptera frugiperda, p. 1425.

SPSS PROGRAM SOFTWARE, 1999. *SPSS base 9.0 user's guide* [software]. Chicago: SPSS.

SUPARTHA, I.W., SUSILA, I.W., SUNARI, A.A.A.A.S., MAHAPUTRA, I.G.F., YUDHA, I.K.W. and WIRADANA, P.A., 2021. Damage characteristics and distribution patterns of invasive pest, *Spodoptera frugiperda* (J.E Smith) (Lepidoptera: Noctuidae) on maize crop in Bali, Indonesia. *Biodiversitas*, vol. 22, no. 6, pp. 3378-3389. http://dx.doi.org/10.13057/biodiv/d220645.

TENDENG, E., LABOU, B., DIATTE, M., DJIBA, S. and DIARRA, K., 2019. The fall armyworm *Spodoptera frugiperda* (J.E. Smith), a new pest of maize in Africa: biology and first native natural enemies detected. *International Journal of Biological and Chemical Sciences*, vol. 13, no. 2, pp. 1011-1026. http://dx.doi.org/10.4314/ijbcs.v13i2.35.

TEPA-YOTTO, G.T., TONNANG, H.E.Z, GOERGEN, G., SUBRAMANIAN, S., KIMATHI, E., ABDEL-RAHMAN, E.M., FLØ, D., THUNES, K.H., FIABOE, K.K.M., NIASSY, S., BRUCE, A., MOHAMED, S.A., TAMÒ, M., EKESI, S. and SÆTHRE, M.G., 2021. Global habitat suitability of Spodoptera frugiperda (JE Smith)(Lepidoptera, Noctuidae): key parasitoids considered for its biological control. *Insects*, vol. 12, no. 4, p. 273. http://dx.doi.org/10.3390/insects12040273. PMid:33804807.

VALDEZ-TORRES, J.B., SOTO-LANDEROS, F., OSUNA-ENCISO, T. and BÁEZ-SAÑUDO, M.A., 2012. Modelos de predicción fenológica para maíz blanco (Zea mays L.) y gusano cogollero (*Spodoptera frugiperda* JE Smith). *Agrociencia*, vol. 46, no. 4, pp. 399-410.

VARELLA, A.C., MENEZES-NETTO, A.C., ALONSO, J.D.S., CAIXETA, D.F., PETERSON, R.K.D. and FERNANDES, O.A., 2015. Mortality dynamics of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) immatures in corn. *PLoS One*, vol. 10, no. 6, e0130437. http://dx.doi.org/10.1371/journal.pone.0130437. PMid:26098422.

WATSON, G.W. and MIFSUD, D., 2017. Invasive mealybugs (Hemiptera: Pseudococcidae) and the threats they present to Mediterranean countries. *Bulletin of the Entomological Society of Malta*, vol. 9, pp. 34-35.

WILLIAMS, I.S. and DIXON, A.F.G., 2007. Life cycles and polymorphism. In: H.F. VAN EMDEN and R. HARRINGTON, eds. *Aphids as crop pests*. Wallingford: CAB International, pp. 69-85. http://dx.doi.org/10.1079/9780851998190.0069.

WILLINK, E., COSTILLA, M. and OSORES, V., 1993. Daños, pérdidas y nivel de daño económico de *Spodoptera frugiperda* (Lep., Noctuidae) en maíz. *Revista Industrial Agrícola*, vol. 70, pp. 49-50.

WOIWOD, I., 1997. Detecting the effects of climate change on Lepidoptera. *Journal of Insect Conservation*, vol. 1, no. 3, pp. 149-158. http://dx.doi.org/10.1023/A:1018451613970.