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Biology, Host Selection Behavior and Growth Indices of Invasive Fall Armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) on Two Host Plants under Laboratory Conditions

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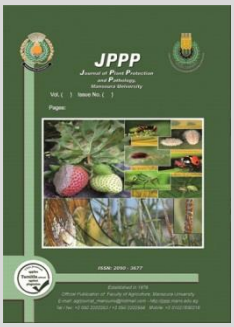

ABSTRACT

The present laboratory study focused on studying the biology of a recent invasive insect pest in Egypt, fall armyworm; *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) on leaves of two host plants, maize and castor bean. This pest species has recently invaded Egyptian fields causing unexpected damage to maize crop, so, biology of *S. frugiperda* was studied under laboratory conditions to estimate its larval instar durations, total larval period, pupal weight, pupal duration, adult emergence%, sex ratio, male and female longevity and fecundity. Obtained results showed that mean incubation period of egg were 2.75 and 3.06 days, while larval durations were 16.26 and 22.03 days and pupal duration lasted 9.93 and 10.40 days, respectively, after rearing on maize and castor bean leaves, respectively. Means of total egg production were 1836.67 and 1562.33 eggs/female by rearing on these two hosts, respectively. Pre-oviposition; oviposition and post-oviposition periods were 3.36, 6.77 and 2.20 days, for females fed during larval stage on maize leaves, opposed to 4.97, 5.80 and 2.50 days when reared on castor bean leaves. Adult longevities were longer by feeding larvae on castor bean leaves than on maize leaves. Also, results indicated that FAW growth indices were higher by feeding on maize leaves than on castor bean leaves. So for rearing *S. frugiperda*, maize leaves may be used as preferred, but castor bean leaves can be also, successfully used in case of the absence of the former host plant.

Keywords: maize, fall armyworm, biology, host preference, growth indices.

INTRODUCTION

Maize (Fam: Poaceae) is a crop of global importance, it has a unique position in world agriculture. Its importance lies in the fact that it is not only used as human and animal food, but at the same time, it is also widely used in corn starch industry, corn oil production, and as baby corn in different recipes. The six major types of maize are dent, flint, pod, popcorn, flour and sweet corn. *S. frugiperda* attacks maize during all plant growth stages (Castro and Pitre, 1988) from seedling up to ear development, starting from the third larval instar onwards, larval feeding causes severe defoliation of leaves as well as the appearance of huge numbers of fecal pellets in whorls (Reddy *et al.*, 2021). Maize growth stages vary in susceptibility to fall armyworm (FAW) attacking, as during the mid-vegetative growth stages, larvae can be found within the whorl of the plant where larval feeding causes tattering of developing leaves. Studies showed that young maize plants are more susceptible to damage by FAW compared to older plants (Buntin, 1986).

Yield losses commonly exceed 30% and it is not uncommon for an entire crop to be lost (Aguirre *et al*., 2016). It could potentially cause from 8.3 million to 20.6 million tonnes of corn yield losses in 12 African countries per annum (if no control methods are applied) Shylesha *et al.*, (2018). Fall armyworm is polyphagous and 247 host plant species have been attacked with preference to Fam: Gramineae plants such as maize, millet, sorghum, sugarcane, rice, wheat, etc. There are reports on its infestation on other field crops like cowpea, groundnut, potato, soybean, cotton, etc. (Perez-Zubiri *et al.*, 2016; Aguirre *et al*., 2016 and Shylesha *et al.*, 2018).

FAW is a native insect pest to the Americas. It first appeared in Africa in January 2016 in Nigeria (Goergen *et al.*, 2016). It was recorded in sub-Saharan Africa, (Abrahams *et al.*, 2017) and in 2017, was also reported for the first time In Senegal by (Brévault *et al.*, 2018) then by the Agricultural Pesticide Committee (APC) of the Ministry of Agriculture in Egypt where the first case was found in a maize field in a village in Kom Ombo city (Aswan Governorate, Upper Egypt) in 2019 then the northern part of Egypt (Rashed *et al.*, 2022). This pest threatens the food security of more than 300 million people in Africa and may cause significant economic losses (FAO, 2018), as its large destructive impact could push 300 million people into hunger in Africa.

Host selection can be described as a series of decisions made by the insect that ultimately lead to the acceptance or rejection of the plant as a host (Rausher, 1983). Host plant selection can be divided into the 'host plant finding' and 'host plant acceptance' phases (Finch and Collier, 2004; 2012).To qualify as a host plant, larvae must accept the plant as a host and must be able to fully develop on the plant when it is used as a food source (Saeed *et al*., 2010; Henniges-Janssen *et al*., 2014). Development and survival of FAW larvae have been found to vary with host plant species. Since different species of host plants play a significant influence in maintaining the continuity of the pest throughout the year (Sharanabasappa *et al.*, 2018).

This present work represents a comparative study of the biology of *Spodoptera frugiperda* on maize as its main

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host plant and castor bean leaves as an economic rearing host under laboratory conditions.

MATERIALS AND METHODS

***Spodoptera frugiperda* rearing**

The culture of FAW was initiated with larvae (F0 generation) collected from maize fields of three regions of Al-Qalyubia Governorate (Tokh, Moshtohor and Shibin El-Qanater) during June- July 2022. This work was carried out at the Plant Protection Department, Faculty of Agriculture, Benha University, Egypt. The collected larvae were, singly, placed in plastic cups and fed on maize leaves as a natural host until pupation. The emerging adults were introduced every 2 moths (one male and one female) into a plastic jars (20*30 cm.) and supplied with a piece of cotton soaked in 10% sugar solution placed in small plastic cups at the bottom of the cages for adult nutrition to be replaced daily with another piece of cotton soaked in sugar solution. Also, a small glass tube containing maize seedlings (15-20 cm. length) for egg laying, finally the cages covered with aerated lids. The maize plants were replaced every day and inspected for egg masses. Eggs were collected and kept in another plastic cup until hatching.

Experimental design of biological studies

Eggs: egg masses were collected daily from the adult cages, to record the egg incubation period and hatchability percentage. The collected eggs were transferred into plastic cups (5 x 5 cm), subsequently; the incubation took place under laboratory conditions of 25±2 ºC and 65±5% RH. Four replicates of 100 eggs/each were used. Observations were made daily to record the incubation period (in days) during this experiment.

Larvae: after egg hatching**,** 20 neonate larvae of (F3 generation) were transferred, each in a separate plastic cup (3x5 cm.) covered with towel paper and containing fresh pieces of maize leaves. Other twenty larvae were reared on castor bean leaves. Larval of the 6th instar were left in the plastic cups containing a thin layer of fine saw-dust (or a piece of towel) until pupation. Food was replaced at two-day intervals. Larval development and duration were estimated on maize and castor bean leaves. Daily observations were made to estimate % of successful pupation and developmental periods.

Pupae: twenty freshly formed pupae (♀ and ♂) were placed, singly, in the plastic cups (3×5 cm.). Cups were covered tightly with muslin pieces. Three replicates (each of 15 pupae) were placed at the same conditions of °C and R.H. and observed daily till the adults' emergence. Pupal duration, pupal weight, malformed pupae, and adults' emergence % were estimated and recorded.

Adult: 15 pairs (♂&♀) of newly emerged adult moths were transferred directly to a large plastic jars and held at the same conditions of temperature and R.H. 15 replicates; each had (one male and one female). Daily observations were made to record the adult survival and the number of laid eggs was recorded/♀. Sex ratio and pre-oviposition, oviposition, and post-oviposition periods, adult longevity and fecundity were recorded.

Growth index:

The growth fitness indices of different FAW stages were calculated according to Pretorius, (1976) and Itoyama *et al*., (1999) formula:

$$\textbf{Larval growth index} = \frac{\textbf{Pupation\%}}{\textbf{larval period (day)}}$$

$$\textbf{Pupal growth index} = \frac{\textbf{Adult emergence\%}}{\textbf{pupal period (day)}}$$

$$\textbf{Standerize growth index} = \frac{\textbf{Pupal weight (mg)}}{\textbf{larval period (day)}}$$

$$\textbf{Fitness index} = \frac{\{\textbf{Pupation \%} * \textbf{pupal weight (mg)}\}}{\textbf{larval period} + \textbf{pupal period (day)}}$$

Host preference:

Presence percentage on different host plants: Fifty 3rd instar larvae were placed into a plastic box (40×50 cm.) with seven host plants were placed on its edges (maize, wheat, castor bean, cabbage, lettuce and spinach leaves, with equal weights). Larvae were released in the middle of the box. Count of larvae on each host plant was noticed and recorded after 30 and 60 minutes to calculate the presence percentage on each host plant.

Feeding capacity and weight gained: Freshly molted 3rd larval instar was placed individually on plastic cups and provided with 2 g. of each host plant leaves and the larvae were weighed before feeding and 24 hours after feeding. Also, the consumption amount of leaves was estimated, and this experiment was replicated 10 times on each host plant.

RESULTS AND DISCUSSION

Effect of two host plants on *S. frugiperda* life stages:

Egg stage

The mean incubation period of *S. frugiperda* eggs was nonsignificantly shorter (2.75 days) after rearing on maize leaves than that reared on castor bean leaves (3.06 days). The hatchability percentages were, significantly, higher (98.0%) after rearing on maize leaves than 92% in the case of rearing on castor bean leaves (Table, 1). Eggs are dorso-ventrally flattened; initially pale green for one day turned to golden yellowish and ultimately turned to black before hatching. Eggs were laid in batches; the mean size of the egg batches were smaller in females reared on maize than that of females reared on castor bean. Egg-masses were covered by scales from those covering the abdomen of female (plate, 1b), the scales cover was denser in the case of rearing on castor bean than maize. In similar studies, Shranabasappa *et al.*, 2018 indicated that the incubation period of *S. frugiperda* ranged between two and three days with a mean of 2.50 days, after rearing on maize. Also, Gamil (2020) mentioned that the hatchability percentage was 97.33 on castor leaves with an incubation period of 2.9 days.

Larval stage

By laboratory rearing, the mean of FAW larval stage duration was significantly longer by feeding on castor bean leaves (22.03±0.24 days) than on maize leaves (16.26±0.23 days). Each FAW larva passed through six instars, lasted (3.38, 2.26, 1.91, 2.00, 2.37 and 4.36 days) for the 1st, 2nd, 3rd, 4th, 5th and 6th instars, respectively, after rearing on maize leaves, opposed to 4.30, 3.17, 2.81, 2.72, 3.78 and 5.25 days, respectively for rearing on castor bean leaves (Table, 1 and Fig. 1). Among the reared larvae, the total larval mortality was 10% after feeding on castor bean leaves, while no mortality occurred when larvae were reared on maize leaves. Shranabasappa *et al*., 2018, indicated that the total larval stage period ranged from 14 to 19 days after rearing on maize leaves. These results agree with those of Gamil (2020) who indicated that the total larval duration was (21.4

days) after rearing on castor bean leaves. But on the contrary, Salem *et al.*, 2021 indicated that the larval duration was not, significantly, different after feeding larvae on maize or castor bean leaves as it was 23.36 and 23.58 days on castor bean and maize, respectively. Also, on similar studies Ramos *et al.*, (2022) recorded the shortest duration of the larval stage of *S. frugiperda* (16.73 days) after rearing on maize comparing with cotton (25.18 days) and castor bean (21.43 days) at 25 ± 2˚C, relative humidity of 60 ± 10 under laboratory conditions.

Statistical analysis shows that the pupal stage, being, slightly, longer 10.40 days after feeding on leaves of castor bean than on maize leaves (9.93 days) (Table, 1 and Fig. 1).

Table 1. Biological aspects of *S. frugiperda* reared on maize or castor bean leaves under laboratory conditions.

Stage	Parameter	Maize	Castor bean
Egg	Incubation period (day)	2.75±0.12^{A}	3.06±0.11^{A}
	Hatchability %	98.00±0.82^{A}	92.00±0.71^{B}
Lava	1st (day)	3.38±0.11^{bB}	4.30±0.13^{bA}
	2nd (day)	2.26±0.07^{cB}	3.17±0.10^{dA}
	3rd (day)	1.91±0.07^{dB}	2.81±0.08^{eA}
	4th (day)	2.00±0.07^{dB}	2.72±0.08^{eA}
	5th (day)	2.37±0.10^{cB}	3.78±0.07^{cA}
	6th (day)	4.36±0.13^{aB}	5.25±0.13^{aA}
	Total larval period (day)	16.26±0.23^{B}	22.03±0.24^{A}
	Mortality % (day)	0.00%	10%
Pupa	Pupal period (day)	9.93±0.30^{A}	10.40±0.32^{A}
	Pupal weight (gram)	0.20±0.00^{B}	0.23±0.01^{A}
	Emergency %	100%	93.33%
	Pupal mortality %	0.00%	6.67%

a, b & c: There is no significant dizfference (P>0.05) between any two means, within the same column have the same superscript letter.
A, B & C: There is no significant difference (P>0.05) between any two means, within the same row have the same superscript letter.

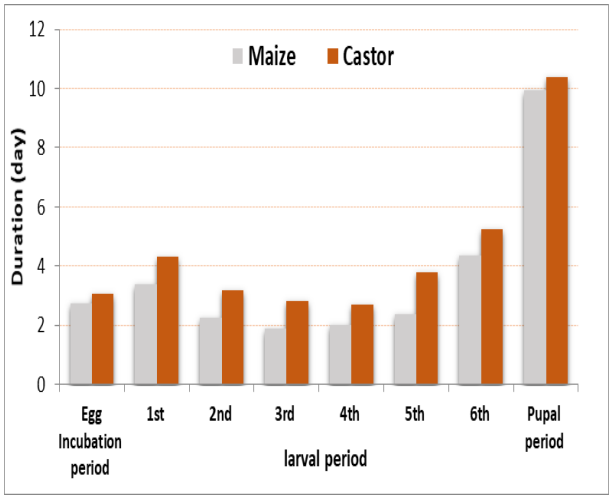

Figure 1. Biological aspects of *S. frugiperda* reared on maize or castor bean leaves under laboratory conditions.

As for the weights of the pupae, they were (0.23 and 0.20 g/pupa) resulting from feeding on castor bean and maize leaves, respectively. On the contrary, the adult emergence rate occurred from pupae by rearing on maize leaves (100 %) opposed to 93.33% after rearing on castor bean leaves. The present results agree with Shranabasappa *et al.*, (2018) who recorded a mean of 10.50 days for the pupal stage duration of *S. frugiperda* reared on maize leaves. Also, Salem *et al.*, (2021) recorded 10.75 and 10.52 days as pupal periods after rearing on maize and castor bean leaves, respectively, the same author recorded, also, heavier pupae (0.274 gm./pupa) from rearing on castor bean and 0.191 g/ pupa by rearing on maize leaves.

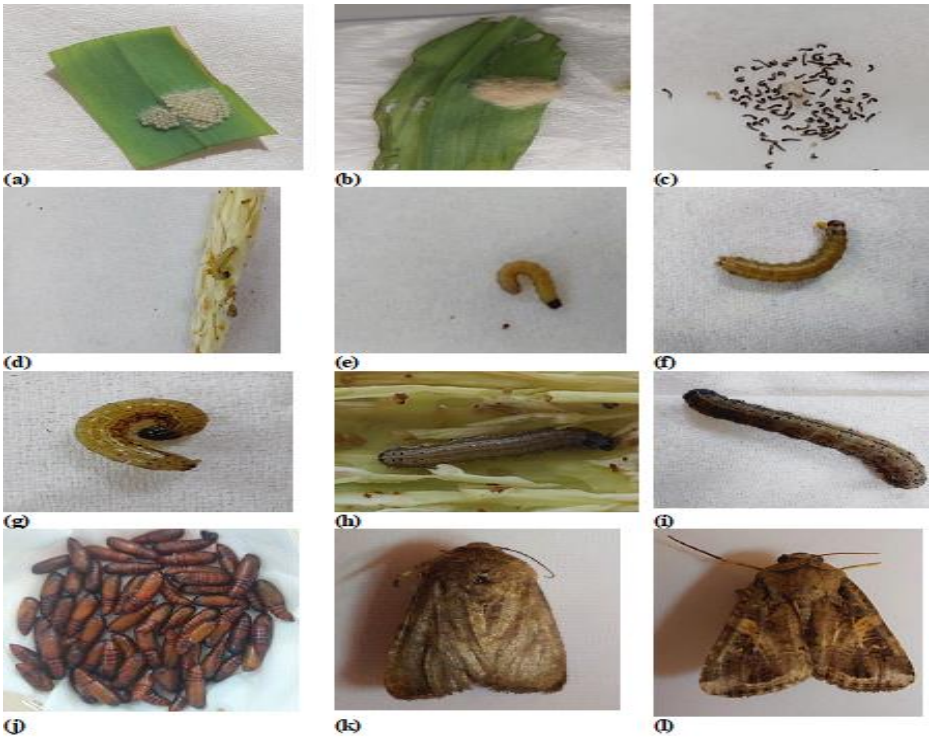

Plate 1. Developmental stages of *Spodoptera frugiperda*; (a) a cluster of eggs laid by females fed on maize, (b) a cluster of eggs laid by females fed on castor bean, (c) neonate larvae of fall armyworm, (d) 1st instar larvae, (e) 2nd instar larva, (f) 3rd instar larva, (g) 4th instar larva, (h) 5th instar larva, (i) 6th instar larva (j) newly formed pupa, (k) adult female and (l) adult male.

Adults' longevity, sex ratio, fecundity and fertility

The sex ratio of *S. frugiperda* was affected by the host plants as it was 1.5 ♀: 1 ♂ after emergence from pupae fed during the larval stage on maize leaves compared to that after feeding on castor bean leaves 1♀: 1 ♂. These results indicated that more female moths were produced by feeding the larvae on maize than on castor bean leaves (Table, 2 and Fig. 2). Pre-oviposition, oviposition and post-oviposition periods recorded 3.36, 6.77 and 2.20 days, respectively, after feeding on maize, opposed to 4.97, 5.80 and 2.50 days, respectively, after feeding on castor bean leaves. Results in (Table, 2) showed that the mean longevity of females and males were 12.33 and 10.67 days, respectively, in rearing on maize, while, those were 13.27 and 12.07 days for males and females, respectively, after rearing on castor leaves, that indicated that females had, generally, a longer longevity than males and, also, that adults' longevity was longer for adults resulted by rearing on castor bean leave than maize (Table, 2 and Fig. 2).

Also, the life span of adults was, generally, longer when feeding on castor leaves (45.70 and 44.50 days) for females and males, respectively, opposed to 38.52 and 36.86 days when feeding on maize leaves. The mean laid eggs was affected significantly by food type during larval stage, being 1836.67egg/♀ for maize leaves and 1562.33egg/♀ for castor bean leaves leave (Table, 2 and Fig. 2). The presented results indicated that maize leaves could be considered as a more favorable food material during larval stage as it led to a longer oviposition period, shorter adult longevity and the highest fecundity compared with those after rearing on castor bean leaves. Also, castor bean leaves can be considered a suitable food source to the fall armyworm larvae as it, successfully, complete their life on it and succeeded in laying fertile eggs (95% emergence). Gamil (2020) demonstrated that the pre-oviposition, oviposition and post-oviposition periods of *S. frugiperda* females reared during their larval stage on castor beans were 3.5, 5.11 and 2.61 days, respectively, with a mean duration of 11.22 days for female and 13 days for male, and recorded that egg productivity reached 1787.5 eggs on castor leaves. Ramos *et al.*, (2022) indicated that the pre- oviposition, oviposition and post-oviposition periods and fecundity (2.11, 4.67, 1.00 days and 663.78 /♀ eggs, respectively) were higher for *S. frugiperda* females originating from larvae fed on maize leaves, than that originated from larvae fed on cotton (3.00, 2.50, 0.90 days and 312.11 egg/♀, respectively) or castor bean leaves (3.70, 2.40, 0.90 days and 216.63 egg/♀).

Table 2. Sex ratio, longevity, fecundity and fertility of *S. frugiperda* adults after rearing larvae on maize and castor leaves under laboratory conditions.

Adult parameters		Maize	Castor bean	LSD at 0.05 for
Sex ratio %		53.33:46.66(1.5♀: 1♂)	50:50(1♀: 1♂)	
Female	Pre-oviposition (day)	3.36 ±0.07^{b}	4.97±0.08^{a}	0.22
	Oviposition (day)	6.77 ±0.14^{a}	5.80±0.14^{b}	0.40
	Post-oviposition (day)	2.20±0.08^{b}	2.50±0.08^{a}	0.24
	Fecundity (eggs/♀)	1836.67±25.45^{a}	1562.33±39.00^{b}	95.37
	Hatchability %	98%	95%	
Longevity	♀ (day)	12.33±0.23^{b}	13.27±0.18^{a}	0.60
	♂ (day)	10.67±0.25^{b}	12.07±0.21^{a}	0.67
Adult longevity (day)		11.50±0.15^{b}	12.60±0.16^{a}	0.44
Total female life span (day)		38.52	45.70	
Total male life span (day)		36.86	44.50	

a, b & c: There is no significant dizfference (P>0.05) between any two means, within the same column have the same superscript letter

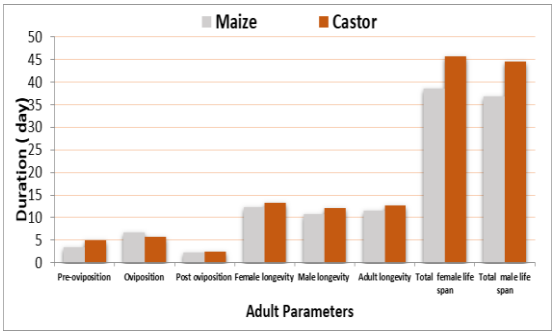

Figure 2. Adult longevity and total life span of fall armyworm on two host plants.

***S. frugiperda* growth rate and fitness index**

The relation between the developmental time and survival rate, depending on food quality, can be expressed in the growth index parameters. The growth index emphasizes the importance of both survival rate and developmental time in measuring the value of food quality. Data in Table, 3 shows that the larval growth index of *S. frugiperda* was higher by feeding on maize leaves (6.150) than castor bean leaves (4.085). Also, the pupal growth index was higher after rearing on maize (10.070) opposed to 8.974 when fed on castor bean leaves. Higher survival rates and shorter developmental durations yield higher values of growth index (Table, 3 and Fig., 3).The standardized and fitness indices were 0.0123 and 0.7636 on maize and 0.014 and 0.638 on castor leaves, respectively.

Table. 3. Effect of two host plants on growth indices and fitness index of *S. frugiperda*.

Host plant	Maize	Castor
Larval growth index	6.150	4.085
Pupal growth index	10.070	8.974
Standardized index	0.0123	0.0104
Fitness index	0.7636	0.6382

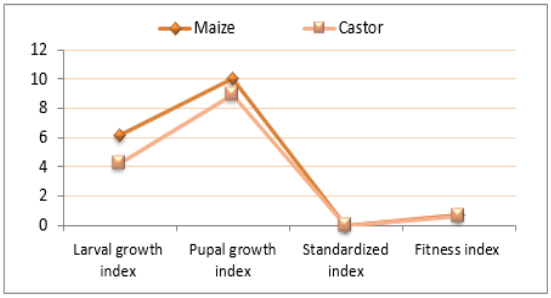

Figure 3. FAW growth and fitness indices parameters.

Host preference

After exposure of seven host plants to 50 *S. frugiperda* 3rd instar larvae and monitoring their orientation to the different hosts after 30 and 60 minutes; the results were as follows; after 30 minutes, 29.33% of the released larvae settled on wheat seedlings, followed by spinach (16.66%), then lettuce (15.33%) and maize (12%) and the lowest rate was recorded on cabbage, radish and castor bean leaves (8 % each). After 60 minutes of release the presence rates of larvae on different hosts were; highest on wheat seedlings (24%), spinach and lettuce (14%), maize, cabbage and castor bean (12% each) and finally radish (8%). Thus, higher attraction was observed to leaves of wheat, being more than maize and castor bean leave (Table, 4 and Fig. 4).

Table 4. Host preference and food consumption of *Spodoptera frugiperda* 3rd instar larvae on different host plants by after 24 hrs. under laboratory conditions.

Host plant	Attraction percentage		Host reduction (g) (After 24 h.)	Increasing in weight (g) after 24 h. of feeding
	After 30 mins. exposure	After 60 mins. Exposure		
Maize	12.00 (++)	12.66(++)	0.911±0.125	0.057±0.013
Wheat	29.33 (+++)	24.00 (+++)	0.844±0.131	0.057±0.007
Spanish	16.66(++)	14.00 (++)	0.312±0.057	0.032±0.006
Cabbage	8.00 (+)	12.00 (++)	0.282±0.007	0.024±0.004
Lettuce	15.33 (++)	14.00(++)	0.336±0.058	0.050±0.015
Radish	8.00 (+)	8.00(+)	0.384±0.384	0.050±0.015
Castor	8.00(+)	12.00 (++)	0.148±0.024	0.043±0.012

(+) range from 1- 10, (++) range from 10-20 and (+++) range from 20-30

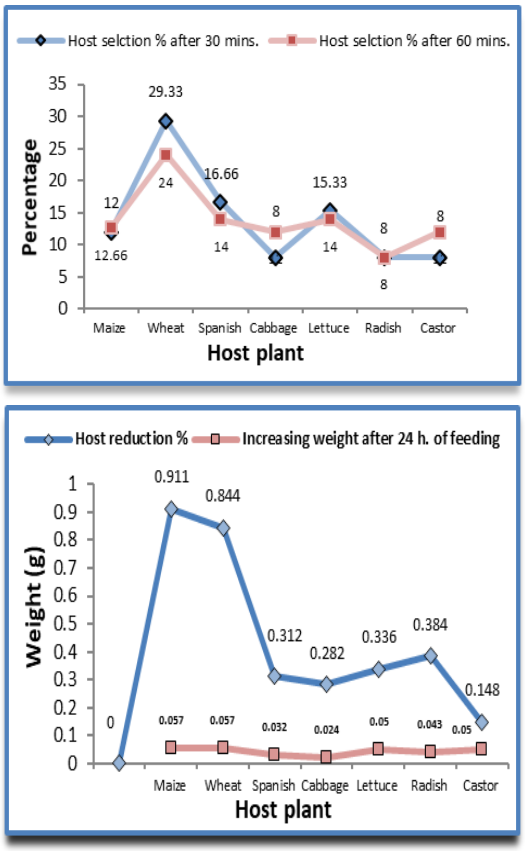

Figure 4. Host selection and host weight reduction on the 3rd larval instar of *S. frugiperda* after 24hs. under laboratory conditions.

Host reduction and larval weight gain after 24 hours of feeding

After providing two grams of each host separately for one 3rd instar larva, consumption of food from different hosts was the highest (0.911g) from maize seedlings, followed by wheat seedlings (0.844 g) and lowest feeding amount was recorded in the case of castor bean leaves (0.148 g). On the other hand, the larval weight gain rate after feeding on each of the seven host plants for 24h. could be arranged descendingly as, 0.057, 0.057, 0.050, 0.050, 0.043, 0.032 and 0.024 g after feeding on maize, wheat, lettuce, castor, radish, spinach and cabbage, respectively. These results indicated that the highest host reduction rate and highest weight increasing rate of larvae was recorded on maize and wheat seedlings.

CONCLUSION

Fall armyworm has been recently the most dangerous pest, in Egypt, on several economically crops; it has a big role in reducing the yield of maize crop, as it feeds on all its growth stages. This study concerned the biology of *S. frugiperda* on two host plant leaves; maize and castor bean. Results of the study concluded that maize is more favorable host to *S. frugiperda* than, castor which also, is an uneconomically host for easier rearing of fall armyworm larval stages. This study concluded that *S. frugiperda* incubation period, total larval period and pupal period were shorter after feeding on maize leaves, while for oviposition period of females where higher when feeding during its larval stage on maize leaves than castor bean leaves with highest female fecundity on maize leaves, these results can be supported by growth and fitness indices which indicated that maize leaves were more suitable than castor bean leaves for rearing *S. frugiperda* under laboratory conditions.

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البيولوجي والتفضيل العوائلي ومؤشرات النمو لدودة الحشد الخريفية الغازية علي عائلين نباتيين تحت ظروف المختبر

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الملخص

تمت هذه الدراسة علي دودة الحشد الخريفية *Spodoptera frugiperda* الغازية لمصرحديثا وتمت تربيتها علي أوراق الذرة و الخروع. غزت هذه الآفة الحقول المصرية وسجلت مؤخرًا في مصر متسببة في خسائر لمحصول الذرة، لذلك تمت دراسة البيولوجي لدودة الحشد الخريفية معمليا لتقدير طول فترة الأعمار اليرقية، مدة طور العذراء، نسبة خروج الحشرات الكاملة، النسبة الجنسية، طول عمر الحشرات الكاملة وعدد البيض الذي تضعة الأنثي علي كل من العائلين النباتيين. و أظهرت نتائج هذه الدراسة أن متوسط طول الأعمار اليرقية كان ١٦,٢٦ و ٢٢,٠٣ يوما بينما استمرت فترة عمر العذراء ٩,٩٣ و ١٠,٤٠ يوما بعد التغذية علي كل من أوراق الذرة والخروع, على التوالي. كما بلغ متوسط عدد البيض الكلي ١٨٣٦,٦٧ و ١٥٦٢,٣٣ بيضة /أنثى بعد التربية على نفس العائلين على التوالي. وكانت فترات وضع البيض أطول للإناث التي تغذت خلال الطور اليرقي على أوراق الذرة من تلك التي تغذت علي أوراق الخروع. و كان طول فترة عمر الحشرات الكاملة أطول عند تغذية اليرقات على أوراق الخروع منها على أوراق الذرة. كما اوضحت النتائج ان مؤشرات نمو دودة الحشد كانت أعلي علي أوراق الذرة منها علي أوراق الخروع مما أكد أن أوراق الذرة كانت أكثر ملاءمة لتغذية يرقات دودة الحشد الخريفية من أوراق الخروع ولكن بمكن أعتبار أوراق الخروع أفضل كعائل إقتصادى معمليا خاصة في حالة غياب العائل الرئيسي.