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Effect of Artificial and Corn Leaves Diets on Development, Survival and Reproduction of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in Sierra Leone

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Abstract

The use of artificial diets to mass reared insect stock under laboratory conditions, promotes knowledge about the biology, behavior, and nutritional requirements of insects; with such information being fundamental for the formulation of efficient integrated pest management programs (IPM) strategies. However, the artificial diets used for rearing *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) in the laboratory in this study, do not contain wheat germ, used for routine laboratory rearing. The aim of this study was to compare food preference and consumption by *S. frugiperda* larvae, as well as evaluate insect developmental parameters in the standard diet and the bean-based diets under laboratory conditions. Four artificial diets were used: a standard diet based on broad beans (*Phaseolus vulgaris* L.) used to rear *S. frugiperda* (D1), a diet with the substitution of two types of beans, cowpea (*Vigna unguiculata* L.) (D2) and pigeon pea (*Cajanus cajan* L) (D3); and a diet of fresh corn leaves (D4), the host plant of the pest species. Using a multiple-choice test, we observed that the larvae preferred diets D4 followed by D1. The relative consumption rate (RCR), relative growth rate (RGR), relative metabolic rate (RMR), approximate digestibility (AD), efficiency of conversion of ingested food (ECI), efficiency of conversion of digested food (ECD), and the metabolic cost (CM) for *S. frugiperda* fifth instar larvae varied among diets. The diet D4 resulted in better ingestion, digestion, assimilation, and conversion of food, but with a metabolic cost to assimilate the food. The different bean varieties present in the diet influenced larval length, larval periods, larval survival, pupal periods, sex ratio, pupal weight, and pupal survival; but fecundity and longevity of adults were not affected. The different bean-based diets did positively influence population growth, with the most outstanding being D4. From the results of this study, the most adequate diet for rearing *S. frugiperda* in the laboratory is D4.

Keywords

Fertility Life Table, Fall Armyworm, Insect Biology, Mass Rearing, Nutrition

1. Introduction

The fall armyworm *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae) is a polyphagous pest of more than 300 plant species, including some of substantial economic value such as soybean, cotton, sugarcane, and wheat [1] [2]. The insect originates from the western tropical hemisphere and was recognized as a severe threat to farmers in West and Sub-Saharan Africa in 2016 [3] [4]. In Sierra Leone, it was first identified and confirmed by the Ministry of Agriculture Forestry and Food Security (MAFFS) and the Food and Agriculture Organisation (FAO) on November 4, 2017. Owing to the speed with which it spreads and the fact that it can feed on so many different plants, *S. frugiperda* has the potential to devastate yields and damage crops in Sierra Leone, thereby dramatically affecting food security and threatening the livelihoods of smallholder farmers.

As a result, practical pest management options, including the cultivation of tolerant genotypes, adjusting sowing windows, and practicing specific intercultural and cropping systems measures in addition to chemical and non-chemical pest management strategies showed encouraging results for sustainable management of *S. frugiperda*.

The availability of insects from mass reared stock using artificial diets under laboratory conditions, promotes knowledge about the biology, behavior, and nutritional requirements of insects. In this context, several studies were carried out aiming to develop a rearing methodology able to supply a large number of *S. frugiperda* individuals with good biological using artificial diets [5]-[10].

The use of corn-based diets could enhance consumption and nutrition, although corn has a lower protein content (7.45%) than beans (20.10%) [11] [12]. However, in this study, in addition to corn, bean-based diets were evaluation. According to Lajolo *et al.* [13] and Donadel *et al.* [14], beans are composed of 75% globulins and albumin and are deficient in sulphur amino acids, tryptophan and methionine. These amino acids make food more attractive, stimulating, enhance insect fecundity [15].

Although a number of studies, already stated above, have compared the development of *S. frugiperda* using different artificial diets, there are no studies that relate the use of the fertility life table to food consumption and use, using bean-based artificial diets as well as the corn leaf. Furthermore, in Sierra Leone, studies on *S. frugiperda* are still scarce as this pest has just been introduced. An in-depth study on this pest is critical to gain knowledge of the pest's behavior and appropriate control techniques in such resource poor country.

In this context, the aim of this study was to evaluate food preference of the insect, as well as, to compare the biology and food consumption and use by *S. frugiperda* larvae, on beans-based diets and a diet of fresh corn leaves, the host plant of the pest species.

2. Materials and Methods

2.1. Experimental Location

The study was conducted at the Bio-factory, Crop Protection Department, School of Agriculture and Food Sciences, Njala Campus, Njala University, Southern Sierra Leone. The location is located at N08.06, W12.06 and altitude: 63 m), in the southern region of Sierra Leone. The study area acquires an annual rainfall of 2800 mm. Annual temperature ranges from 28˚C to 33˚C and relative humidity 70% were observed during the experimental period. The area has relatively high rainfall pattern, high temperature during the day and humid during the night, having silty-loam kind of a soil.

2.2. Experimental Diets Evaluated and Insect Rearing

The diets that were used in this study are modifications of Nalin [16]. Four formulations were evaluated, namely a standard diet based of broad beans (*Phaseolus vulgaris* L.) used to rear *S. frugiperda* (D1), a diet with the substitution of two types of beans, cowpea (*Vigna unguiculata* L.) (D2) and pigeon pea (*Cajanus cajan* L) (D3), and a diet of fresh corn leaves (D4), the host plant of the pest species. Regarding the corn leaves, excised leaves were cut into small pieces, 5cm long, disinfected in 0.5% sodium hypochlorite for 10 min, and washed two times with sterile distilled water. Finally, these were blot-dried with sterile tissue paper, prior to use. The insects were kept under controlled laboratory conditions (temperature of 25˚C ± 1˚C, relative humidity of 70% ± 10%, photoperiod of 12 h light/12 h dark). The description of the compositions of the diets is indicated in **Table 1**. Following the preparation of the diets, using the composition in **Table 1**, while hot, the mixture was poured into sterilized plastic container (21 cm in length × 14.5 wide × 9.5 in height) and allowed to cool. The diet was refrigerated until use after solidifying at room temperature. The diet was removed from the fridge and conditioned at room temperature for 2 - 3 h before use. The solidified diets were cut into pieces of about 2 g and transferred to sterilized plastic cups (38.4 mm, bottom × 47.8 mm, top × 43.2 mm high) for larval feeding.

2.3. Food Preference Test

This test was conducted as per method described by Pinto *et al.* [5]. First-instar larvae were submitted to the multiple-choice test (feeding test) in Petri dishes (15.0 cm diameter, 2.0 cm height) containing one cube of each diet (2.2 cm)

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

Constituent/Ingredient	D1	D2	D3	D4	Purpose
Bean powder*	62.5 g	62.5 g	62.5 g	Corn leaf	Source of protein
Corn flour	50 g	50 g	50 g		Source of roughage and mineral
Maize leaf powder	25 gm	25 gm	25 gm		Natural diet
Milk powder	19 g	19 g	19 g		Casein protein source
Torula yeast	32 g	32 g	32 g		Feeding attractant/induction and mineral source
Ascorbic acid	3 g	3 g	3 g		Vitamin C source
Methyl paraben	2.5 g	2.5 g	2.5 g		To prevent the growth of bacteria
Sorbic	1.5 g	1.5 g	1.5 g		To prevent the growth of fungi/mold
Distilled water	500 ml	500 ml	500 ml		Mixing the paste
Distilled water	300 ml	300 ml	300 ml		For boiling agar
Agar	11.5 g	11.5 g	11.5 g		Gelling the diet
Vitamin mix	1 ml	1 ml	1 ml		Vitamin B complex for healthy and uniform growth
Formalin 40%	2 ml	2 ml	2 ml		Long term preservative of food
Suprapen (Tetracycline)	2.5 g	2.5 g	2.5 g		Antimicrobial, treatment of insects if infected

*Bean powder is either of the following bean-based diets: *Phaseolus vulgaris* (L) (**D1**), or *Vigna unguiculata* (L) (**D2**), or *Cajanus cajan* (L) (**D3**), or *Zea mays* (L) leaf (**D4**).

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 12 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.

2.4. Nutritional Indices

Newly hatched larvae (<24 h) were kept individually in Petri dishes (6 cm diameter, 2 cm height) containing pre-weighed diet cubes (2 × 2 cm) of all four diets, which were replenished (when necessary). When the larvae reached the fifth-instar, 20 mm of length [17], as confirmed by the presence of ecdysis, 10 insects were removed from the Petri dishes, weighed, killed by freezing, and air-dried. Another 10 insects were weighed and kept in the Petri dishes, provided with fresh and pre-weighed diets. On daily basis, in addition, dietary leftovers and excrements from the insects and 10 whole cubes of each diet (2 × 2 cm) were weighed and oven-dried. After a drying period of 3 d until reaching a constant weight, the diets, excrements and larvae were weighed. Thus, the weight of the dry larvae, the food consumed, and the weight gain of the larvae were obtained for the determination of the indices of food consumption and use. Similarly, the experiment was repeated until the larvae become pupae. The weight of pupa formed was recorded individually using an electronic balance.

For determining the growth indices of *S. frugiperda*, the methodology proposed by Waldbauer [18] and modified by Scriber and Slansky [19], was used to determine the quantitative nutritional indices (in dry matter weight) of fifth instar of the larvae stage in different diets are as follows:

1) $$\text{Relative consumption rate (g/g/day) (RCR)} = \frac{\text{I}}{\text{B} \times \text{T}} \quad (1)$$

2) $$\text{Relative growth rate (g/g/day) (RCR)} = \frac{\text{B}}{\text{B} \times \text{T}} \quad (2)$$

3) $$\text{Relativemetabolic rate (g/g/day) (RMR)} = \frac{\text{M}}{\text{B} \times \text{T}} \quad (3)$$

4) $$\text{Approximate digestibility (\%) (AD)} = \frac{\text{I} - \text{F}}{\text{F}} \times 100 \quad (4)$$

5) $$\text{Efficiency of conversion of ingested food (\%) (ECI)} = \frac{\text{B}}{\text{I}} \times 100 \quad (5)$$

6) $$\text{Efficiency of conversion of digested food (\%) (ECI)} = \frac{\text{B}}{\text{I} - \text{F}} \times 100 \quad (6)$$

7) $$\text{Metabolic cost (\%) (MC)} = 100 - \text{ECD} \quad (7)$$

where, T = duration of feeding period (days); Af = weight of foodsupplied to the insect (g); Ar = weight of leftover food provided to the insect (g) after T; F = weight of excre tory produced (g) during T; B = (I − F) − M = weight gain by larvae (g) during T; B = mean weight of larvae (g) During T; I = weight of food consumed (g) during T; I − F = food assimilated(g) during T; M = (I − F) − B = food metabolized during T (g).

2.5. Biological Parameters

For each diet treatment, 25 newly hatched larvae (<24 h) obtained from stock rearing were placed individually in plastic vials (5.0 cm diameter × 5.5 cm height × 3.2 cm base) containing artificial diet cubes (2.0 cm × 2.0 cm) which were replaced when necessary. In another set-up, larval feeding on the natural diet (corn leaf) was prepared likewise, containing pieces of leaves taken from seedlings at 10 - 15 DAS (days after sowing). Daily thereafter, fresh pieces of leaves were supplied to replace the previous ones. Fresh leaves were supplied daily since young leaves of corn dried up easily and not palatable to larvae anymore. Moreover, during this larval stage, larvae consumed mostly all the pieces of leaves offered, hence the need for additional food. Rearing in individual containers for *S. frugiperda* is commonly used due to cannibalism of older larvae [5]. These larvae were divided into five replicates per treatment and monitored throughout the larval and pupal stages. This study evaluated the following biological parameters were evaluated: larval period, larval survival, pupal weight, sex ratio, pupal development duration, and pupal survival.

After the emergence of the adults, a male and a female adult emerging on the same day were paired in a copula and oviposition cage of polyvinyl chloride (19.5 cm diameter × 15 cm height), lined with paper towels and supported on a plastic cover (23.5 cm diameter × 3 cm height) lined with paper towels, with the top closed with voile fabric fastened with elastic. The couples were conditioned per cage and 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) for feeding. Five replicates per treatment were observed daily, and fecundity (eggs/female) and longevity of male and female adults were recorded.

Groups of approximately 50 eggs were collected and placed in rectangular plastic rubber containers (19.5 cm diameter × 15.0 cm height) to determine the viability of the eggs and the time required for the larvae hatching.

With the biological parameters obtained, the parameters for the construction of fertility life tables were estimated, according to Price [20]: x = age of parental females, age is considered starting in the egg phase; lx = specific survival rate to age x, expressed as a fraction per female and male (total adults); mx = specific fertility or number of offspring produced per female at age x; lx.mx = age-specific maternity. The growth parameters resulting from life tables were R0 = net rate of population growth, T = mean generation time, r_m = intrinsic rate of increase, λ = finite rate of increase. In addition to these parameters, we also determined Dt, which is the time required for the population to double in number, according to Krebs [21].

The growth parameters (R_0, T, r_m, λ, and D_t): were calculated using the following equations:

$$R_0 = \sum(\text{lx.mx}) \tag{8}$$

$$T = \frac{\sum(x.\text{lx.mx})}{\sum(\text{lx.mx})} \tag{9}$$

$$r_m = \frac{\ln R0}{T} \tag{10}$$

$$\lambda = e^{rm} \tag{11}$$

$$Dt = \frac{\ln(2)}{rm} \tag{12}$$

2.6. Statistical Analysis

Data of *S. frugiperda* larvae in each artificial diet, in the multiple-choice test, were analyzed using PROC ANOVA and means were compared using the Student-Newman-Keuls test ($P < 0.05$). Data from nutritional indices RCR, RGR, RMR, ECD, and AD were analysed using the analysis of variance (ANOVA), and their means were compared by Student-Newman-Keuls test ($P < 0.05$). Data for larval period, larval survival, weight of pupae, pupal period, pupal survival, fecundity of females, and longevity of males and females as well as sex ration were submitted to ANOVA and compared using the Student-Newman-Keuls test. The same was done for the population parameters of the fertility life table. All statistical analyses were conducted using the software package SAS [22].

3. Results

3.1. Food Preference Test

In the multiple-choice tests (feeding tests), it should be noted that the highest percentages of *S. frugiperda* larvae were observed in D2 and D3, but over, they migrated to mostly to D4, followed by D1, clearly showing that D4 was more attractive to *S. frugiperda* larvae, followed by D1 (**Table 2**).

3.2. Nutritional Indices

For the nutritional indices, the RCR ($F_{3,65}$ = 1461.08, $P < 0.0001$), RGR ($F_{3,65}$ = 1.33, $P = 0.0277$), RMR ($F_{3,65}$ = 2226.51, $P < 0.0001$), and AD ($F_{3,65}$ = 133.77, P <0.0001) for *S. frugiperda* fifth-instar larvae fed different diets were highest in D4, with values of 9.4 g/g/day, 0.69 g/g/day, 8.8 g/g/day, and 72.9%, respectively, (**Table 3**).

Regarding the ECI, the highest value was in D1 (49.3%) and D4 (51.7%), whereas the lowest value was in D2 (30.3%) and D3 (36.4%) ($F_{2,65}$ = 122.43, P = 0.0001) (**Table 3**).

Table 2. Percentages of *Spodoptera frugiperda* larvae on diets D1, D2, D3 and D4 in multiple-choice tests at all evaluated times.

Time	**Diet**				
	D1 (*Phaseolus vulgaris*)	D2 (*Vigna unguiculata*)	D3 (*Cajanus cajan*)	D4 (Maize leaf)	Mean ± SE
15	1.75 ± 0.87	0.75 ± 0.97	2.00 ± 1.22	2.42 ± 1.78	1.73 ± 1.43b
30	2.25 ± 1.06	1.83 ± 1.11	2.20 ± 0.84	2.75 ± 1.60	2.26 ± 1.30ab
45	2.41 ± 1.16	1.67 ± 1.15	2.60 ± 1.34	3.17 ± 1.95	2.46 ± 1.47ab
60	2.58 ± 1.08	1.41 ± 1.08	2.20 ± 1.10	3.92 ± 2.02	2.53 ± 1.64ab
24 hrs	2.75 ± 1.06	1.33 ± 0.89	1.60 ± 1.14	4.67 ± 2.96	2.59 ± 2.24a
Mean ± SE	2.35 ± 1.07b	1.04 ± 1.08c	2.12 ± 1.09b	3.83 ± 2.20a	P = 2.62, P = 0.0362

Mean ± SE followed by the same letter in the line, do not differ by the SNK test ($P > 0.05$). N = 120 individuals were used in the analysis.

Table 3. Nutritional indices in fifth-instar larvae of *Spodoptera frugiperda* on diets D1, D2, D3 and D4.

Index	**Diet**				***f* and *P* values**
	D1 (*Phaseolus vulgaris*)	D2 (*Vigna unguiculata*)	D3 (*Cajanus cajan*)	D4 (Maize leaf)	
RCR (g/g/day)	9.09 ± 0.16b	3.79 ± 0.81c	3.29 ± 0.00d	9.40 ± 0.00a	*f* = 1461.08; *P* < 0.0001
RGR (g/g/day)	0.58 ± 0.00b	0.51 ± 0.13c	0.54 ± 0.00d	0.69 ± 0.00a	*f* = 1.33; *P* < 0.0277
RMR (g/g/day)	8.45 ± 0.00b	3.23 ± 0.64c	2.75 ± 0.00d	8.80 ± 0.00a	*f* = 2226.51; *P* < 0.0001
AD (%)	67.8 ± 0.00b	45.3 ± 12.7c	41.3 ± 0.00d	72.9 ± 0.00a	*f* = 133.77; *P* < 0.0001
ECI (%)	49.3 ± 0.00a	30.3 ± 8.43c	36.4 ± 0.02b	51.7 ± 0.00a	*f* = 122.43; *P* < 0.0001
ECD (%)	43.3 ± 0.00b	32.3 ± 9.01c	38.5 ± 0.00d	54.0 ± 0.69a	*f* = 86.27; *P* < 0.0001
CM (%)	56.7 ± 0.00a	41.0 ± 17.1c	41.6 ± 0.00c	53.2 ± 0.00b	*f* = 21.92; *P* < 0.0001

Mean ± SE followed by the same letter in the line, do not differ by the SNK test ($P > 0.05$). $N = 69$ individuals were used in the analysis.

For the ECD, the highest value was found for D4 (54.0%) and the lowest for D1 (43.3%), D3 (38.5%) D2 (32.3%) ($F_{2,65} = 86.27$, $P = 0.0001$). In contrast, the MC was higher for D1 (56.4%) and lower for D4 (53.2%) ($F_{2,65} = 21.92$, $P = 0.0001$), but similar for D2 (41.0%) and D3 (41.6%) (Table 3).

3.3. Biological Aspects

The diets D1 and D4 resulted in a similar development of *S. frugiperda*, with a shorter cycle and higher pupal weights of 2580 and 2083 mg, respectively ($F_{3,65} = 132.96$, $P < 0.0001$). The observed larval periods of 2.5d and 2d, respectively ($F_{3,65} = 1.12$, $P < 0.0001$) (Table 3). While the lowest larval survival was observed for D2 (52.0%) and D3 (72.0%); survival was similar for D1 and D4 (76.0 and 76.0%, respectively) ($F_{3,65} = 112$, $P < 0.0001$).

Pupal weights were higher (ranging from 1030.5 mg - 2580 mg), but, the pupal periods were not influenced by the different diets ($F_{3,65} = 0.27$, $P < 0.8450$) (Table 4).

The lowest survival capacity also occurred in the pupal stage, with 71.6% for D2 compared to 86.7% for D3, whereas, pupal survival was 100% for both D1 and D4 ($F_{3,65} = 34.83$, $P < 0.0001$). The sex ratio was influenced by the different diets and ranged between 0.69 and 1.38 ($F_{3,65} = 1206.89$, $P < 0.0001$) (Table 4).

Diets during the larval phase did not influence female fecundity, with values between 1746 and 1850 eggs/female ($F_{3,46} = 0.54$, $P = 0.6714$) (Table 5).

Table 4. Biological characteristics of the larval and pupal stages of *Spodoptera frugiperda* on diets D1, D2, D3 and D4.

Characteristics	N	Diet				*f* and *P* values
		D1 (*Phaseolus vulgaris*)	D2 (*Vigna unguiculata*)	D3 (*Cajanus cajan*)	D4 (Maize leaf)	
Larval length (cm)	69	1.98 ± 0.38b	1.82 ± 0.17bc	1.73 ± 0.22c	3.28 ± 0.07a	$f = 159.06$; $P < 0.0001$
Larval period (days)	69	2.00 ± 1.78a	3.50 ± 0.97b	3.10 ± 1.22b	2.50 ± 0.87a	$f = 1.12$; $P < 0.0001$
Larval survival (%)	69	76.0 ± 0.00a	52.0 ± 0.00c	72.0 ± 0.00b	76.0 ± 0.00a	$f = 112$; $P < 0.0001$
Pupal weight (mg)	57	2083 ± 0.00b	1838.6 ± 5.28c	1030.5 ± 2.18d	2580 ± 0.00a	$f = 132.96$; $P < 0.0001$
Sex ratio	54	0.71 ± 0.00b	0.69 ± 0.09c	0.86 ± 0.00c	1.38 ± 0.00a	$f = 1206.8$; $P < 0.0001$
Pupal period (days)	57	8.64 ± 0.47a	9.08 ± 0.90a	9.00 ± 0.85a	8.92 ± 2.33a	$f = 0.27$; $P = 0.8450$
Pupal survival (%)	57	100 ± 0.00a	71.6 ± 20.3c	86.7 ± 0.00b	100 ± 0.00a	$f = 34.83$; $P < 0.0001$

Mean ± SE followed by the same letter in the line, do not differ by the SNK test ($P > 0.05$).

Table 5. Fecundity and Longevity of *Spodoptera frugiperda* in diets D1, D2, D3 and D4.

Parameter	Diets				*f* and *P* values
	D1 (*Phaseolus vulgaris*)	D2 (*Vigna unguiculata*)	D3 (*Cajanus cajan*)	D4 (Maize leaf)	
Fecundity (eggs/female)	428. ± 50.55a	375.75 ± 59.63a	208.5 ± 45.25a	498.25 ± 82.65a	$f = 0.54$; $P = 0.6559$
Male longevity (days)	9.00 ± 1.41a	8.20 ± 0.83a	8.00 ± 0.82a	10.5 ± 2.38a	$f = 0.73$; $P = 0.5454$
Female longevity (days)	10.5 ± 2.38a	8.40 ± 2.88a	9.25 ± 3.59a	11.8 ± 0.50a	$f = 0.73$; $P = 0.5454$

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

The number of eggs per female of *S. frugiperda* varied according to longevity. The highest amounts of eggs/female were observed between the 4th and 5th day of age, between 302 to 1150 eggs/day (**Figure 1**).

Females of *S. frugiperda* have longer longevity than males; however, no significant difference was found in the longevity of males ($F_{1,26} = 0.73$, $P = 0.5454$) and females ($F_{1,26} = 0.73$, $P = 0.5454$) among diets (**Table 5**).

The Fertility Life Table, based on the results obtained for the biological parameters of *S. frugiperda*, showed differences amongst the evaluated diets. The net reproduction rate (R_0), was significantly ($F_{3,16}$ = 727.79, $P < 0.0001$) highest for D4 followed by D1, and ranged from 242to 728 females/females per generation. For the average generation time (T), the lowest value was found for D4, while D3 presented the highest value. The intrinsic increase rate (r_m) was ($F_{3,16}$ = 3326.67, $P < 0.0001$) highest for D4 and lowest for D2, ranging from 0.062 females/female/d to 1.253 females/female/d. The finite increase rate (λ) was also significantly ($F_{3,16}$ = 3326.67, $P < 0.0001$) highest for D4 followed by D1. The time for the population to double in size (D_t) was significantly lowest for D4 followed by D1; while for D2 and D3, it took more days for the population to double in the number of individuals when the larvae were fed on these diets (**Table 6**). Among the diets evaluated, D4 had the highest net reproduction rate, the shortest time for the population to double in number, and the highest rates of population growth (**Table 6**).

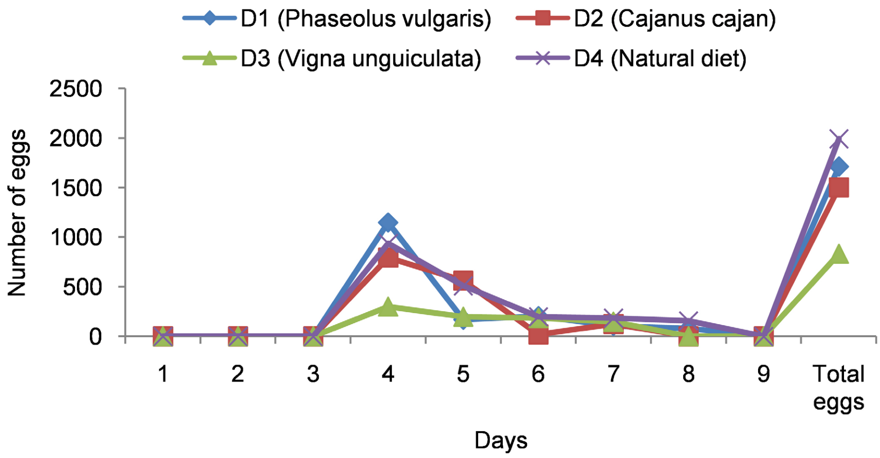

Figure 1. Number of eggs laid per female per day by *Spodoptera frugiperda* fed on different bean-based diets under laboratory conditions.

Table 6. Life table parameters of *Spodoptera frugiperda* in diets D1, D2, D3 and D4.

Parameter	Diets				*f* and *P* values
	D1 (*Phaseolus vulgaris*)	D2 (*Vigna unguiculata*)	D3 (*Cajanus cajan*)	D4 (Maize leaf)	
Net reproductive rate (R_0)	543 ± 1.58b	308 ± 1.58c	242 ± 1.58d	728 ± 36.97a	f = 727.79; P < 0.0001
Generation time (T_c)	28.1 ± 0.16c	31.9 ± 0.16b	35.2 ± 0.16a	26.0 ± 0.16d	f = 3326.67; P < 0001
Intrinsic rate of increase (r_m)	1.070 ± 0.00b	0.062 ± 0.00d	0.072 ± 0.00c	1.253 ± 0.00a	f = 964.37; P < 0.0001
Finite rate of increase (λ)	1.053 ± 0.00b	0.053 ± 0.00d	0.062 ± 0.00c	1.093 ± 0.00a	f = 0.54; P = 0.6559
Doubling time (D_t)	28.6 ± 0.18c	30.3 ± 0.16b	32.7 ± 0.16a	26.3 ± 0.16d	f = 134.71; P < 0001

4. Discussion

The experimental design was performed in this way to test the replacement of the wheat germ, which was not available, by a standard bean-based diet, D1 diet, with the substitution of two types of beans, powdered cowpea D2 and D3; and D4, the host plant of the pest species.

In the multiple-choice tests (feeding tests), it should be noted that the larvae were initially attracted to D2 and D3, but over, they migrated to D4, followed by D1. Choice of foods by this insect as well as subsequent consumption, the RCR (amount of food ingested per mg of insect body weight per day), areinfluenced by their physical structures (hardness, surface pilosity, shape and water content) [5], 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 [15]. Thus, among the evaluated diets, D4 and D1, remained fresh and maintained their water content for a comparatively longer time; with D4 having most individuals feeding it. For the other diets (D2, and D3), over time, these diets became drier, which also presented greater surface stiffness; these factors may have impeded the ingestion and continuous consumption of the diets. The reason why the diets lost water faster would be related to the water content of its ingredients [23]. As ready stated above, D4 being the host plant species, was supplied young and at the 2-leaf stage. Maize is widely considered as a highly-suitable host plant for invasive *S. frugiperda* populations [24] [25], and our trials confirm these results.

Regarding the other parameters, RGR which indicates the biomass gain by the insect in relation to its weight, the RMR representing the amount of food spent in metabolism per unit weight, AD which represents the percentage of ingested food that is effectively assimilated by the insect, ECI which represents the percentage of food ingested that is transformed into biomass, and ECD, which indicates the conversion of the assimilated substance into biomass by the biological system, were interrelated in this study and found to be highest, for *S. spodoptera* larvae fed on D4 and D1 as compared to the others; demonstrating that, most of the foods consumed was effectively assimilated and completely converted into biomass by the biological system, for growth and development.

According to Truzi *et al.* [6] and Ambarningrum *et al.* [26] low ECD reflects the high larval metabolic cost. Moreover, high metabolic cost (MC) also marks that the diet consumed by the larva contains toxic allelochemicals, requiring the larva to spend much energy on detoxifying them in its body to prevent them from disturbing its physiology [27]. But, the high ECD in this study, for D4 consumed diet was reflected in the increased AD; while the MC was lower (higher for D1 and but similar for D2 and D3), indicating that the insect, despite a higher consumption, required a lower energy expenditure for its assimilation. On this, Waldbauer [18] stated that every increase in ECD was compensated by increased AD, and vice versa. High AD is explained by the larva's digestive system being exposed to enzymes for a longer period of time. Besides, the urgent need for energy for growth, development, and detoxification requires that the larva must increase the amount of food digested in order for its growth not to be disturbed. The increase in AD could be seen in the number of feces produced by the test larvae; which might have come from unabsorbed digestive remains, as well as from the peritrophic membrane that was destroyed due to the allelochemicals that were present in the diet [27] [28]. Da Silva *et al.* [1] also added that, herbivorous insects have a number of detoxification enzymes, such as mixed-function oxidases (MFOs) and general esterases, in their digestive system, to be exact in the mid-gut, to digest plant allelochemicals. This indicates D4 was better used by the insect than the other diets.

Insects with appropriate and sufficient nutrition produce a fit body such as a long body, a short life cycle, and many eggs produced. From the results of this study, *S. frugiperda* larvae that fed on D4, reached the final instar stage faster and had a longest body length than larvae those fed other diets. The nutrition in a plant is a primary factor that regulates the growth, reproduction, and development of an insect. Also, varying developments were observed, with a comparatively shortest cycle and highest pupal weight of *S. frugiperda* fed on D4. The observed larval periods of 2.5d and 2d, respectively, were lower than the observations of Pinto *et al.* [5], who obtained a larval period in the range of 15.3 d to 34.5d; and Marcomini *et al.* [29], who reported a total larval period of 17.25 days.

According to Silva *et al.* [1], *S. frugiperda* fed with corn feed had a shorter development stage than other feeds. This was also observed by Hutasoit *et al.* [30], which showed that maize was an appropriate feed for the growth and development of *S. frugiperda*. Furthermore, this is supported by other data that *S. frugiperda* generally attacks maize crops in various countries [31] [32]. The highest larval and pupal survival observed was also similar for D4 and D1.

The sex ratio was influenced by the different diets and ranged between 0.69 and 1.38. Silva *et al.* [1], when evaluating the effects of five hosts and an artificial diet on the development of *S. frugiperda*, reported sex ratios ranging from 0.37 to 0.54. In addition, Pinto *et al.* [5], when evaluating the biology and comparing 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, found sex ratios ranging from 0.39 to 0.55, both results lower than the sex ratios obtained in this study. However, Truzi *et al.* [6] evaluated developmental parameters of *S. frugiperda* and compared the consumption and use of food by larvae reared using diets containing different protein levels under laboratory conditions, they found a constant sex ratio of 0.5 across different diets.

Female longevities reported in this study, are within the range reported by Truzi *et al.* [6] (6.5 days to 11.5). However, it was shorter than 17.0 days as reported by Bernardi *et al.* [33] and Pinto *et al.* [5]. This difference might be as a result of differing rearing conditions, where room temperature was about 25˚C ± 1˚C and 70% ± 10% RH in our laboratory.

The number of eggs per female is most likely due to the quantity and quality of the ingested food; this results into heavier pupae and subsequently higher fecundity. But, this relationship was not observed in the present study, as the diet offered during the larval period did not affect female fecundity and adult longevity. However, the fecundities recorded in this study are within the range reported by other workers (between 1061.0 and 1850.0 eggs/per female) [5] [33] but higher than those reported by Truzi *et al.* [6] (592.9 and 667.5 eggs/female), 544.07 eggs reported by He Li *et al.* [7] and 955.05 eggs/female for population collected in maize reported by Murua *et al.* [34].

The results of the fertility life table showed influence of diets on *S. frugiperda* population growth. The net rate of population growth (R_0) was greater than one, while the intrinsic rate of increase (r_m) and the finite rate of increase (λ) were positive, indicating population growth. The mean generation period (T_c) is the average time taken from when the eggs are laid until the female imago produces half of its offspring [35]. The species of a population with a lower T_c value will experience faster growth compared to population species with a high T_c value [36]. In line with this, the mean generation of *S. frugiperda* that fed on maize leaf-based diets (D4) was the lowest, as compared to the others. The shortest time required for *S. frugiperda* to multiply (Dt.) was also found in D4. The smaller T_c and D_t values indicated that the insects will reproduce and multiply faster. However, the mean generation time (T) recorded in this study was within that recorded by the early report of Rosa *et al.* [37] with *S. frugiperda* on five maize lines, in which the values range between 21.3 and 45.7 days.

5. Conclusion

Spodoptera frugiperda reared on natural food, maize, produced healthy larvae and pupae which emerged into healthy adults that laid eggs comparable to those reared on standard diet and other bean-based diets. The natural diet was able to support growth and development of *S. frugiperda* ensuring continuous supply of homogenous stage specific insects for efficacy testing and for colony maintenance in the Bio-factory, Crop Protection Department, School of Agriculture and Food Sciences, Njala Campus, Njala University, Southern Sierra Leone.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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