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Research Article

Biology and nutritional indices of the fall armyworm *Spodoptera frugiperda* fed on five Egyptian host plants as a new invasive insect pest in Egypt

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Abstract: In this study, the effect of five host plants on the biology and food consumption of the fall armyworm *Spodoptera frugiperda* (Smith) (Lepidoptera: Noctuidae) was evaluated in Egypt. Developmental periods and weight of different growth stages, percentages of pupation and adult emergence, survival, and nutritional indices were evaluated on maize, castor oil, clover, broad bean, and lettuce. The results showed that the developmental period of *S. frugiperda* was significantly longer on the broad bean. The pupation percentage of *S. frugiperda* was significantly affected by the host plant. In contrast, the adult emergence was not significantly different on host plants. Our result also showed maximum weights in food consumption, and frass occurred in the larvae fed on lettuce. While the lowest weights for consumption were observed in larvae on maize and broad bean resulting in minimum frass weights. The highest percentage of approximate digestibility (AD) of the larvae was on broad bean and clover, and the lowest AD was by larvae fed on maize. The highest percentages of conversion of ingested food (ECI) and conversion of digested food (ECD) were observed for larvae fed on maize leaves. The lowest values of ECI and ECD were observed on larvae fed on broad bean leaves. Based on the results, it seems that lettuce, castor, and maize were preferred for *S. frugiperda*.

Keywords: fall armyworm, maize leaves, host plants, life history, food utilization

Introduction

The fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) is major insect pest for several field crops with more than 80 host plants, causing major damage to maize, rice, sorghum, sugarcane and also other vegetable crops and cotton (Murúa *et al.,* 2006; Prasanna *et al.,* 2018). Recently, it has become the main pest for cereal crops, mainly maize, in tropical and subtropical regions of the Americas and most African countries (Day *et al.,* 2017). This pest was first encountered in Egypt, on May 2019, in a maize field in Aswan Governorate, Upper Egypt, and is now distributed in some other Egyptian governorates (Dahi *et al.,* 2020; Gamil, 2020). Young larvae feed on epidermal leaf tissue and cause holes in plant leaves, which is the typical damage symptom of this insect pest. However, large larvae of *S. frugiperda*

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consume foliage. Larvae may cause death to young plants after feeding on these plants (Abrahams *et al.,* 2017; Capinera, 2017). The larvae of fall armyworms can attack corn crops from the vegetative to the generative phase. Still, in the vegetative phase, the level of damage by *S. frugiperda* attacks is higher than in the generative phase (Prasanna *et al.,* 2018). Damage to corncobs and leaves resulted in significant yield losses, as happened in Honduras, resulting in a yield loss of up to 40%, in Argentina by 72%, and in Africa from 21-53% (Day *et al.,* 2017).

Spodoptera frugiperda prefers maize crop but is a polyphagous insect pest considered a generalist feeder, feeding on a wide range of plants in several families (Andrews, 1980; Marenco *et al.,*1992; Cruz *et al.,* 1999). This insect pest could turn out to be a potential threat to most economic crops in Egypt. However, no information is available on the biology, food consumption, and utilization of *S. frugiperda* in different Egyptian economic plants. Hence, the present study aimed to know the *S. frugiperda* larvae's quantified consumption rate of some host plants grown in Egypt, namely; maize *Zea mays*, castor oil *Ricinus communis*, clover *Trifolium alexandrium*, broad bean *Vicia faba* and lettuce *Lactuca sativa* and to determine food utilization and the various biological characteristics of *S. frugiperda*. This knowledge may help better planning for the integrated pest management of *S. frugiperda* in both the main and alternate host plants.

Materials and Methods

Insect rearing

Larvae of *S. frugiperda* from the maize fields were initially reared in Ash Sharqia Governorate, Egypt. The larvae were reared on maize leaves, and the pupae obtained were kept to adult emergence. Healthy adult males and females were selected from cultures and allowed to lay eggs in plastic containers with the neonate larvae fed on fresh leaves of maize (cv. High Tec. 2031), castor oil (cv. Hindi 21), clover (cv. Giza 6), broad bean (cv. Sakha 1) and lettuce (cv. Baladi) under laboratory conditions (28 ± 1 ºC, 65 ± 5% relative humidity (RH) and 12L: 12D h photoperiod).

Biology of *S. frugiperda* on five host plants

The insect was reared on the host mentioned above plants for several generations to study the effect of host plants on the biology of S. frugiperda. Ten individual newly hatched larvae at five replicates (a total of 50 larvae per treatment) were fed on the five host plants, and the larvae were examined daily. Therefore, the developmental periods, weight of larvae and pupae, pupation, and adult emergence were recorded.

Food consumption and utilization of *S. frugiperda*

The selected neonate larvae were reared on the same host plants till they turned to the third instar, and every larva was individually placed in a plastic cage (4 × 4 cm) covered with muslins with one mature and fresh leaf. Twenty-five larvae at five replicates were used for each host plant (five treatments × five replicates). As a control, fresh leaves of each treatment were kept in clean jars without larvae, under the same conditions, to determine the natural loss of moisture, which was used for calculating the corrected weight of the consumed leaves. After 24 h, the frass was removed from the leaves and weighed, and the remaining leaves were weighed again. The plastic cage was cleaned, and the newly weighed leaves were given to the larvae. The amount of food consumed by each larval instar from (3^{rd} to 6^{th}) was determined by subtracting the weight of the leftover food from the weight of the food introduced. These procedures were carried out daily for each replicate until feeding ceased in pupation. The following food consumption, digestion, and utilization indices were calculated on a fresh weight basis according to Waldbauer formulas (Waldbauer, 1968):

Consumption index (CI) = E / [T x A]
Growth rate (GR) = P/ [T x A]
Approximate digestibility (AD) = [(E-F)/E] x 100

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Efficiency of conversion of ingested food to body tissue (ECI) = (P/E) x 100
Efficiency of conversion of digested food to body tissue (ECD) = [P/ (E-F)] x 100
Where E = weight of food consumed, T = duration of the feeding period,
A = mean weight of the larvae during the feeding period,
P = weight gain of the larvae, F = frass weight during the feeding period.

Data analysis

Statistical analysis was conducted using the software SPSS 21.0 (SPSS, Chicago, IL, USA). The percentages of pupation, adult emergence, survival, and utilization parameters, including approximate digestibility (AD), conversion of ingested food (ECI), and conversion of digested food (ECD), were arcsine transformed before analysis. All data were submitted to one-way analysis of variance (ANOVA). Mean separations were performed by Tukey's HSD test at a significance level ($P < 0.05$).

Results

Effect of host plants on the biology of *S. frugiperda*

The effect of different host plants on the life history of *S. frugiperda* is shown in Table 1. Our results demonstrated that the developmental periods of larvae, prepupae, pupae, and adult longevity were affected significantly by the different host plants, wherein on the broad bean, the larval duration was more prolonged (22.6 ± 0.2 days) than other host plants. The pupation percentages of *S. frugiperda* were significantly affected by the host plant. The highest pupation percentage was on castor leaves. The adult emergence was not significantly different on various host plants.

On the other hand, the results in Table 2 showed that host plants significantly influenced the larval and pupal weight. The results indicated that the larval instars weight, 3rd to 5th, differed significantly on different host plants. However, host plants did not affect the last instar larval weights. Moreover, the lowest prepupal and pupal weights were evaluated on maize.

Consumption and frass weight of *S. frugiperda* larvae

The data in Table 3 shows that the food consumption and frass weight of different larval instars of *S. frugiperda* were significantly different on host plants. The highest weight in food consumption occurred in the larvae fed on lettuce (1357.0 ± 83.36 mg), and the lowest weight was observed in larvae fed on maize (516.40 ± 29.17 mg) (F = 42.58; df = 4, 20; $P < 0.01$). The same trend was obtained in frass weight produced by *S. frugiperda* larvae on lettuce, resulting in a maximum weight of frass (572.10 ± 20.0 mg), and broad bean resulted in minimum frass weight (106.30 ± 3.95 mg) (F = 25.41; df = 4, 20; $P < 0.01$).

Table 1 Effect of five Egyptian host plants on the biology of *Spodoptera frugiperda*.

Host plants	Larval Duration (day)	Pre-pupae period (day)	Pupal period (day)	Longevity of adults (day)	Pupation (%)	Adult emergence (%)	Survival (%)
Maize	16.4 ± 0.2b	1.4 ± 0.2a	11.6 ± 0.7a	13.2 ± 0.6a	79.0 ± 7.5ab	87.5 ± 7.3a	69.0 ± 4.9ab
Castor	17.2 ± 0.3b	1.8 ± 0.2a	12.2 ± 0.4a	14.4 ± 0.6a	87.9 ± 9.0a	94.9 ± 4.8a	84.1 ± 8.5a
Clover	16.8 ± 0.5b	1.8 ± 0.2a	11.8 ± 0.4a	13.6 ± 0.7a	80.0 ± 4.0ab	80.0 ± 5.0a	64.0 ± 4.0ab
Broad bean	22.6 ± 0.2a	2.2 ± 0.1a	12.2 ± 0.4a	14.8 ± 0.3a	56.0 ± 5.5c	83.0 ± 9.7a	47.0 ± 9.0b
Lettuce	16.2 ± 0.4b	1.6 ± 0.2a	12.0 ± 0.4a	13.2 ± 0.4a	64.0 ± 7.5bc	83.3 ± 10.5a	56.0 ± 11.6ab
F	56.5	2.04	0.315	1.71	7.8	0.4	3.7
P	< 0.01	0.126	0.865	0.19	< 0.01	0.82	0.021

Mean values in each column with different letter(s) are significantly different (Tukey's HSD test, $P < 0.05$)

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Table 2 Effect of five Egyptian host plants on the weight of immature stages of *Spodoptera frugiperda*.

Host plants	Larval instars weight (mg ± SE)				Pre pupae Weight (mg)	Pupae Weight (mg)
	Third instar larvae	Fourth instar larvae	Fifth instar larvae	Sixth instar larvae		
Maize	12.93 ± 0.53a	35.5 ± 1.12bc	181.56 ± 6.95a	307.63 ± 15.66a	198.80 ± 4.67b	165.80 ± 8.71b
Castor	13.52 ± 0.81a	54.93 ± 8.50ab	169.80 ± 20.57a	329.06 ± 14.90a	252.80 ± 17.20ab	229.60 ± 17.47a
Clover	14.27 ± 0.19a	62.20 ± 6.39a	204.70 ± 18.16a	331.43 ± 18.29a	260.00 ± 11.71a	202.60 ± 2.87ab
Broad bean	7.33 ± 0.18b	23.65 ± 1.70c	90.54 ± 9.95b	316.22 ± 23.40a	214.50 ± 19.29ab	193.75 ± 10.89ab
Lettuce	12.17 ± 1.92a	69.17 ± 7.52a	174.26 ± 8.08a	348.30 ± 13.94a	229.60 ± 10.03ab	192.20 ± 10.58ab
F	8.00	10.33	9.68	0.784	3.51	4.22
P	< 0.01	< 0.01	< 0.01	0.55	0.03	0.01

Mean values in each column with different letter(s) are significantly different (Tukey's HSD test, P < 0.05).

Table 3 Nutritional indices of whole (3rd, to 6th) instars of *Spodoptera frugiperda* on five Egyptian host plants.

Host plants	Nutritional indices (Mean ± SE)							
	E (mg/larva)	F (mg/larva)	P (mg/larva)	Cl	GR (mg/mg/larva)	AD (%) (	ECI (%) ± S. E.)	ECD (%)
Maize	516.40 ± 29.17c	208.90 ± 6.46b	152.23 ± 3.73a	2.79 ± 0.13b	0.59 ± 0.03a	66.38 ± 3.11b	26.05 ± 0.53a	70.59 ± 12.0a
Castor	694.89 ± 61.14bc	136.60 ± 3.69b	162.60 ± 5.82a	2.76 ± 0.19b	0.49 ± 0.03ab	80.74 ± 2.80a	21.20 ± 1.34ab	29.81 ± 4.05b
Clover	594.58 ± 34.08bc	110.40 ± 2.14b	140.10 ± 8.58a	2.87 ± 0.10b	0.44 ± 0.02b	82.86 ± 1.32a	21.49 ± 2.44ab	26.94 ± 3.58b
Broad bean	738.78 ± 18.0b	106.30 ± 3.95b	116.60 ± 2.06b	4.86 ± 0.21a	0.30 ± 0.01c	88.10 ± 2.45a	11.90 ± 0.23c	14.15 ± 0.47b
Lettuce	1357.0 ± 83.36a	572.10 ± 20.0a	173.10 ± 5.10a	4.97 ± 0.34a	0.60 ± 0.04a	68.05 ± 2.71b	16.97 ± 0.71bc	25.19 ± 1.88b
F	42.58	25.41	10.66	29.94	17.56	13.88	16.48	13.2
P	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01

Mean values in each column with different letter(s) are significantly different (Tukey's HSD test, P < 0.05), E = weight of food consumed, F = frass weight during the feeding period, P = weight gain of the larvae.

Weight gain and consumption index of *S. frugiperda* larvae

Data in Table 3 also indicate that weight gain values increased according to the larval age. Our results show that a significant highest weight gain was observed in *S. frugiperda* larvae fed on lettuce (173.10 ± 5.10 mg) and broad bean resulted the lowest weight gain of *S. frugiperda* larvae (116.60 ± 2.06 mg) (F =10.66; df = 4, 20; P < 0.01). While the values of consumption index (Cl) presented in Table 3 indicate that the highest values of Cl for larvae were (4.97 ± 0.34) on lettuce, followed by larvae fed on broad bean (4.86 ± 0.21) (F =29.94; df = 4, 20; P < 0.01) and minimum CI was showed by larvae fed on castor and maize (2.76 ± 0.19 and 2.79 ± 0.13), respectively.

Growth rate and approximate digestibility of *S. frugiperda* larvae

Our results in Table 3 Clearly show that host plants significantly affected the growth rate and approximate digestibility (AD) of larval instars. Significant highest growth rate of *S. frugiperda* larvae was obtained on lettuce and maize (0.60 ± 0.04 and 0.59 ± 0.03 mg/mg/day), and the lowest growth rate of larvae resulted on broad bean (0.30 ± 0.01 mg/mg/day) (F =17.56; df = 4, 20; P < 0.01). Our results also show that the highest percentages of AD were obtained in larvae fed on broad bean (88.10%), followed by clover (82.86%), respectively, and the lowest percentage of AD was given by larvae fed on maize (66.38%) (F = 13.88; df = 4, 20; P < 0.01).

Conversion of ingested food (ECI) and conversion of digested food (ECD) of *S. frugiperda* larvae

ECI and ECD values for *S. frugiperda* larvae reared on different host plant leaves are presented in Table 3. The highest values of ECI and ECD were observed for larvae fed on maize leaves (26.05 and 70.59%), respectively, and the lowest values of ECI and ECD were on broad bean leaves (11.90 and 14.15%) with significant parameters (F = 16.48; df = 4, 20; P < 0.01) and (F = 13.20; df = 4, 20; P < 0.01).

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Discussion

The effect of different host plants on fall armyworm *S. frugiperda* has been reported by several researchers (Sparks,1979; Silva *et al.*, 2017; Montezano *et al.*, 2018; Pinto *et al.*, 2019; Gamil, 2020; Kranthi *et al.*, 2021). However, this is the first study on the biology and nutritional indices of *S. frugiperda* on five Egyptian host plants. Our results showed that the developmental periods of different stages and pupation percentages were affected significantly by the different host plants. The highest pupation and adult emergence percentages were observed on castor leaves and decreased on the broad bean. Similar results were obtained by Débora *et al.* (2017) showed that the pupal duration of *S. frugiperda* was 8.54 days on maize. Silva *et al.* (2017) studied the biology of *S. frugiperda* on host plants (soybean, cotton, maize, wheat, and oat). They found that the larvae fed on wheat showed the shortest developmental period, in contrast, larvae fed on cotton and soybean had longer larval development period. Deshmukh *et al.* (2018) indicated that the developmental period of larvae and pupae of *S. frugiperda* on maize leaves were (15.9 and 10.5 days), respectively. Gamil (2020) observed the pupation and adult emergence percentages on castor oil leaves were (91.2 and 96.0%), respectively. Our results showed that the larvae that fed on broad bean had prolonged larval periods and reduced larval instars weights. An extended developmental duration compensates for a larva to recover when feeding on a low-quality host. This may explain the biological differences resulting from feeding larvae on different host plants (Barros *et al.*, 2010).

Our results showed that the food consumption and frass weight of *S. frugiperda* larvae which fed on five host plants, differed based on the host plant. Maximum weights in consumption and frass occurred in the larvae fed on lettuce, and the lowest weights for consumption were observed in larvae fed on maize, and broad bean, resulting in minimum frass weights. Also, our results indicated that the highest weight gain was observed in *S. frugiperda* larvae fed on lettuce and the lowest weight gain of larvae was on the broad bean. While the highest value of Cl was for larvae fed on lettuce, followed by larvae fed on the broad bean, and minimum CI was given by larvae fed on castor and maize. Similar results were obtained by Silva *et al.* (2017) found that the highest weights in consumption and frass occurred in the case of larvae fed on wheat and oat and resulted in weight gain of larvae fed on their leaves more than maize and soybean. Kranthi *et al.* (2021) found that the highest weight of food consumed and weight gain of third instar larvae of *S. frugiperda* belonged to those fed on artificial diet and maize and concluded that larvae preferred maize and consumed more from their leaves which resulted in higher weight gain. In contrast, though, sorghum was consumed a little less than sugarcane by larvae but resulted in weight gain. These differences in the amount of food consumed and frass weight, weight gain of larvae, and CI may be due to the quality and quantity of host plants which decreased their consumption by the larvae and can be considered as antifeedants or feeding deterrents (Isman, 2002). Our results showed that host plants have an obvious influence on growth rate of larval instars. Significant growth rate of *S. frugiperda* larvae fed on lettuce and maize, and broad bean was in a minimum growth rate of larvae. Similarity, Dwivedi *et al.* (1999) examined the consumption and utilization of ten food plants by *S. litura* larvae and found the growth rate was low on mulberry and tomato and high on castor leaves. Khedr *et al.* (2015) observed the growth rate of fourth instar larvae of *S. littoralis* on castor bean leaves was high, more than on leaves of cotton varieties. Truzi *et al.* (2019) showed that the growth rate of *Helicoverpa armigera* was higher for the diet with a higher protein content, demonstrating that larvae need a greater amount of food to meet their nutritional needs due to the high amount of protein required for their development.

Our results indicated that the parameters of food utilization (AD, ECI, and ECD) were affected significantly by the type of host plant introduced to larvae. The highest percentage of AD of larvae was for those fed on broad bean and clover, and the minimum AD was given by larvae fed on maize. While the highest percentages of ECI and ECD were observed for larvae fed on maize leaves, and

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the lowest values of ECI and ECD were observed for larvae fed on broad bean leaves. Similar results were obtained by Veenstra *et al.* (1995) reported that higher ECI and ECD values were observed for *S. frugiperda* larvae fed on maize leaves. Barcelos *et al.* (2019) observed AD values of *S. frugiperda* fed with different sorghum varieties were low. Pinto *et al*. (2019) reported the same results on some of artificial diets of S. *frugiperda.* Kranthi *et al.* (2021) found that the highest values of (AD, ECI, and ECD) of third-instar larvae of *S. frugiperda* were evaluated on an artificial diet and maize than on sorghum and sugarcane. These parameters of food utilization which represent the percentage of ingested food that is effectively assimilated by the insect, were also higher for the host plants containing a higher content of protein. These protein-rich host plants, such as lettuce and maize in the present study indicated that the amount of food assimilated by the insect was associated with the protein level; therefore, in plants rich in protein, a higher food intake is necessary to satisfy the nutritional needs of the insect (Truzi *et al.*, 2019).

In conclusion, this study provides basic information about the nutritional indices of larval stage of *S. frugiperda*. Moreover, the results obtained from the present study can help better planning for the integrated pest management of S. frugiperda on both main and alternate host plants. Currently, the insect pest is spread to entire maize growing areas of some of Egypt's governorates, such as Aswan, Qena, and Ash Sharqia. Further spreading may occur as the pest is a migratory species.

Conflict of Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Authors' Contributions

Adel A. Al-Ayat: Conceptualization; Main/Subsidiary Researcher, Data Analyzer, Methodologist. Ayman A. M. Atta: Conceptualization; Main/Subsidiary Researcher, Data Analyzer, Methodologist. Hassan A. Gad: Methodologist, Writing-original draft; Writing-review and editing.

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بیولوژی و شاخص‌های تغذیه‌ای *Spodoptera frugiperda* تغذیه شده از پنج گیاه میزبان مصری به‌عنوان یک آفت حشره مهاجم جدید در مصر

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چکیده: در این مطالعه اثر پنج گیاه میزبان روی بیولوژی و شاخص‌های غذایی کرم برگخوار پاییزی *Spodoptera frugiperda* (Lepidoptera: Noctuidae) (Smith) در مصر بررسی شد. وزن مراحل مختلف رشدی، درصد شفیره و ظهور حشرات کامل، میزان بقا و شاخص‌های تغذیه‌ای لارو روی گیاهان ذرت، روغن کرچک، شبدر، لوبیا و کاهو ارزیابی شد. نتایج نشان داد که دوره رشدی *S. frugiperda* در لوبیا به‌طور معنی‌داری طولانی‌تر بود. درصد شفیره *S. frugiperda* به‌طور معنی‌داری تحت تأثیر گیاه میزبان قرار گرفت. در مقابل، ظهور حشرات کامل در گیاهان میزبان تفاوت معنی‌داری نداشت. هم‌چنین بیشترین میزان مصرف غذا و تولید مدفوع در لاروهای تغذیه شده از کاهو رخ داد. درحالی‌که کم‌ترین میزان مصرف غذا و تولید مدفوع روی گیاهان ذرت و لوبیا مشاهده شد. بیشترین درصد هضم نسبی (AD) لاروها روی لوبیا و شبدر و کم‌ترین درصد AD مربوط به لاروهای تغذیه شده از ذرت بود. بیشترین درصد تبدیل غذای خورده شده (ECI) و تبدیل غذای هضم شده (ECD) برای لاروهای تغذیه شده از برگ ذرت مشاهده شد. کم‌ترین مقدار ECI و ECD روی لاروهای تغذیه شده از برگ لوبیا مشاهده شد. براساس نتایج به‌نظر می‌رسد کاهو، کرچک و ذرت برای *S. frugiperda* ارجحیت داشته باشند.

واژگان کلیدی: کرم برگخوار پاییزی، برگ ذرت، گیاهان میزبان، دوره زندگی، استفاده از غذا

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