Relative Feeding Potential and Biology of Fall Armyworm, *Spodoptera frugiperda* Fed on Different Host Plants

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Abstract

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Fall armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) is a polyphagous insect pest causing major losses of corn crop in Pakistan. Biology and feeding potential of *S. frugiperda* was evaluated on three economically important crops including maize, *Zea maize* L. (Poaceae); sorghum, *Sorghum bicolor* L. (Poaceae); and cabbage, *Brassica oleracea* L. (Cruciferae) under laboratory conditions. The findings of this study showed that relative consumption rate (RCR) of *S. frugiperda* was 3.61 mg/mg/day, relative growth rate (RGR) was 0.78 mg/mg/day, the efficiency of conversion of ingested food (ECI) was 31.6%, and approximate digestibility (AD) was 56.46% feeding on maize leaves and was higher compared to other host plants. However, RCR (0.687 mg/mg/day), RGR (0.29 mg/mg/day), ECI (17.5%) and AD (33.96%) values were lower when larvae fed on cabbage leaves. Similarly, large larval instars completed their development faster when they fed on maize leaves. The larval mortality rate was also lower (13.3%) when they fed on maize leaves as compared to sorghum (20.0%) and cabbage (36.7%). Overall, it is concluded that the maize crop was the most suitable host plant for *S. frugiperda* as the growth and development of the insect was higher compared to other host plants in this study. But in the absence of a favored host i.e. maize, it can feed and develop on other hosts such as sorghum and cabbage. Information on the biology and feeding indices of pests could be very useful in developing integrated pest management tactics and improving crop production.

Keywords: *Spodoptera frugiperda*, biology, nutritional indices, insect-plant interaction.

Introduction

The fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) is the most economical and destructive pest of various crops (Clark *et al.*, 2007). It is a voracious pest of agricultural crops native to tropical and subtropical regions of north and south America (Harrison *et al.*, 2019). The corn yield in African countries was reduced by 4.1-17.7 million tons per year due to the feeding of *S. frugiperda* over the expected production of 39.3 million tons annually. The maize production losses alone are expected to be US $13 billion per year after 2018 in sub-Saharan Africa, threatening the survival of millions of poor farmers (Yigezu & Wakgari, 2020). *S. frugiperda* is an invasive pest in west and central Africa where the outbreak occurred for the first time in 2016 (Goergen *et al.*, 2016). Apart from African countries, this pest is well-established in the United States, Mexico, Brazil, and Argentina (Clark *et al.*, 2007; Gutierrez-Moreno *et al.*, 2020). In January 2019, *S. frugiperda* was first reported in Yunnan Province, southwest China, and afterward attacked 26 different provinces except for Xinjiang, Qinghai, and northeastern China (Guo *et al.*, 2020; Jing *et al.*, 2020). So far, *S. frugiperda* has been found in eastern and southern Asian countries (Sun *et al.*, 2020). Now it is a threatening pest in almost 100 countries throughout the world. The occurrence of *S. frugiperda* has been reported in Pakistan during 2019 (Ullah *et al.*, 2019). It is a highly competitive pest due to its characteristic features such as a high reproductive rate, and a short generation time of approximately 30 days in favorable climatic conditions (Casmuz *et al.*, 2010). Around 350 host plants of *S. frugiperda* have been reported belonging to 76 families (Montezano *et al.*, 2018). The most preferred host plant is maize, however, it can feed on other plants in the absence of the preferred host (Wu *et al.*, 2021).

The larval growth, pupae viability, adult emergence rate, and fecundity of *S. frugiperda* may be influenced by larval diet (Goergen *et al.*, 2016). Identifying the suitability of the major field crops in the agricultural system as hosts for *S. frugiperda* is essential for developing preventive measures (Wu *et al.*, 2021). Being a polyphagous pest, *S. frugiperda* may cause damage to certain other fodder crops or vegetables in the absence of maize crop (Wu *et al.*, 2021).

The awareness of pest biology is necessary for ensuring successful and timely control (Cruz *et al.*, 2007; Du Plessis *et al.*, 2020). Host plants may affect the biology of insects in terms of development, survival, reproduction, and longevity (Westbrook *et al.*, 2016). The consumption of host plants by insect pests gives crucial information that directs the activity and preference of pests on various hosts (Slansky, 1990).

As this pest is threatening food security, the study aimed to assess its biology and nutrient indices feeding on maize, sorghum, and cabbage crops which are economically important in Pakistan. *S. frugiperda* has the ability to spread quickly over the continent to attack a wide range of crops,

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produce a large number of eggs, and migrate over long distances. Since the arrival of *S. frugiperda* in Pakistan, few reports, overviews, and guidelines are available. So far, there is no study available on the biology and relative feeding of this pest when feeding on other crops.

Materials and Methods

***Spodoptera frugiperda* culture**

The egg batches of *S. frugiperda* were collected from the maize field (32°08'07.9"N 72°41'14.4"E) from the research station of the College of Agriculture, University of Sargodha. Eggs were placed in clean Petri plates. The culture was maintained in the laboratory under controlled conditions of 25±2ºC and 65% R.H. (Arif *et al*., 2009; Gupta *et al*., 2005). After hatching, newly emerged larvae were provided an artificial diet daily (Sorour *et al.,* 2010). Pupae were placed in separate rearing cages. Adults were released in transparent cages (3x3 square feet) and moist cotton with honey solution (9:1) was placed at the bottom of the cages to feed the adults. A white paper was hung in plastic cages to facilitate oviposition. The F_3 generation was used in further experiments.

Host plants

Three host plants; maize (Poaceae), sorghum (Poaceae), and cabbage (Brassicaceae) were tested in this study. Seeds were purchased from a local market and were sown in plastic pots. No pesticides were applied to the plants. Fresh young leaves of each host plant were collected to feed the *S. frugiperda* larvae.

Feeding indices parameters

Second instar larvae were collected from the reared culture and used in the experiment. Larvae were starved for 24 hr before the experiment. One larva was released into each Petri dishe. The experiment was replicated three times, each replicate consisted of ten larvae, totaling 30 larvae per treatment (host plant). The larval length was recorded daily before and after the feeding of 24 hr using a measuring scale. Similarly, the weight of each larva and its feces was also recorded daily using digital weight balance (Electronic Technology Co., Ltd, Huazhi, Fujian, China). When the larvae were converted into pupae, the pupal weight and length were recorded. The weight of the diet was also recorded before and after 24 h it was provided to larvae. The mortality rate of larvae was also recorded daily. Data for the developmental period of each larval instar, pupa, and adult were also recorded. The following parameters of feeding indices (RGR: Relative growth rate; RCR: Relative consumption rate; ECI: Efficiency of conversion of injested food; AD: Approximate digestibility) were calculated using formulas suggested by Waldbauer *et al.* (1968) and Pinto *et al.* (2019):

$$RGR = \frac{\text{Change in larval dry weight/day}}{\text{Starting larval dry weight}}$$

$$RCR = \frac{\text{Change in diet dry weight/day}}{\text{Starting larval dry weight}}$$

$$ECI = \frac{\text{Dry weight gain of insect}}{\text{Weight of food ingested}} \times 100$$

$$AD = \frac{\text{Dry weight gain of insect - Dry weight of frass}}{\text{Dry weight of food ingested}} \times 100$$

Statistical analysis

One-way analysis of variance (ANOVA) was performed to test the significance of host plants on the developmental biology, and feeding indices parameters of *S. frugiperda*. Means were separated by the least significant difference (LSD) test at $\alpha = 0.05$. All the analyses were performed using SPSS 20.0 software.

Results

Relative consumption rate of *S. frugiperda* was significantly ($F= 803.0$, $P< 0.001$) higher (3.61 mg/mg/day) on maize leaves followed by sorghum (1.83 mg/mg/day). The consumption rate was lower (0.687 mg/mg/day) when larvae fed on cabbage leaves. Relative growth rate of *S. frugiperda* was significantly ($F=499.0$, $P<0.001$) higher (0.78 mg/mg/day) when larvae fed on maize leaves than on sorghum (0.55 mg/mg/day) and cabbage (0.29 mg/mg/day) leaves. Similarly, efficiency of conversion of ingested food of *S. frugiperda* was significantly ($F=759.0$, $P<0.001$) higher (31.6) when fed on maize leaves than on sorghum (23.8) and cabbage (17.5) leaves. In case of approximate digestibility of *S. frugiperda*, a significant ($F=1135.0$, $P<0.001$) difference was found and the values were higher (56.46) when larvae fed on maize leaves compared to sorghum (44.63) and cabbage (33.96) leaved (Figure 1). The results showed that there was no significant ($P>0.05$) difference in the developmental period of immature stages of larvae ($1^{st} – 3^{rd}$) feeding on the three host plants. Fourth instar larvae completed their developmental period (2.6 d) faster on maize as compared to sorghum (3.12 d) and cabbage (4.43 d). Similarly, the 5^{th} and 6^{th} instar larval period was found shorter (2.8 d and 2.9 d, respectively) when they fed on maize crop. Both larval instars took a longer time (4.8 d for 5^{th} and 5.1 d for 6^{th} instar) when they fed on cabbage leaves. The total larval period of *S. frugiperda* was found 16.1 d on maize leaves, 18.06 d on sorghum, and 22.2 d on cabbage leaves (Table 1). The pupal period of *S. frugiperda* was significantly ($F=16.7$, $P<0.001$) higher (19.26 d) when larvae fed on cabbage leaves. However, the pupal period was shorter (12.13 d) when larvae were fed on maize leaves (Table 1). The results also showed that the host plant had a significant ($F= 4.68$, $P< 0.001$) effect on the adult emergence rate of *S. frugiperda*. Adult emergence rate was higher (93.33%) when larvae fed on maize leaves. However, the adult emergence rate was shorter (63.33%) on cabbage leaves (Figure 2). Larval mortality of *S. frugiperda* was significantly ($F=2.47$, $P<0.05$) lower (13.3%) when fed on maize leaves. Higher mortality was recorded (36.67%) when larvae fed on cabbage leaves (Figure 2).

Table 1. Developmental period (days) of *Spodoptera frugiperda* feeding on three host plants.

Host plants	Larval Period (no. of days)							Pupal period
	1st instar	2nd instar	3rd instar	4th instar	5th instar	6th instar	Total larval period	
Maize	2.36 a	2.56 a	2.89 a	2.60 c	2.80 c	2.90 c	16.1 c	12.1 c
Sorghum	2.43 a	2.43 a	3.12 a	3.16 b	3.47 b	3.63 b	18.1 b	16.1 b
Cabbage	2.37 a	2.98 a	3.43 a	4.43 a	4.83 a	5.13 a	22.2 a	19.3 a

Means followed by the same letters in the same column are not significantly different at P=0.05

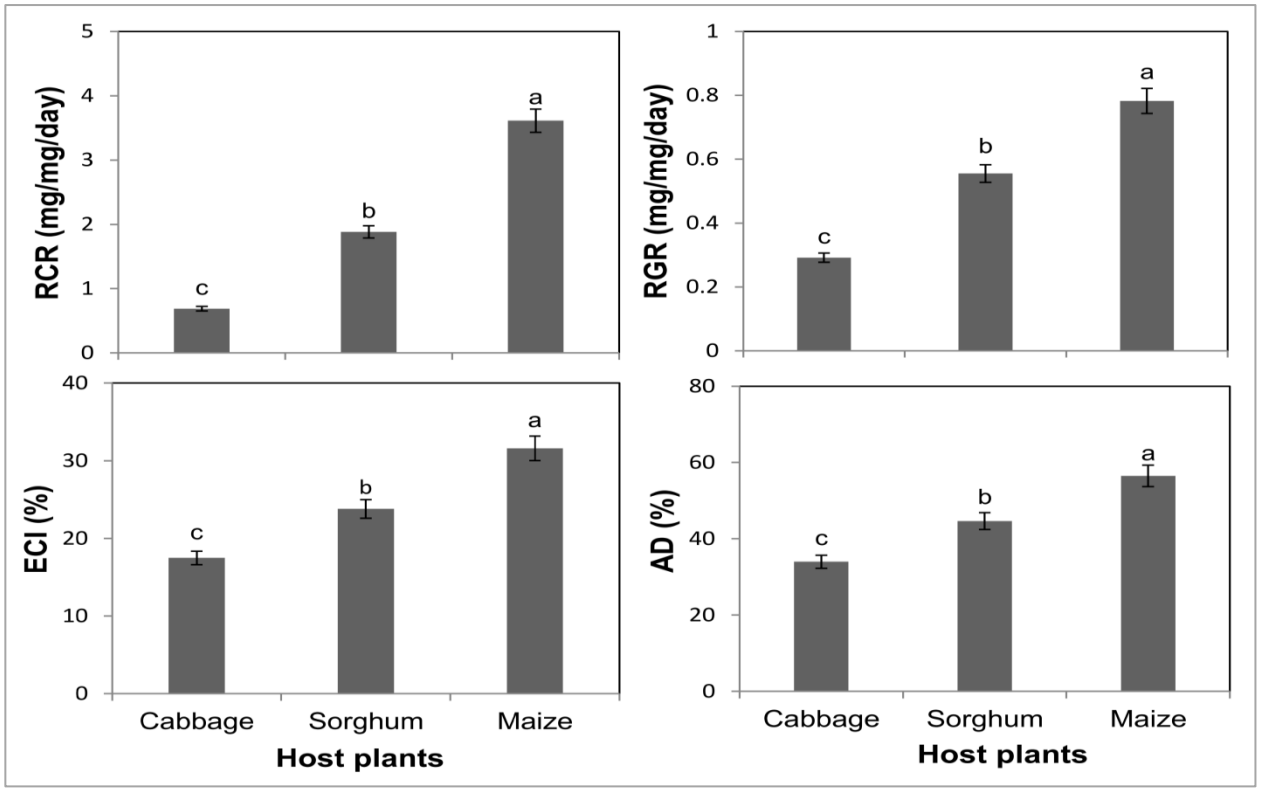

Figure 1. Feeding indices parameters of *Spodoptera frugiperda* feeding on three host plants. RCR = relative consumption rate, ECI = efficiency of conversion of ingested food, RGR = relative growth rate, and AD = approximate digestibility.

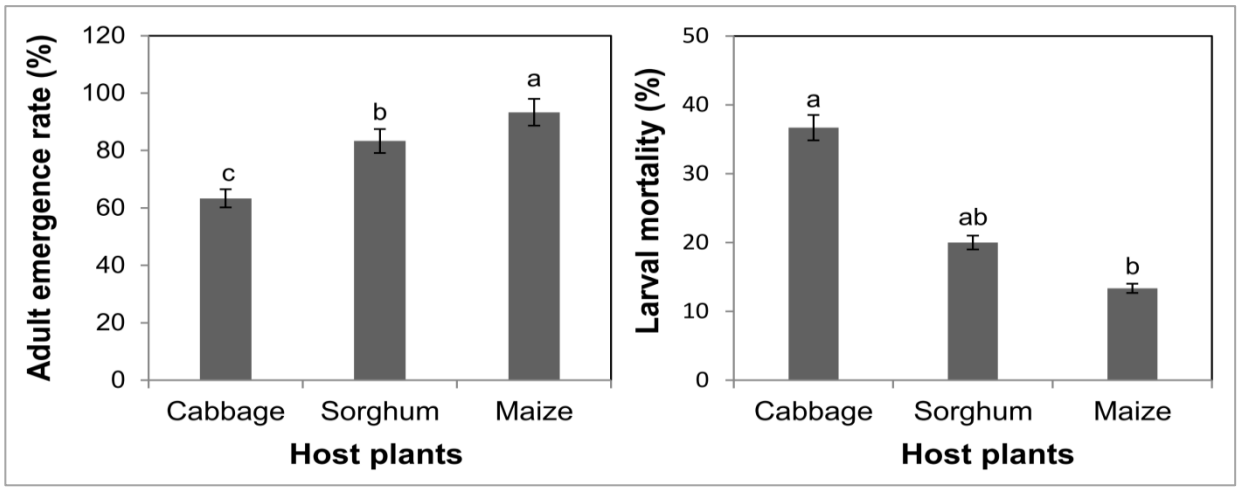

Figure 2. Adult emergence rate (%) and larval mortality (%) of *Spodoptera frugiperda* feeding on three host plants. Means marked with the same letters are not significantly different at P=0.05.

Discussion

The growth and development of insects generally depend on the quality of diet ingested (Barros *et al.,* 2010). Therefore, the survival of insects is strongly related to the selected host plant (Bavaresco *et al.,* 2004; Koussoroplis & Wacker, 2016; McCormick *et al.,* 2019). When the larvae of *S. frugiperda* fed on different host plants, a significant difference occurred in biological parameters. Higher values of feeding indices parameters, shorter developmental period of mature larval instar, higher adult emergence rate, and lower mortality of larvae on maize suggest that *S. frugiperda* develops better on maize than on sorghum and cabbage. According to Sharanabasappa *et al.* (2018), the development of *S. frugiperda* i.e., larval, pupal and adult periods were shorter, and pupae gained maximum weight on maize as compared to other crops. Our findings are supported by previous reports which suggested that *S. frugiperda* development was best on maize (Buntin *et al.,* 1986; Nagoshi *et al.,* 2007). Silva *et al.* (2017) reported that when larvae of *S. frugiperda* fed on cotton, soybean, and maize, larvae life span was reduced and pupae gained higher weight feeding on maize crop which is similar to the results obtained in this study.

Spodoptera frugiperda larvae fed on maize had higher nutritional indices than other hosts, which means larvae after feeding on maize increased their consumption and body mass (Pinto *et al.,* 2019). Maize contained balanced nutrition for insect growth and development, including carbohydrates, amino acids, trace elements, fatty acids, vitamins, and water (Behmer *et al.,* 2009). The feeding indices and growth of the insect body can also be explicated as larval survivorship of *S. frugiperda* was higher on maize leaves. The performance of insects in terms of feeding and developmental period was significantly changed with host plant stress that ultimately affects the survival of herbivores (Galway *et al.,* 2003). Decreased rate of feeding indices parameters may lead to a longer larval life span, delayed larval growth, and smaller pupae development which may affect the fecundity rate and adult longevity (Galway *et al.,* 2003). Accordingly, the ability of insect herbivores to get nutrients from the plant surface will impact their biological development.

The host preference affects the food consumption and utilization of *S. frugiperda* larval growth and development. After feeding on sorghum and cabbage, larvae gained a lower rate of food consumption, feces production, weight, RCR, RGR, and AD, which led to lower efficiency in food assimilation and conversion to body mass (Giongo *et al.,* 2015; Nathan *et al.,* 2005; Slansky *et al.,* 1985). Changes in ECI and ECD fluctuate the conversion of food into body biomass (Abdel-Rahman & Al-Mozini, 2007). In the current study, *S. frugiperda* larvae fed on sorghum and cabbage had lower values of ECI, which showed that transformation of food into biomass was reduced. These findings suggested that cabbage and sorghum leaves have some toxic components that inhibit pest development (Fite *et al.,* 2018). Maximum food availability has a positive and significant impact on insect growth and development, while deficiency in nutrients affects the body mass (Slansky *et al.,* 1985). Our findings are supported with the results of Holmes *et al.* (2020) who reported that food quality affects the growth and development of each insect stage.

Due to the presence of allelochemicals and toxic components in the food, RCR gradually decreased (Scriber & Slansky, 1981). Rapid conversion of food in the digestive tract moderates the interaction of proteolytic enzymes on the food, because of the active toxins in the insect gut (Dinglasan *et al.,* 2009). The increase in larval life span and mortality initiated by poor nutritional values with the presence of toxins in the host plant exposed the pest to natural enemies (Slansky, 1990). Thus, the results of this study are of primary importance to integrated pest management programs, since they can be used as a basis for developing management strategies for *S. frugiperda* in maize.

All feeding indices parameters support the highest consumption index of *S. frugiperda* on maize making it the best host plant as compared to cabbage and sorghum. The larvae of *S. frugiperda* feeding on maize as a highly nutritious diet complete their life span quickly and develop more rapidly than feeding on other host plants (Hwang *et al.,* 2008). Host plants with different nutritional values can affect the growth, survival, and longevity of various stages of the insect that ultimately affect the behavior of insects including migration, and population abundance. Thus, studies related to feeding indices together with biological studies could be useful in understanding the physiology of insects and their relation to the host plants which is critical for any integrated pest management program.

It can be concluded from this study that insect-plant interaction is very important to understand the biology and feeding behavior of insect herbivores. Our findings suggest that maize is a preferred host for *S. frugiperda* as compared to sorghum and cabbage in terms of high feeding indices, short developmental period, and lower mortality of larvae on maize. In another context, *S. frugiperda* can reproduce and successfully survive on all three selected host plants. Studies on the long-term interaction of insects and host plants, like the host plant suitability and plant resistance or tolerance to insect pests, should be investigated further.

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الملخص

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تعدّ دودة الحشد الخريفية (J.E. Smith) *Spodoptera frugiperda* (FAW)، (Lepidoptera: Noctuidae)، آفةً حشرية متعددة العوائل، وتسبّب خسائر كبيرة في محصول الذرة في باكستان. تمّ تقييم حياتية/بيولوجيا *S. frugiperda* وقدرتها على التغذّي على ثلاثة محاصيل مهمّة اقتصادياً شملت الذرة (*Zea maize* L.) والذرة الرفيعة (*Sorghum bicolor* L.) من العائلة النجيلية Poaceae، والملفوف/الكرنب (*Brassica oleracea* L.) من العائلة الصليبية Cruciferae، تحت ظروف المختبر. أظهرت نتائج هذه الدراسة أن معدّل الاستهلاك النسبي (RCR) لـ *S. frugiperda* كان 3.61 مغ/مغ/يوم، ومعدل النمو النسبي (RGR) 0.78 مغ/مغ/يوم، وبلغت كفاءة تحويل الأغذية المبتلعة (ECI) 31.6%، وكانت قابلية الهضم التقريبية (AD) 56.46%، مع تفوّق معدل التغذية على أوراق الذرة مقارنةً بالعوائل النباتية الأخرى. بيد أنّ قيم RCR (0.687 مغ/مغ/يوم)، RGR (0.29 مغ/مغ/يوم)، ECI (17.5%) وAD (33.69%) كانت أدنى عند تغذية اليرقات على أوراق الملفوف. وعلى نحوٍ مشابه، أكملت اليرقات الكبيرة نموها بشكل أسرع عند تغذيتها على أوراق الذرة. كما كان معدل نفوق اليرقات أقلّ (13.3%) عند تغذيتها على أوراق الذرة مقارنة بالذرة الرفيعة (20.0%) والملفوف (36.7%). عموماً، يمكن الاستنتاج بأنّ محصول الذّرة كان أنسب العوائل النباتية لـ *S. frugiperda*، حيث كان معدّل نمو وتطور الحشرة أعلى مقارنة بما هو عليه في العوائل النباتية الأخرى المستخدمة في هذه الدراسة؛ إلّا أنّها في حال غياب العائل المفضل (كالذرة مثلاً) يمكنها أن تتغذى وتتطور على عوائل أخرى مثل الذرة الرفيعة والملفوف. يمكن أن تكون المعلومات المتعلقة بالمؤشرات الحيوية/البيولوجية ومؤشرات تغذية الآفات مفيدةً جداً في تطوير أساليب الإدارة المتكاملة للآفات وتحسين إنتاج المحاصيل.

كلمات مفتاحية: *Spodoptera frugiperda*، حياتية/بيولوجيا، مؤشرات التغذية، تآثر النبات−الحشرة.

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