Artificial Corn-Based Diet for Rearing *Spodoptera frugiperda* (Lepidoptera: Noctuidae)

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Abstract

*Spodoptera frugiperda* (J.E. Smith, 1797) is considered a key pest of maize. However, the artificial diets used for rearing this insect in the laboratory do not contain corn. The aim of this study was to evaluate the biology and to compare the food consumption by *S. frugiperda*, as well as the food preference of the larvae in the standard diet and the corn-based diet. Three of the following diets were evaluated: a standard diet based on beans (D1), a diet with corn flour as substitute for wheat germ (D2), and a diet replacing beans with green corn (D3). The biological parameters evaluated were period and survival of larvae and pupae; weight of male and female pupae; sex ratio; fecundity; egg incubation period; and adult longevity. The nutritional indices were determined and the biological data obtained were used to determine the parameters of fertility life tables; we also performed a multiple-choice test (feeding test). Larval development of *S. frugiperda* occurred in all three diets, although without oviposition by females developed from larval fed on D2. There was no difference among the diets in relation to the fertility life table parameters. The diet D2 resulted in better ingestion, digestion, assimilation, and conversion of food, but was associated with a metabolic cost to assimilate the food. Using a multiple-choice test, we observed that the larvae preferred diet D2. Based on our results, the most adequate diets for rearing *S. frugiperda* in the laboratory are D1 and D3.

Key words: fertility life table, insect biology, nutrition, mass rearing

*Spodoptera frugiperda* (J.E. Smith, 1797) is an insect from the tropics and subtropics of the Americas. It is widely distributed throughout the Americas, mainly in Brazil, the United States, and Argentina (Clark et al. 2007). The species causes severe losses in several crops, especially corn (*Zea mays* L.), soybean (*Glycine max* (L.) Merrill), cotton (*Gossypium hirsutum* L.), and bean (*Phaseolus vulgaris* L.) (Pogue 2002, Nagoshi 2009, Bueno et al. 2011), with a reduction in grain yield of up to 55% and annual losses of US $ 400 million (Figueiredo et al. 2005, Carvalho et al. 2010).

The use of artificial diets to rear insects promotes knowledge about the biology, behavior, and nutritional requirements of insects, and such information is fundamental for the development of efficient integrated pest management programs (IPM). In this context, *S. frugiperda* has been reared under laboratory conditions in a variety of studies (e.g., Silva and Parra 2013). However, experiments focusing on the amounts and proportions of nutrients in larvae diets are still scarce, although food resources may significantly impact insect biology by facilitating or preventing their development or by influencing the adult phase and, consequently, reproductive capacity. Such dietary aspects can be evaluated through indices of food consumption and use (Kogan 1980, Scriber and Slansky Junior 1981, Parra 1991, Panizzi and Parra 2009).

The artificial diet commonly used for the rearing of *S. frugiperda* does not have corn in their composition, which is the main host of this species. Therefore, the use of corn-based diets could enhance consumption and nutrition. Although corn has a lower protein content (7.45%) than beans (20.10%) (Farinelli and Lemos 2010, Alves et al. 2015). Beans are composed of 75% globulins and albumin and are deficient in sulphur amino acids, tryptophan and methionine (Lajolo et al. 1996, Donadel and Prudencio-Ferreira 1999). These amino acids, besides making food more attractive and stimulating, are important in insect fecundity (Panizzi and Parra 2009).

Although several studies have compared the development of *S. frugiperda* using different diets and alternative hosts, there are no studies that relate the use of the fertility life table to food consumption and use, using an artificial diet containing corn as the...
base ingredient. However, such information is important in understanding the basic conditions for growth, development and reproduction, taking into account the quantity and quality of the food ingested, absorbed, and used by insects (Parra 1991).

In this context, the aim of this study was to evaluate the biology and to compare the food consumption and use by *S. frugiperda* larvae, as well as the food preference of the insect on bean-based diet without corn and two corn-based artificial diets.

**Material and Methods**

The rearing of *S. frugiperda* and the experiments were conducted at the Laboratory of Biology and Insect Rearing (LBIR), Department of Plant Protection, São Paulo State University (UNESP), Jaboticabal, SP. The insects were kept under controlled laboratory conditions (temperature of 25 ± 1°C, relative humidity of 70 ± 10%, photoperiod of 12 h light/12 h dark).

**Artificial Diets Evaluated**

The artificial diets that were used in this study are modifications of Nalin (1991). Three formulations were evaluated, namely a standard diet based of beans (*Phaseolus vulgaris* L. var. carioca) used to rear *S. frugiperda* (D1), a diet with the substitution of corn flour for wheat germ (D2), and a diet in which beans were replaced with green corn (fresh corn) providing (D3) to insert each diet with a component of the host plant (corn) of the pest species. The compositions of the diets are described in Table 1. We prepared the vitamin solution using the ingredients and amounts described in Table 2.

**Biological Aspects**

For each diet, 90 newly hatched larvae (<24 h) were selected placed individually in Petri dishes (6 cm diameter × 2 cm height) containing cubes of the diets (2 × 2 cm), replenished when necessary, to observe the larval and pupal periods of the insect. We evaluated the following biological parameters: larval developmental period, larval survival, pupal weight at 24 h, sex ratio of emerged adults, pupal period, pupal survival, and percentage of deformed adults. Individuals with malformations in the wings, legs, abdomen or thorax, as well as difficulty in emergence, were considered deformed when adults were attached to the pupal exuviae.

After the emergence of the adults, five cylindrical PVC cages (10 cm diameter × 20 cm height) were constructed for each diet, lined with a paper sheet, supported on a plastic cover (15 cm diameter × 2 cm height) lined with filter paper, with the top closed with voile fabric fastened with elastic; for each treatment and replicate, where two couples of *S. frugiperda*, which had emerged on the same day, were released. Adults were fed with a 10% honey–water mixture on a piece of soaked cotton packed inside a plastic top (3 cm diameter × 1.5 cm height). We also observed female fecundity (eggs/female) and longevity of male and female adults. The experimental design was completely randomized, with each cage being considered one replicate.

With the biological parameters of *S. frugiperda* obtained in the three artificial diets, the parameters for the construction of fertility life tables were estimated, according to Birch (1948), Silveira Neto et al. (1976), Southwood (1978), and Price (1984), as well as the time required for the population to double in number (Dt), according to Krebs (1994).

**Nutritional Indices**

Newly hatched larvae (<24 h) were kept individually in Petri dishes (6 cm diameter × 2 cm height) containing cubes of the diets (2 × 2 cm), which were replenished (every week). When the larvae reached the fourth-instar stage, 10 insects were removed from the Petri dishes, weighed, killed by freezing, and oven-dried. Another 10 insects were weighed and kept in the Petri dishes; when they reached the fifth instar stage, confirmed by the presence of larval exuviae, the same procedure as described above was performed. In addition, dietary leftovers and excrements from the insects during the fourth instar and 10 whole cubes of each artificial diet (2 × 2 cm) were weighed and oven-dried. The diets, excrements, and larvae stayed in the oven for 3 d until reaching a constant weight and were then weighed.

For determination of the quantitative nutritional indices of fourth instar of the larval stage, the methodology proposed by Waldbauer (1968), modified by Scriber and Slansky Junior (1981), was adopted. For the calculation of these indices, the following parameters were used:

\[ I - F: \text{weight of food consumed} (g) \]
\[ F: \text{weight of excreta produced} (g) \]
\[ Ar: \text{weight of leftover food} (g) \]
\[ T: \text{duration of feeding period} (\text{days}) \]
\[ Af: \text{weight of food supplied to the insect} (g) \]
\[ B: \text{mean weight of larvae} (g) \]
\[ I - F: \text{food assimilated} (g) \]
\[ I - F: \text{food metabolized} (g) \]

**Table 1. Composition of the artificial diets for Spodoptera frugiperda**

| Constituent              | D1       | D2       | D3       |
|--------------------------|----------|----------|----------|
| Bean                     | 240.0 g  | 240.0 g  | -        |
| Green corn               | -        | -        | 60.0 g   |
| Wheat germ               | 120.0 g  | -        | 120.0 g  |
| Corn flour               | -        | 240.0 g  | -        |
| Brewer’s yeast           | 72.0 g   | 72.0 g   | 72.0 g   |
| Ascorbic acid            | 7.3 g    | 7.3 g    | 7.3 g    |
| Sorbic acid              | 2.4 g    | 2.4 g    | 2.4 g    |
| Methyl parahydroxybenzoate (Nipagin) | 4.4 g | 4.4 g | 4.4 g |
| Vitamin solution         | 10.0 ml  | 10.0 ml  | 10.0 ml  |
| Formaldehyde (40%)       | 6.0 ml   | 6.0 ml   | 6.0 ml   |
| Agar                     | 20.0 g   | 20.0 g   | 20.0 g   |
| Distilled water          | 1.000 ml | 1.000 ml | 1.000 ml |

D1—Artificial diet modified from Nalin (1991), used at rearing.

D2—Artificial diet modified from Nalin (1991), with substitution of wheat germ for corn flour.

D3—Artificial diet modified from Nalin (1991), with substitution of beans for green corn.
The indices of food consumption and use were determined using the following equations:

Relative consumption rate (g/g/day) – RCR = \frac{1}{t} 

Relative growth rate (g/g/day) – RGR = \frac{R}{B} \times \frac{1}{t} 

Relative metabolic rate (g/g/day) – RMR = \frac{M}{B} \times \frac{1}{t} 

Approximate digestibility (%) – AD = \frac{100 - ECD}{100} 

Efficiency of conversion of ingested food (%) – ECI = \frac{F}{I} \times 100 

Efficiency of conversion of digested food (%) – ECD = \frac{F}{I} \times 100 

Metabolic cost (%) – CM = 100 – ECD

The experimental design was completely randomized, with each larva being considered one replicate.

**Multiple-Choice Test**

First-instar larvae were submitted to the multiple-choice test (feeding test) in Petri dishes (15.0 cm diameter \times 2.0 cm height) containing one cube of each artificial diet (2 \times 2 cm) arranged equidistantly. In the center of each Petri dish, 10 first-instar larvae of *S. frugiperda* were released, with a subsequent record of the number of attracted insects on each diet cube at five different evaluation intervals (15, 30, 45, 60 min, and 24 h). The experimental design was completely randomized with 15 replications, in which each dish was considered one replicate. The larvae were recorded in each artificial diet if they were present on the diet cube at the respective interval.

**Statistical Analysis**

Frequency data of *S. frugiperda* larvae in each artificial diet, in the multiple-choice test, were analyzed using PROC FREQ and interpreted using the \( \chi^2 \) test \( (P < 0.05) \). Data from nutritional indices met the requirements of the analysis of variance (ANOVA), and their means were compared by Tukey’s test \( (P < 0.05) \). Period and survival data of the larval and pupal periods, fresh and dry weight of larvae, and pupae weight did not meet the requirements for the ANOVA and were thus compared using the Kruskal–Wallis test (PROC NPAR1WAY). Data on sex ratio and fecundity were submitted to ANOVA and compared using the Student–Newman–Keuls test. Adult deformation data were transformed by the root of \( x + 0.5 \) to meet the requirements for the ANOVA and then analysed using the Student–Newman–Keuls test, while the population parameters of the fertility life table were submitted to the Student \( t \)-test \( (P < 0.05) \). All statistical analyses were conducted using the software package SAS (SAS Institute, 2015).

**Results**

**Biological Aspects**

The diets *D*₁ and *D*₃ resulted in a similar development of *S. frugiperda*, with a shorter cycle and a higher pupae weight. The larval periods were 15.6 and 15.3 d, respectively \( (F_{2,173} = 697.93, P < 0.0001) \), while the pupal periods were 11.6 and 11.3 d, respectively \( (F_{2,173} = 253.3 = 258.5 \text{ mg} (F_{2,173} = 175.38, P < 0.0001) \). On the other hand, *D*₂ resulted in a longer larval period \( (34.5 \text{ d}) \), a longer pupal period \( (22.1 \text{ d}) \), and a lower pupae weight \( (156.7 \text{ mg}) \) (Table 3).

The lowest larval survival was observed for *D*₂ (48.0%); survival was similar for *D*₁ and *D*₃ \( (92.0 \text{ and } 94.7\% ) \), respectively \( (F_{2,222} = 40.80, P < 0.0001) \). The lowest survival capacity also occurred in the pupal stage, with 73.4% for *D*₁ and 89.3% for *D*₃, whereas for *D*₂, it was only 22.1% \( (F_{2,222} = 33.90, P < 0.0001) \). The sex ratio was not influenced by the different diets and ranged between 0.39 and 0.56 \( (F_{2,222} = 2.23, P = 0.1103) \) (Table 3).

The highest percentage of adults with deformed wings was obtained for *D*₁ with 64.7%, while the lowest percentages were found for *D*₁ and *D*₃ with 6.4 and 2.9%, respectively \( (F_{2,173} = 70.49, P < 0.0001) \). Except for females of *D*₂, which did not oviposit, fecundity was not affected by the diets, with values between 1,746 and 1,830 eggs/female \( (F_{1,12} = 0.19, P = 0.6714) \) (Table 4).

The number of eggs per female of *S. frugiperda* varied according to longevity. The highest amounts of eggs/female were observed between the 3rd and 5th day of age, reaching approximately 300 eggs/day, with another oviposition peak observed between the 7th and the 11th day, with about 270 eggs/day. As the female approached the end of her life, the number of eggs was reduced (Fig. 1).

The fertility life table parameters were not determined for *D*₂ since under this diet regime, oviposition did not occur. In relation to *D*₁ and *D*₃, there were no significant differences for the development parameters of the insects (Table 5). The average generation time \( (T) \) was 29.1 and 28.8 d for *D*₁ and *D*₃, respectively.

**Table 2.** Composition of the vitamin solution used for artificial diets

| Component     | Amount |
|---------------|--------|
| Niacinamide   | 4.0 mg |
| Calcium pantothenate | 4.0 mg |
| Thiamine HCl  | 1.0 mg |
| Riboflavin    | 2.0 mg |
| Pyridoxine HCl| 1.0 mg |
| Folic acid    | 1.0 mg |
| Biotin        | 0.08 mg|
| Vitamin B12   | 0.008 mg|
| Distilled water| 400 ml |

**Table 3.** Biological characteristics of the larval and pupal stages of *Spodoptera frugiperda* on diets *D*₁, *D*₂, and *D*₃

| Characteristics      | *D*₁       | *D*₂       | *D*₃       |
|----------------------|------------|------------|------------|
| Larval period (days) | 148        | 15.6 ± 0.16b₁ | 34.5 ± 0.91a | 15.3 ± 0.15b |
| Larval survival (%)  | 225        | 92.0 ± 2.49a₁ | 48.0 ± 12.18b | 94.7 ± 2.49a |
| Pupal weight (mg)    | 176        | 253.3 ± 2.94a₁ | 156.7 ± 4.41b | 258.5 ± 3.87a |
| Sex ratio            | 176        | 0.56 ± 0.08a₁  | 0.39 ± 0.07a  | 0.55 ± 0.07a  |
| Pupal period (days)  | 148        | 11.6 ± 0.29b₁  | 22.1 ± 0.59a  | 11.3 ± 0.20b  |
| Pupal survival (%)   | 225        | 73.4 ± 16.99a₁ | 34.7 ± 26.83b | 89.3 ± 7.59a  |

₁Means ± SE followed by the same letter within one line do not differ by the Kruskal–Wallis test \( (P > 0.05) \).

₂Means ± SE followed by the same letter within one line do not differ by the Student–Newman–Keuls test \( (P > 0.05) \).

₃\( N \) = number of individuals used in the analysis.
The net reproduction rate ($R_0$), the intrinsic increase rate ($r_m$) and the finite increase rate ($\lambda$) for $D_1$ were 755.4, 0.235, and 1.265, respectively, while for $D_3$, they were 920.8, 0.236, and 1.266, respectively (Table 5).

**Nutritional Indices**

There was no significant difference between dry ($F_{2,18} = 0.03, P = 0.9679$) and fresh weight ($F_{2,18} = 1.12, P = 0.3487$) of $S. \text{frugiperda}$ fifth-instar larvae fed different diets (Fig. 2).

Regarding nutritional indices, relative consumption rate (RCR) ($F_{2,18} = 6.03, P = 0.0099$), relative growth rate (RGR) ($F_{2,18} = 8.98, P = 0.0020$), relative metabolic rate (RMR) ($F_{2,18} = 6.49, P = 0.0075$), and approximate digestibility (AD) ($F_{2,18} = 32.26, P < 0.0001$) were higher in $D_2$, with values of 4.8 g/g/day, 1.4 g/g/day, 2.2 g/g/day, and 72.8%, respectively (Table 6).

The efficiency of conversion of ingested food (ECI) was similar for all diets, ranging from 28.5 to 31.2% ($F_{2,18} = 0.72, P = 0.4994$). For the efficiency of conversion of digested food (ECD), the highest value was found for $D_3$ (63.6%) and the lowest for $D_2$ (43.6%) ($F_{2,18} = 6.30, P = 0.0084$). In contrast, the metabolic cost (CM) was higher for $D_2$ (56.4%) and lower for $D_3$ (36.3%) ($F_{2,18} = 6.30, P = 0.0084$) (Table 6).

**Discussion**

Diet 1 would be the control treatment because it is the diet normally used for rearing $S. \text{frugiperda}$. The experimental design was performed in this way to test the replacement of the wheat germ by corn flour (diet 2) or to replacement of the bean by green corn in the diet (diet 3) to insert a component of the main host plant of the species.

The development of $S. \text{frugiperda}$ in $D_2$ and $D_3$ was similar to the observations of Giongo et al. (2015), who obtained a larval period of 17.25 d and a pupal weight of 279.51 mg when rearing $S. \text{frugiperda}$ on the diet developed by Greene et al. (1976).

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**Table 4.** Percentages of deformed adults and fecundity of *Spodoptera frugiperda* in diets $D_1$, $D_2$, and $D_3$

| Characteristics | $D_1$ | $D_2$ | $D_3$ |
|----------------|-------|-------|-------|
| Deformations (%) | 6.4 ± 3.09b<sup>1</sup> | 64.7 ± 13.89 a | 2.9 ± 1.77b |
| Fecundity (eggs/female) | 1850.0 ± 214.98a | - | 1746.3 ± 86.23a |

<sup>1</sup>Means ± SE followed by the same letter within one line do not differ by the Student–Newman–Keuls test ($P > 0.05$).

<sup>2</sup>N = number of individuals used in the analysis.

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**Table 5.** Parameters of the fertility life table of *Spodoptera frugiperda* on diets $D_1$ and $D_3$

| Parameters | $D_1$ | $D_3$ |
|------------|-------|-------|
| $R_0$      | 755.4a<sup>1</sup> (640.4–1,270.5) | 920.8a (710.6–1,130.9) |
| $r_m$      | 0.235a (0.209–0.261) | 0.236a (0.208–0.265) |
| $\lambda$  | 1.265a (1.233–1.298) | 1.266a (1.230–1.302) |
| $T$        | 29.1a (26.7–31.6) | 28.8a (25.3–32.4) |
| $D_T$      | 2.9a (2.6–3.3) | 2.9a (2.6–3.3) |

<sup>1</sup>Means (confidence interval at 95%) followed by the same letter within one line do not differ by the Student $t$-test ($P > 0.05$).

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Fig. 1. Numbers of eggs per day and total eggs per female of *Spodoptera frugiperda* in diets $D_1$, $D_2$, and $D_3$.

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Fig. 2. Numbers of eggs per day and total eggs per female of *Spodoptera frugiperda* in diets $D_1$ and $D_3$.
According to Cunha et al. (2008), the nutritional quality of each diet can cause differences in the duration of the larval period of S. frugiperda, and the quantity and quality of the food consumed during this period may alter the biological performance of the insect. Food quality is influenced by physical attributes (hardness, surface pilosity, and shape) that interfere with the insect’s capacity to consume and digest food, as well as with allelochemicals (alkaloids, glucosinates, protein inhibitors, lipids, among others) present in plants and nutritional components, particularly water and nitrogen contents (Panizzi and Parra 2009). Thus, among the evaluated diets, the water contents in D1 and D3 were higher than those in D2, which also presented greater surface stiffness when compared to the other diets; these factors may have impeded the ingestion and consumption of the diet.

Pupae reared on diets D1 and D3 were heavier, which is a good indication, since according to the data obtained by Bernardi et al. (2014), even when larvae are exposed to negative factors, such as plants expressing Bacillus thuringiensis (Berliner 1911) proteins, differences are found between pupal weight and oviposition of S. frugiperda, where the tendency is that the heavier pupae result in females of higher fecundity.

Applying the Benrey and Denno (1997) hypothesis of ‘slow-growth high-mortality’, we observed that both D1 and D3 provided a higher development rate, while D2 promoted a longer development period and a higher mortality, indicating that D2 is not the most adequate diet for the rearing of S. frugiperda.

Regarding the sex ratio, Silva et al. (2017), when evaluating the effects of five hosts and an artificial diet on the development of S. frugiperda, have found sex ratios ranging from 0.37 to 0.54, not verifying the relationship between sex ratio and larval weight, larval period, larval and pupal survival, and pupal weight. In addition, Murúa et al. (2008), carrying out research with populations of
S. frugiperda from different hosts, have observed a sex ratio ranging between 0.35 and 0.54, similar to that found in the present study.

Relative to the adult period, according to Parra (2001), a deficiency in fatty acids (linoleic and linolenic) or the interaction of these acids with temperature, especially when elevated, can result in wing deformation in S. frugiperda. Thus, as the insects were reared in the laboratory under controlled conditions (25 ± 1°C), the deformation observed in the wings may be related to the palmitic, oleic, and linoleic fatty acids present in the diets. Thus, when evaluating the chemical composition of the diets in relation to the amount of modified materials (bean, green corn, wheat germ, and corn flour) (DIS, 2018), that the diets D1 and D2 presented higher amounts of palmitic and linoleic fatty acids (190.4 and 654.4 g; 190.4 and 653.0 g, respectively) and lower amounts of oleic fatty acid (167.3 and 171.7 g, respectively), while D3 contained 108.7 g of palmitic fatty acid, 246.0 g of oleic fatty acid, and 421.2 g of linoleic fatty acid. Thus, the total amounts of these three fatty acids were higher for D1 (1,012.1 g) and D2 (1,015.1 g), relative to D3, which only contained 775.9 g.

The fecundity observed in this study was higher than that found by Muriia et al. (2008), who reported values of 955.05, 885.89, 519.83, 978.10, and 758.89 eggs/female for populations collected in maize, alfalfa, soybean, wheat, and weeds, respectively; the authors also found no positive relationship between longevity and fecundity. Siloto (2002), also in maize genotypes, found values of 1,121.20 to 1,247.86 eggs/female, while Silva Lopes et al. (2008) obtained a mean fecundity of 1,125 eggs/female in cassava leaves (Manihot esculenta Crantz).

All females resulting from larvae evaluated in the three artificial diets were mated. However, the nonoviposition of insects reared on D2 may be related to feeding in the immature stage, in which most Lepidoptera feed heavily in the larval stage, and the adults emerge with practically all the nutrients necessary for reproduction, with feeding acting indirectly in the process of sexual maturation by activating the endocrine system, which may influence oviposition behavior. In addition, for some insects, the ingestion of protein sources is essential for the activation of this endocrine system, being directly related to the production of oocytes (Wheeler 1996, Papaj 2000, Panizzi and Parra 2009). Thus, the reduced feeding observed in the larval phase may have been a determinant for nonoviposition, since in relation to the amount of proteins related to the modified ingredients, D3 and D2 had 49.40 and 49.90 g, respectively, while D1 only had 29.83 g (DIS, 2018).

The value of the protein ingested by insects depends on the content of amino acids and also on how these insects will digest them. Nevertheless, proteins or amino acids are required in high concentrations for the development of insects. Thus, in general, insects need 10 essential amino acids for good growth and development, namely arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine, which play an important role in egg production (Panizzi and Parra 2009).

In addition, the carbohydrate/protein ratio needs to be taken into account (DIS, 2018), and D2 had a higher ratio (5.33) when compared to D1 (2.51) and D3 (2.39). In this sense, it is evident that the ingredients of artificial insect diets must be properly balanced (quantitatively and qualitatively), especially in relation to proteins and carbohydrates.

The variability in the number of eggs per female is most likely due to the quantity and quality of the ingested food; in addition, the fecundity and dispersion of adults may also be affected (Luginibill 1928, Browne 1995). Therefore, the diets D2 and D3 were nutritionally more adequate, emphasizing that the number of eggs placed by insects is determined by oogenesis, in which the physiological process is managed by the availability of nutrients present in the female’s body, which is largely influenced by the food ingested and assimilated during the larval period (Wheeler 1996).

Thus, it is possible to state that the best diets for S. frugiperda larvae were D1 and D2, because they provide high larval and pupal survival, as well as a low percentage of deformed adults. In contrast, Silva Lopes et al. (2008) found a larval survival of 81.66% and a pupal survival of 75.51% for S. frugiperda with larvae fed on cassava leaves, while 22% of the adults showed deformation. According to the authors, this value is relatively high. Based on a study by Fernandes (2003), the verification of nutritional deficiency in artificial diets can also be measured by deformations in pupae and adults.

The average generation time (T) found in this study was similar to those obtained by Rosa et al. (2012) with S. frugiperda on five maize lines (between 21.3 and 45.7 d). The values of the net reproduction rate (R0), the intrinsic increase rate (r0) and the finite increase rate (λ) differed from those obtained by Omoto et al. (2016) in non-Bt maize, who measured 272.0, 0.152, and 1.165, respectively. The best performance of those insects reared with artificial diets may be related to the higher concentration of nutrients, such as protein, in the food resource.

Therefore, according to the parameters of the fertility life table, it was possible to observe that the population increased, being able to double in size (Dt) in approximately 3 d, since the net reproduction rate (R0) was greater than 1, that is, each female generated more than one female. The intrinsic increase rate (r0) was positive, and the finite increase rate (λ) indicates that the number of females in the population increased by more than 1.2 times in each unit of time. This leads us to infer that S. frugiperda can reproduce in D2 and D3.

In terms of the weight of the S. frugiperda last-instar larvae, Silva et al. (2017) found similar results when using the artificial diet formulated by Greene et al. (1976). In contrast, when the larvae were fed leaves of other hosts (soybean, cotton, corn, oats, and wheat), the weight was reduced by up to 50%.

When consuming D2, S. frugiperda larvae consumed more food, probably because the insects needed larger amounts to meet their nutritional requirements, resulting in a higher biomass gain. According to Panizzi and Parra (2009), insects can counterbalance poor nutritional quality by ingesting more food or by changing the efficiency of their use. These authors also report that the interpretation of the results of nutritional indices must be carried out in conjunction with biological research. Thus, the presence of allelochemicals and their interaction with the nutrients present in D2 may have caused a decrease in digestibility, which would lead to an increase in food consumption, albeit with a low growth rate.

The parameters RCR (amount of food ingested per mg of insect body weight per day), RGR (insect biomass gain in relation to weight), and RMR (amount of food spent in metabolism per mg of body weight) observed for S. frugiperda in the present experiment were higher than those found by Giongo et al. (2015) in a study of fourth-instar larvae on artificial diets, whereas ECI was similar for all diets, with AD and ECD being similar only when compared to D2. Regarding the results reported by Chang et al. (2000), with a diet based on wheat germ and casein, as well as those cited by Souza et al. (2001), with diets based on bean, yeast, and wheat germ, the parameters AD, ECI, ECD, and CM were similar.

The efficiency of the conversion of ingested food (ECI), which corresponds to the percentage of ingested food that is transformed into biomass, shows that the percentage of ingested food that is transformed into biomass was similar. On D1, the insects converted more food into biomass, demonstrated by the efficiency of
conversion of digested food (ECD), which indicates the conversion of the assimilated substance into biomass by the biological system, while the CM was higher for D2, indicating that the insect, despite a higher consumption, required a higher energy expenditure for its assimilation, while for D1 and D3, there was no difference.

In view of these results, the diet D2 resulted in higher intake and greater assimilation when compared to D1 and D3, but with a lower digestion, which suggests the need for greater food intake to meet the nutritional needs. This is probably due to the intrinsic characteristics of each diet, because the insects’ ability to digest food is affected by an inadequate nutrient balance, although water content and the presence of allelochemicals also play a role (Beck and Reese 1976). Thus, the stiffened surface of D3, which is related to the lower water content, may have influenced the digestibility of this diet.

Regarding the multiple-choice test, it should be noted that the larvae were initially attracted to D2, but over time, this diet became drier, and some individuals migrated to other diets which maintained their physical characteristics (hardness, shape and water content) for longer. The reason why D2 lost water faster would be related to the water content of its ingredients, since 100 g of corn flour contain 9.04 g of water, whereas the wheat germ present in D1 and D2 contained 11.12 g of water per 100 g (DIS, 2018).

The choice of food by the insect is determined by the balance of nutrients, including amino acids, carbohydrates, fatty acids, sterols, phospholipids, trace elements, vitamins, minerals, and water (Behmer 2009). Furthermore, physical characteristics and allelochemicals also play an important role (Panizzi and Parra 2009). Thus, the texture of the diet, influencing the efficiency of intake and the assimilation of the food, is an important factor. In our study, the inclusion of corn flour (D2) increased the carbohydrate/protein ratio and the allelochemical–nutrient interaction, but the hardness of the diet might have been a limiting factor.

Therefore, although the diet D2 was more attractive, changes must be made in its composition. The physical characteristics of a diet (hardness, shape, and water content) should be maintained for a longer time, since the insects were unable to use this diet as a food resource to complete development.

In relation to D1 and D3, this study showed that both diets presented satisfactory results for the rearing of S. frugiperda, with a similar performance among the various biological parameters evaluated and differing from D2 only in relation to the greater attractiveness after 24 h.

There are only few studies on the use of corn in artificial diets for the establishment of S. frugiperda, and our study demonstrates that the use of corn in artificial diets is feasible for the rearing of this insect. However, the choice between D1 or D3 should be based on the cost/benefit ratio of the availability of the ingredients (corn or beans) and in the local market prices. For example, the average price of 1 kg of green corn is US$0.29, while 1 kg of beans cost US$0.76 (US$1.00 = R$ 3.69) (CEASA, 2018), indicating that, besides green corn, it is used in quantity four times lesser than the beans, thus reducing the cost of the artificial diet.

Conclusions

The most suitable diets for the rearing of S. frugiperda in the laboratory were the standard diet based on beans (D1) and green corn (D3), allowing the complete development of the insect, with high survival and fecundity.

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