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BIOLOGY AND MORPHOMETRICS OF THE FALL ARMYWORM, *Spodoptera frugiperda* J. E. SMITH (LEPIDOPTERA: NOCTUIDAE) IN IBADAN, SOUTHWEST NIGERIA

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ABSTRACT

Studies on the development and morphological description of the fall armyworm, *Spodoptera frugiperda* are important for its sustainable management on the continent. Such studies are, however scanty in Africa and non-existent in Nigeria. Consequently, we studied fall armyworm development on maize leaves from egg to moth. Data was collected on egg hatchability, development duration, and morphometrics of life stages. Total development duration for egg, larva, and pupa was 2–3, 11–12, and 7–10 days, respectively. Egg incubation period, diameter, and percentage hatchability were 2.10±0.06 days, 0.24±0.01 mm, and 81.50±2.28 %, respectively. Larva comprised six-instars; with the first and last respectively measuring 1.64±0.03 mm and 26.45±0.44 mm body-length, 0.18±0.01 and 3.45±0.07 mm body-width, 0.12±0.01 mm, and 2.45±0.02 mm head-capsule-width. Pupa body-length and body-width were 14.38±0.14 mm and 4.21±0.04 mm, respectively. Female moths were larger and emerged a day ahead of males. Body length, body width, and wingspan of male and female moths were 14.93±0.25 mm and 14.66±0.19 mm; 2.71±0.08 mm and 3.14±0.05 mm; and 13.65±0.24 mm and 14.17±0.14 mm, respectively. Development duration of *S. frugiperda* larvae in Nigeria is shorter than that reported in the Americas but within the range reported in other parts of Africa. Findings in the study also confirm the ability of *S. frugiperda* moths to survive without food for up to a week making them a possible contaminant of maize grains and other agricultural commodities during transcontinental trades. Information provided in this study will aid the detection, identification, and management of the pest on farmers' field and on traded commodities.

Keywords: egg mass; larval instars; moth longevity; Sexual Size Dimorphism; Integrated Pest Management

INTRODUCTION

The fall armyworm, *Spodoptera frugiperda* J. E. Smith (Lepidoptera: Noctuidae), is an invasive insect pest native to the tropics of North, Central, and South America (Sparks, 1979; Kamara *et al.*, 2020; Liu *et al.*, 2020). It is an economic insect pest with a larval stage that attacks and damages more than 350 host plant species in the Americas (Montezano *et al.* 2018). In Africa, the fall armyworm has primarily damaged field maize since it was first reported in 2016, causing severe yield and economic losses (Goergen *et al.*, 2016; ICIPE, 2020).

As a new invasive insect pest in Africa, research has mainly focused on its management, especially within local maize cropping systems (ICIPE, 2020; Kasoma *et al.*, 2020). However, effective management of an invasive insect pest like *S. frugiperda* will depend on a good understanding of its biology and morphometrics. Specifically, studies on insect biology help identify damaging and vulnerable life stages that should be targeted for chemical spray applications or exploited in classical biological

control programs (Gillot, 2005; Assefa & Ayalew, 2019). Additionally, such studies provide information on the number of generations an insect pest may have in a growing season thus enabling appropriate pest management interventions (Gillot, 2005). Similarly, insect morphometric studies would help identify distinguishing morphological features of successive larval instars and other life stages. These would, in turn, inform proper insect pest identification (Ojo & Omoloye, 2015; Patel *et al.*, 2017) and the development of effective monitoring traps or other pest management strategies (Prasanna *et al.*, 2018).

Most information on fall armyworm biology and morphometrics emanate from research studies conducted in the Americas several decades ago (Luginbill, 1928; Vickery, 1929; Sparks, 1979; Capinera, 2001, Hardke *et al.*, 2015). Insect biology and morphometrics is however affected by climate, geography, and host crop (Patel *et al.*, 2017). Consequently, there is the need to undertake studies on *S. frugiperda* biology and morphometrics in Africa where the agro-climatic and agro-ecological

conditions are very different from what obtains in the Americas. Studies on the biology and morphometrics of all *S. frugiperda* life stages are currently scant in Africa. In South Africa, Du Plessis *et al.* (2020) studied the effect of five temperature levels – 18, 22, 26, 30 and 32 °C, on the development of *S. frugiperda* reared on sweet corn kernel, and reported an inverse relationship between both parameters. Nevertheless, these authors did not investigate the various morphometric differences of larval instars or other life stages. In addition, information on moth life span, and its implication for dispersal and pest risk analysis on the continent remain unavailable.

To bridge the existing knowledge gap, we also studied the biology of all life stages of *S. frugiperda* on maize leaves in Ibadan, Nigeria. Specifically, we investigated the development duration of immature stages, the number and morphological characteristics of instar larvae, and body measurements of all life stages. To provide some information on the potential of unfed moths to survive intercontinental journeys by wind-assisted flights, as contaminants of traded commodities, or as stowaways in aircrafts (Cock *et al.*, 2017), the lifespan of fed and unfed male and female moths was also investigated after their emergence. It was hypothesized in the present study that *S. frugiperda* eggs, larvae, and pupae would develop over shorter durations than the period previously reported during summer in the western hemisphere. We also predicted that the total development duration of male and female *S. frugiperda* would be the same. In addition, we hypothesized that female pupae and moths would have longer body lengths and larger body width than their male counterparts from the same cohort. Finally, we predicted that moths would be unable to survive for up to one week without food.

MATERIALS AND METHODS

Fall Armyworm Culture

Matured larvae were collected from an infested maize field in Ibadan, southwest Nigeria and reared individually on fresh maize leaves until pupation in plastic cups (200 mL) covered with a mesh. Larvae were confirmed to be *S. frugiperda* by the presence of two distinct morphological characteristics, that is, an inverted pale Y-shape marking in front of the head and four dots which are arranged in a square on the penultimate abdominal segment (Hardke *et al.*, 2015; FAO, 2017). Pupated larvae were placed individually in mesh-covered plastic cups (200 mL) until moth emergence. Emerged moths at rest were separated into males and females using the distinct

morphological features of their wings (Vickery, 1929; Sparks, 1979; Prasanna *et al.*, 2018). Then, ten pairs of moths were introduced into a wooden sleeve cage (45 cm x 45 cm x 60 cm) containing four potted two-week-old maize plants and fed on a ten percent sugar solution. Egg batches deposited on leaves were collected daily.

Egg batches laid on the same day were placed amongst fresh and tender maize leaves in a rectangular plastic container (25 cm x 16.5 cm x 12.5 cm) with a meshed lid. Neonates were allowed to feed together for four days after which they were reared individually until adult emergence as earlier described. Throughout the study, leaves and seedlings of a single maize variety (Sammaz-32) were used. The vigour and damaging potential of larvae was maintained by regularly introducing field-collected larvae into the laboratory population. Fall armyworm was cultured under ambient conditions of temperature (29.0 ±3 °C), relative humidity (65± 15 %), and 12 hours (light and dark) photoperiod in the laboratory.

Biology and Morphometrics of Fall armyworm Life Stages

Fall armyworm eggs

Five pairs of newly emerged moths (F₁) were introduced into the sleeve cage containing two-week-old maize plants in small poly-pots. Each day, egg batches deposited on maize leaves were cutout after which eggs per batch were counted. Thereafter, eggs in a batch or cohort were held in separate lidded containers and observed daily for hatching. A total of 30 egg batches were randomly collected from the sleeve cage for six days. The time it took each batch of eggs to hatch was also recorded. Eclosed neonates were subsequently counted to determine the percentage hatchability of eggs. The diameters of 30 randomly sampled eggs were also measured using a carbon fibre composite digital caliper.

Fall armyworm larvae

Neonate larvae from an egg batch (comprising c.a. 350 eggs) were reared from eclosion until pupation. Larval rearing was done at 29.45±0.06°C, 69.77±0.54% relative humidity, 12 hours (light: dark) photoperiods. Ten larvae were sampled daily and the body length, body width, and head capsule width of each were measured using a carbon fibre composite digital caliper. Measurement of larval body length was done from the head to the abdominal segment bearing the anal prolegs. Larval body width was

measured at the mid-abdominal region. The horizontal distance between the right and left sides of larval head was regarded as the head capsule width. Observations were also made on changes in larval body coloration and appearance and these were recorded at each sampling day. Total larval development duration was calculated as the time in days from egg hatch to larval pupation. By the 11th day after larval eclosion, about 90 percent of sampled larvae were at the pre-pupa stage and by the 12th day after larval eclosion, they had pupated. Morphometrics of pre-pupa larvae was not done in this study.

Fall armyworm pupae

Thirty pupae in a cohort were randomly sampled and their body length, body width, and weight were measured. Pupal body length was measured as the horizontal distance from the head to the abdominal tip that bears the cremaster. Pupal body width was measured at the mid-abdominal region. Pupal body length and width were measured using a carbon fibre composite digital caliper while pupal weight was measured using an OHAUS Explorer Pro digital sensitive balance. After measurements, each pupa was placed in labeled plastic cups covered with a mesh and observed daily for moth emergence. The time in days from larval pupation to moth emergence was taken as pupal development duration.

Fall armyworm moths

Upon emergence, moths were sexed as earlier described and the number of males and females in 30 randomly sampled moths were recorded to determine the sex ratio. Thereafter, 20 pairs of moths were randomly sampled from moths that emerged from the cohort of individually reared pupae. These were then immobilized and measured for body length, body width, and wingspan. Measurement of body length was done from the frontoclypeal region of the head to the tip of the abdomen; width of the mid abdominal region while the wings were spread out was taken as body width. Wing span was the distance from the axillary sclerite to the apical angle of a detached wing.

Longevity of Fed and Unfed Fall Armyworm Moths

The longevity of moths was studied by observing the life span of sixty (30♂:30♀) newly emerged and unmated moths. Thirty (15♂:15♀) of the moths were held individually in plastic cups with mesh covering.

The cups were modified to hold cotton tubes which were used to dispense the moth food. The moths were fed daily with ten percent sugar solution and held in isolation from emergence day until death. Each of the remaining 15 pairs of moths was also isolated but not fed until they died. Experiments were setup using a Completely Randomized Design (CRD). The daily survival of each moth was recorded and thereafter its total lifespan (time in days between emergence and death) was calculated.

Data Analysis

Morphometric and developmental data were analysed by calculating means, standard deviations, and ranges in Microsoft Excel (v. 16). A frequency distribution of daily head capsule widths was plotted and used to determine the number of instar larvae (Odebiyi, 1980; Debac *et al.*, 2010; Ojo & Omoloye, 2015). The number of instars was further confirmed by testing head-capsule-width measurements conformity to Dyar's rule using an independent sample t-test (Dyar, 1890; Odebiyi, 1980). Differences between head capsule widths of larval instars, body measurements of male and female pupa and adults were tested with Welch's two-sample t-test in R v. 4.1.0 (R Core Team, 2021). Data on the longevity of fed and unfed moths were submitted to a two-way ANOVA in R (v. 4.1.0). Mean separation, where necessary, was done with Tukey's HSD.

RESULTS

Biology and Morphometrics of Fall armyworm Life Stages

Fall armyworm egg

The fall armyworm egg is spherical with a yellowish-green colour when freshly laid and an average diameter of 0.24 ± 0.01 mm (Table 1). Females laid eggs in batches on the leaves and stems of the young maize seedlings. Usually, an egg batch is covered with a mass of scales immediately after oviposition. However, some batches were observed exposed and without the scale covering. An egg batch contained 118.9 ± 17.92 eggs with a range of 15 – 340 eggs. Eggs in a batch are laid closely packed usually in multiple layers. Just before hatching, eggs assumed a greyish-black colour. The incubation period and percentage hatchability of *S. frugiperda* eggs were 2.1 days and 81.50 % respectively at an average temperature of $29.36 \pm 0.17^\circ\text{C}$, relative humidity of 73.9 ± 1.00 %, and a 12-hour photoperiod (Table 1).

Table 1. Developmental and morphometric parameters of fall armyworm, *Spodoptera frugiperda* eggs

Parameters	Mean ± SE	Range
Incubation period (days)†	2.10 ± 0.06	2.0 – 3.0
Egg diameter (mm)	0.24 ± 0.01	0.1 – 0.3
Eggs per batch	118.9 ± 17.92	15.0 - 340
Hatchability (%)	81.50 ± 2.28	52 - 100

† Incubation and hatching of eggs occurred in the laboratory at 29.36 ± 0.17 °C, 73.90 ± 1.00 % relative humidity, 12 hours light and 12 hours dark photoperiods.

SE = Standard error of the mean

Fall armyworm larva

Head capsule widths and number of instars

Six peaks were observed in the histogram of daily head capsule width distribution (Fig. 1-A). The peaks correspond to the six instar larvae (Fig. 1-B) each with head capsule widths of 0.13 ± 0.01 , 0.31 ± 0.01 , 0.58 ± 0.01 , 1.15 ± 0.02 , 1.63 ± 0.01 and 2.45 ± 0.02 mm respectively (Table 2). The observed head capsule widths were distinct ($F_{(5, 104)} = 4819$, $p < 0.0001$) showing to a 95 % probability level that

measurements within the range shown for an instar belong to the instar (Table 3). A calculated t-value of 0.97 was obtained based on the difference (d) between measured head capsule widths and those obtained by calculation (Table 3). However, the calculated t-value was lower than the tabulated t-values at 5 % (2.78) and 1 % (4.60) showing the absence of significant differences between both head capsule widths. In other words, larval head capsule width measurements in the present study conforms to Dyar’s rule.

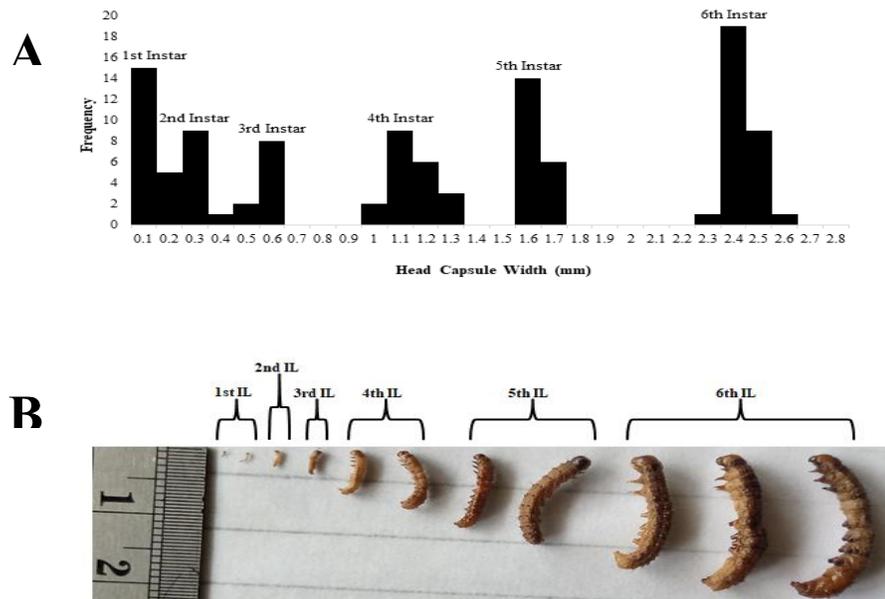


Fig. 1. (A) Frequency distribution of daily head capsule widths of *Spodoptera frugiperda* instar larva (B) Classification of *Spodoptera frugiperda* into instar larva (IL) stages based on daily measurements of head capsule widths.

Table 2. Head capsule width and development period of fall armyworm, *Spodoptera frugiperda* instar larvae

Instar	N	Head capsule width (mm)		Length of stadium (days)	Cumulative developmental period (days)
		Range	Mean ± SE		
I	10	0.1 - 0.2	0.13 ± 0.01 ^a	2	0
II	10	0.3 - 0.4	0.31 ± 0.01 ^b	1	3
III	10	0.5 - 0.6	0.58 ± 0.01 ^c	1	4
IV	20	1.0 - 1.3	1.15 ± 0.02 ^d	2	6
V	20	1.6 - 1.7	1.63 ± 0.01 ^e	2	8
VI	30	2.3 - 2.6	2.43 ± 0.01 ^f	3	11

N = Sample size; SE = Standard error of the mean

Mean in a column followed by different letters are significantly different at 5% level of significance according to the Tukey's Honestly Significant Difference (HSD)

Table 3. Conformity of fall armyworm, *Spodoptera frugiperda* larval head capsule widths to Dyar's rule

Instar	Observed mean head capsule width (mm)	Ratio ⁺	Calculated mean head capsule width (mm) ⁺⁺	Differences (d)
I	0.13	0.42	0.18	-0.05
II	0.31	0.53	0.33	-0.02
III	0.58	0.5	0.65	-0.07
IV	1.15	0.71	0.92	0.23
V	1.63	0.67	1.38	0.25
VI	2.43			
Average ratio =		0.57		

Mean difference (\bar{d}) = 0.07

Standard deviation of differences (s) = 0.16

Sample size (N) = 5

T calculated (t) = $\frac{\bar{d}}{s/\sqrt{N}}$ = 0.97

T tabulated at 5% = 2.78

T tabulated at 1% = 4.60

Reject Ho if T calculated > T tabulated

Decision: Do not reject Ho. Growth ratio is in conformity with Dyar's rule

⁺Ratio was obtained by dividing the observed mean head capsule of an instar by the observed mean head capsule width of its succeeding instar

⁺⁺Calculated mean head capsule width of an instar was obtained by multiplying its succeeding observed mean head capsule width by the average growth ratio

First instar larva

Fall armyworm eggs hatch into first instar larvae that have translucent bodies which later turn greenish after feeding on leaf tissue. First instar larvae also actively produce silk from their labial palps. The body length and width of the first instar larva were 2.28 ± 0.15 mm and 0.25 ± 0.02 mm, respectively (Table 4). First instar larvae developed within two days.

Second instar larva

The body length and width of the second instar larva were 4.79 ± 0.12 mm and 0.56 ± 0.02 mm, respectively (Table 4). Apart from being visibly longer and larger, second instar larvae were greenish in appearance and were actively silking like the first instar larvae. However, the inverted Y-marking in front of the head and the square-arranged dots on the penultimate abdominal segment were not observable at this instar. The second instar larval stage lasted for a day in the present study.

Third instar larva

Third instar larvae had conspicuous body segmentation with the inverted Y-marking and square-arranged spots slightly noticeable. Silking was also observed in third instar larvae but not as a prominent behavior like in earlier instars. Body length and body width were 5.15 ± 0.2 mm and 0.77 ± 0.02 mm, respectively in the third instar larva and development duration was just a day (Table 4).

Fourth instar larva

In the fourth instar larval stage, body segmentation is conspicuous and the distinctive cephalic marking and abdominal tubercles larger and more distinct. Body-color is partly brown at the last few abdominal segments and green towards the head. Silking behavior was, however, not observed at this instar stage. Generally, larvae were larger with body length and body width of 9.60 ± 0.51 mm and 1.30 ± 0.04 mm, respectively (Table 4). Development of the fourth instar larvae lasted for two days.

Fifth instar larva

On the fifth instar larvae, body segmentation was very prominent, the distinctive cephalic marking and

square-arranged spots on the last abdominal segment were larger than in earlier instars. In addition, the body length and body width in the fifth instar larva was 16.05 ± 0.58 mm and 2.02 ± 0.06 mm, respectively (Table 4). Development duration for the fifth instar was two days.

Sixth instar larva

The development of eggs (Fig. 2-A) through the larval stage terminates at the sixth instar larva, which is the most matured larva (Fig. 2-B). Larvae generally had a dark green color on the lateral sides and lighter green color bordered by yellowish lines on the dorsal sides of their bodies. Unlike preceding instar stages, abdominal segments in the last instar stage were conspicuously bigger than preceding segments. In addition, the body length and body width of the sixth instar larva were 24.40 ± 0.54 mm and 3.18 ± 0.07 mm (Table 4). The sixth and last instar stage lasted for four days in the present study. Once matured larvae were ready to pupate, they stopped feeding, turned to shrunken-bodied pre-pupae (Fig. 2-C) that generally pupate (Fig. 2-D) within a day and emerge as moths about a week after (Fig. 2-E). In total, *S. frugiperda* larva developed through six successive instars within 11 to 12 days. This duration includes the additional day spent as pre-pupa. Generally, larval development in the present study occurred at an average temperature of 29.45 ± 0.06 °C, relative humidity of 69.77 ± 0.54 %, and a 12-hours photoperiod.

Fall armyworm pupa

Body length, body width, body weight and developmental duration of pupae were 14.38 ± 0.14 mm, 4.21 ± 0.04 mm, 0.14 ± 0.00 mg and 8.73 ± 0.16 days respectively (Table 4). Furthermore, the morphometrics of male and female pupae shows that both sexes were not different in body length ($t = -1.0311$, $p = 0.3161$; Fig. 3-A), body width ($t = 0.87295$, $p = 0.3942$; Fig. 3-B) and body weight ($t = -1.0152$, $p = 0.3194$; Fig. 3-C). However, development from pupa to adult occurred at a significantly shorter ($t = -4.2546$, $p = 0.0003$, Fig. 3-D) duration in females (8.27 ± 0.11 days) than in males (9.20 ± 0.16 days).

Fall armyworm moth

Body length, body width and wing span of *S. frugiperda* moths were 14.79 ± 0.16 mm, 2.92 ± 0.06 mm and 13.91 ± 0.15 mm respectively (Table 4). There was no significant difference in the body length ($t = -0.84216$, $p = 0.4053$; Fig. 4-A) and wing span ($t = 1.8297$, $p = 0.077$; Fig. 4-B) of male and female moths. In contrast, body widths in female moths (3.14 ± 0.05 mm) were significantly wider ($t = 4.6604$, $p = <0.0001$; Fig. 4-C) than in males (2.71 ± 0.08 mm). Male and female moth had a sex ratio of 1:1.4 in the present study.

Longevity of Fed and Unfed Fall armyworm Moths

Longevity in fed moths ranged from 4 to 13 days within an average of 7.25 ± 0.47 days. In contrast, unfed moths lived for an average of 4.13 ± 0.17 days with a range of 3 to 7 days. Longevity in fed moths was significantly longer ($F_{(1, 55)} = 38.73$, $p = <0.0001$; Fig. 4-D) than in unfed moths (4.13 ± 0.17 days). Moth longevity was, however, not significantly ($F_{(1, 55)} = 0.802$, $p = 0.374$) influenced by sex, whether male (5.86 ± 0.52) or female (5.41 ± 0.36).

Table 4. Morphometrics and development of fall armyworm, *Spodoptera frugiperda* larva, pupa and moth

Life stage	Morphometrics				Development period (days)	
	Body length (mm)	Body width (mm)	Weight of Pupa (mg)	Moth wing span (mm)		
Larva	1 st IL	2.28±0.15 [1.5 - 3.1]	0.25±0.02 [0.1 - 0.4]	-	-	2
	2 nd IL	4.79±0.12 [4.2 - 5.4]	0.56±0.02 [0.5 - 0.6]	-	-	1
	3 rd IL	5.15±0.20 [4.0 - 6.0]	0.77±0.02 [0.6 - 0.8]	-	-	1
	4 th IL	9.60±0.51 [7.0 - 13.5]	1.30±0.04 [1.0 - 1.7]	-	-	2
	5 th IL	16.05±0.58 [12.0 - 20.5]	2.02±0.06 [1.5 - 2.4]	-	-	2
	6 th IL	24.40±0.54 [19.5 - 28.5]	3.18±0.07 [2.5 - 3.8]	-	-	2 - 3
Pupa	14.38±0.14 [12.4 - 15.7]	4.21±0.04 [3.7 - 4.6]	0.14±0.00 [0.11 -0.18]	-	7 - 10	
Moth	14.79±0.16 [12.7 - 16.50]	2.92±0.06 [1.80 - 3.50]		13.91±0.15 [11.40 - 15.20]		

Morphometric values are mean ± standard error [range]

IL = Instar Larva



Fig. 2. *Spodoptera frugiperda* (A) egg batch (B) mature larva (C) pre-pupae (D) pupa (E) male moth [left] with white markings on the fringe of forewings and female moth [right] with less pronounced forewing markings and more uniform wing colouration.

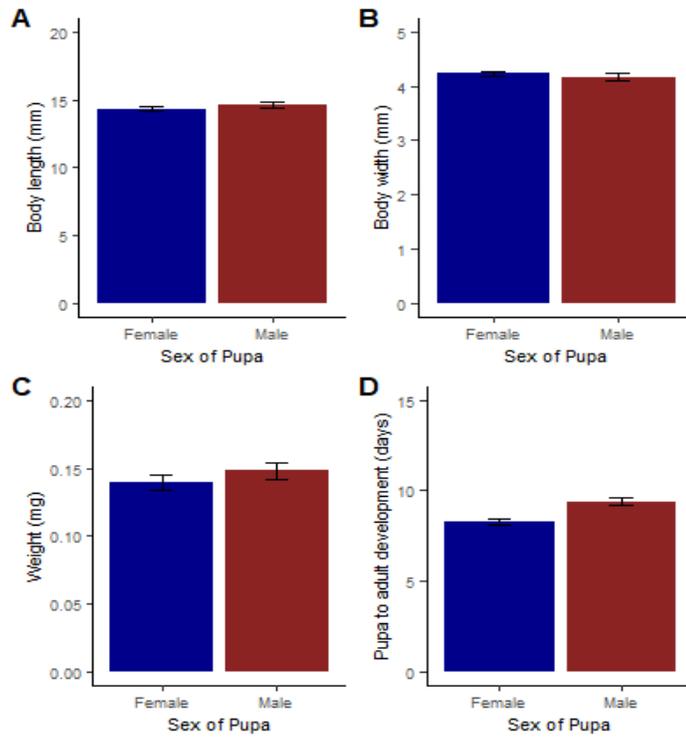


Fig. 3. Morphometrics and development of male and female *Spodoptera frugiperda* pupa (A) body length (B) body width (C) body weight and (D) days to adult development

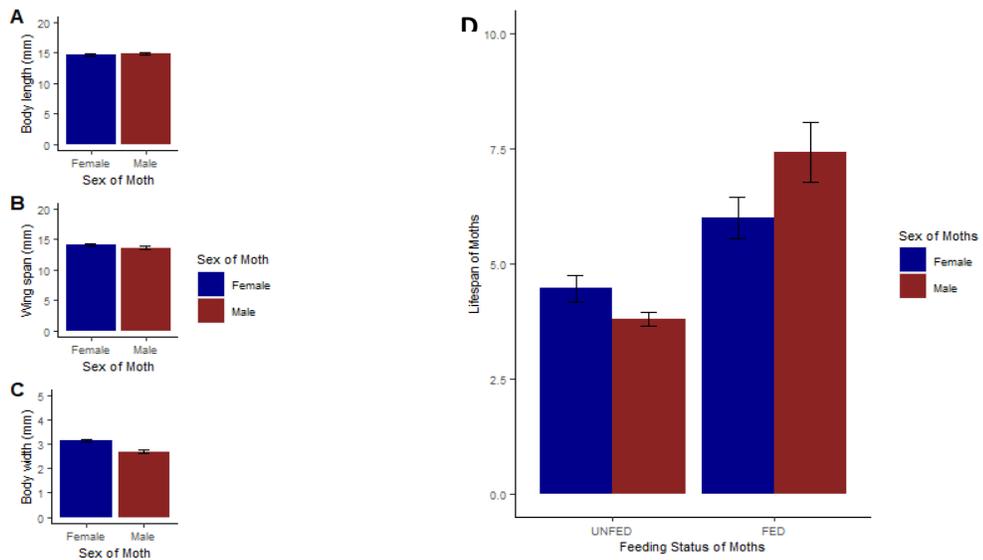


Fig. 4. Morphometrics and development of male and female *Spodoptera frugiperda* moth (A) body length (B) wing span and (C) body width (D) Lifespan as influenced by feeding

DISCUSSION

Studies on insect biology and morphometrics are necessary for developing appropriate insect pest management strategies. However, both insect biology and morphometrics are informed by prevailing agro-climatic conditions (Patel *et al.* 2017), necessitating region-specific studies. The high percentage hatchability of *S. frugiperda* eggs in this study is in line with previous reports (Luginbill, 1928; Busato *et al.*, 2005; Montezano *et al.*, 2019; Du Plessis *et al.*, 2020). We, however, predicted a shorter egg incubation period relative to reports from the Americas in the present study. In contrast to our hypothesis, eggs also developed within two to three days in this study just as was reported in North America (Vickery, 1929; Capinera, 2001) and Asia (Sharanabasappa *et al.*, 2018). At 30°C, Du Plessis *et al.* (2020) also reported an incubation period of two days for laboratory reared *S. frugiperda* eggs in South Africa.

As predicted, fall armyworm developed within a shorter period of 11 to 12 days at a temperature of approximately 30 °C. This is outside the 14 to 19 days range reported in North America during summer (Vickery, 1929; Capinera, 2001) and in India (Sharanabasappa *et al.*, 2018). This duration was also shorter than the 13.2 ± 0.14 days reported for *S. frugiperda* larvae reared on maize at 30 °C in Brazil (Busato *et al.*, 2005). In South Africa, Du Plessis *et al.* (2020) reported total larval development periods in the 10 to 14 days range (average of 11.38 ± 0.25 days) at 30 °C, and between 10 to 12 days at 32 °C. Temperature greatly influences the rate of development, and by extension, the biology, occurrence, abundance, and distribution of insect pests (Howe, 1967; Porter, 1991; Tobin *et al.*, 2003; Abrahams *et al.*, 2017; Du Plessis *et al.*, 2020). In the same vein, the number of instars comprising an insect larval stage is significantly influenced by rearing temperature and diet (Ali *et al.*, 1990; Aguilon *et al.*, 2015; Rojas *et al.*, 2018). Furthermore, *S. frugiperda* larva developed through six instars on natural maize leaf diet at an ambient temperature of approximately 30°C. Du Plessis *et al.* (2020) also reported an optimum temperature of 30°C for the development of *S. frugiperda* larvae, even though it may range between 26 – 30°C. Sharanabasappa *et al.* (2018) reported a 9 – 12 days pupation period for *S. frugiperda* in India. In Brazil, pupation of *S. frugiperda* corn strains took an average of 7.4 ± 0.9 days (Busato *et al.*, 2005). In South Africa, *S. frugiperda* pupation lasted for an average of $9.00 \pm$

0.12 days with a range of 8 – 10 days. In contrast to our hypothesis, *S. frugiperda* pupa development in the present study occurred between 7 – 10 days and was, therefore, consistent with previous reports within and outside Africa.

As predicted, female moths were larger than male moths in the present study. Body size differences in males and females of the same species or Sexual Size Dimorphism (SSD) is common in the Kingdom Animalia (Fairbairn, 1997; Stillwell & Davidowitz, 2010). In Class Insecta, it is not uncommon to find species where the females are larger than the males due to natural selection for fecundity (Stillwell *et al.*, 2010; Stillwell & Davidowitz 2010). According to Stillwell *et al.* (2010), body size differences only occur if sexes differ in size at hatching, or have different rates or duration of growth. For many insect species, however, size at hatching is usually not significant between sexes (Esperk *et al.*, 2007, Stillwell *et al.*, 2010). The emergence of female *S. frugiperda* moths a day earlier than males from the same cohort in the present study indicates that the growth rate was faster and the growth duration shorter in females of this species. Observed differences in body size and emergence time of male and female *S. frugiperda* moths can, respectively, have important applications in the development of *S. frugiperda* management strategies and the timing of control methods. Development of management strategies for *S. frugiperda* may be in the form of mass trapping where many males are caught with pheromone-baited traps and thus reducing the number of mated females (Campos & Phillips, 2014). Such traps may be equipped with holes that allow the entry of male *S. frugiperda* moths while excluding the larger females. Since females emerge earlier than males, the placing of sex-pheromone traps with lures that attract and kill females can be timed to coincide with the emergence of first generation females in infested maize fields.

Studies on the influence of feeding on *S. frugiperda* moth longevity might hold important consequences for pest risk analysis, especially as it relates to moth dispersal across regions. As an invasive transboundary insect pest, *S. frugiperda* has successfully spread to Africa and Asia from its native origin in the Americas (Goergen *et al.*, 2016; Day *et al.*, 2017; Rwomushana *et al.*, 2018). It is speculated that the pest spread from its native America to Africa as contaminants of agricultural produce or by flying wind-aided (Cock *et al.*, 2017; Assefa & Ayalew 2019; Kasoma *et al.*, 2020). Though *S. frugiperda* moths can undertake

wind-assisted travels over several hundred kilometers at heights of several hundred metres (Westbrook *et al.*, 2016; Zhou *et al.*, 2020), no evidence exists of the species ability to travel wind-assisted over very long distances. Nevertheless, whether as contaminants or as a stowaway, it is evident that the ability of unfed *S. frugiperda* moths to survive for up to seven days, as shown in the present study, enhanced its spread to and from the African continent.

CONCLUSIONS AND RECOMMENDATIONS

Based on the findings in the present study, it is concluded that *S. frugiperda* completes its entire lifecycle in Ibadan within 20 to 25 days with the egg, larval and pupal stages having developmental periods of between 2 – 3 days, 11 – 12 days and 7 – 10 days, respectively at an approximate average daily temperature of 30 °C and relative humidity of 70%. Under these rearing conditions, the larvae develop through six instar stages. Furthermore, unfed *S. frugiperda* moths live for up to a week indicating their ability to survive as stow-away or contaminants of traded agricultural products. Information provided in this study will aid the detection, identification, and management of the pest on maize farms and on traded grains by stakeholders including agricultural entomologists, agricultural extension officers, agricultural quarantine officers and maize farmers. Future studies should investigate dispersal and survival of migrating *S. frugiperda* moths between maize cropping seasons in Nigeria.

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REFERENCES

- Ali, A., Lutrell, R. G. & Schneider, J. C. (1990). Effects of the temperature and larval diet on development of the fall armyworm (Lepidoptera: Noctuidae). *Annals of the Entomological Society of America*, 83, 725–733.
- Aguilon, D.J.D. & Velasco, L.R.I. (2015). Effects of larval rearing temperature and host plant condition on the development, survival, and coloration of African armyworm, *Spodoptera exempta* Walker (Lepidoptera: Noctuidae). *Journal of Environmental Science and Management*, 8, 54–60.
- Assefa, F. & Ayalew, D. (2019). Status and control measures of fall armyworm (*Spodoptera*

frugiperda) infestations in maize fields in Ethiopia: A Review. *Cogent Food and Agriculture*, 5, 1641902. <https://doi.org/10.1080/23311932.2019.1641902>.

- Busato, G. R., Grützmacher, A. D., Garcia, M. S., Giolo, F. P., Zotti, M. J. & Stefanello, J. R. (2005). Biologia comparada de populações de *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) em folhas de milho e arroz. *Neotropical Entomology*, 34, 743–750.
- Campos, M. & Phillips, T. W. (2014). Attract-and-Kill and other pheromone-based methods to suppress populations of the Indianmeal moth (Lepidoptera: Pyralidae). *Journal of Economic Entomology*, 107, 473–480.
- Capinera, J. L. (2001). Handbook of vegetable pests. Orlando, FL: Academic press.
- Cock, M. J. W., Beseh, P. K., Buddie, A. G., Cafa, G. & Crozier, J. (2017). Molecular methods to detect *Spodoptera frugiperda* in Ghana, and implications for monitoring the spread of invasive species in developing countries. *Scientific Reports*, 7, 4103.
- Day, R., Abrahams, P., Bateman, M., Beale, T., Clotey, V., Cock, M., Colmenarez, Y., Corniani, N., Early, R., Godwin, J., Gomez, J., Gonzalez Moreno, P., Murphy, S.T., Oppong-Mensah, B., Phiri, N.C., Silvestri, S. & Witt, A. (2017). Fall armyworm: impacts and implications for Africa. *Outlooks on Pest Management*, 28, 196-201.
- Debac, L., Lecharpentier, P. & Thiery, D. (2010). Larval instars determination for the European Grapevine moth (Lepidoptera: Tortricidae) based on the frequency distribution of head-capsule widths. *Crop Protection*, 29(6), 623–630.
- Du Plessis, H., Schlemmer, M-L., & Van Den Berg, J. (2020). The Effect of Temperature on the Development of *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *Insects*, 11, 228. <https://doi.org/10.3390/insects11040228>
- Dyar, H. G. (1890). The number of moults of lepidopterous larvae. *Psyche*, 5, 420 – 422.
- Esperk, T., Tammaru, T., Nylin, S. & Teder, T. (2007). Achieving high sexual sex dimorphism in

- insects: females add instars. *Ecological Entomology*, 32, 243–256. <https://doi.org/10.1111/j.1365-2311.2007.00872.x>
- FAO, Food and Agriculture Organization (2017). Fall armyworm (*Spodoptera frugiperda*): Identification, biology and ecology. <http://www.fao.org/17840EN/1/09.17>
- Fairbairn, D. J. (1997). Allometry for sexual size dimorphism: pattern and process in the coevolution of body size in males and females. *Annual Review of Ecology and Systematics*, 28, 659–687. <https://doi.org/10.1146annurev.ecolsys.28.1.659>
- Gillot, C. (2005). *Entomology*. 3rd Edition. Springer Science and Business Media. Dordrecht, The Netherlands.
- Goergen, G., Kumar, P. L., Sankung, S. B., Togola, A. & Tamò, M. (2016). First Report of outbreaks of the Fall Armyworm *Spodoptera frugiperda* (J E Smith) (Lepidoptera, Noctuidae), a New Alien Invasive Pest in West and Central Africa. *PLoS ONE*, 11, 10.
- Hardke, J. T., Lorenz III, G. M. & Leonard, B. R. (2015). Fall Armyworm (Lepidoptera: Noctuidae) Ecology in Southeastern Cotton. *Journal of Integrated Pest Management*, 6(1), 10, <https://doi.org/10.1093/jipm/pmv009>
- Howe, R.W. (1967). Temperature effects on embryonic development in insects. *Annual Review of Entomology*, 12, 15–42.
- ICIPE (International Centre of Insect Physiology and Ecology) (2020). ICIPE launches mass release of indigenous natural enemies to control fall armyworm. <https://www.icipe.org/news/icipe-launches-mass-release-indigenous-natural-enemies-control-fall-armyworm>
- Kamara, A. Y., Kamai, N., Omoigui, L. O., Togola, A. & Onyibe, J. E. (2020). Guide to maize production in Northern Nigeria, IITA, Ibadan, Nigeria, 18 pp.
- Kasoma, C., Shimelis, H. & Laing, M. D. (2020). Fall armyworm invasion in Africa: implications for maize production and breeding. *Journal of Crop Improvement*, <https://doi.org/10.1080/15427528.2020.1802800>
- Liu, T., Wang, J., Hu, X & Feng, J. (2020). Land-use change drives present and future distributions of Fall armyworm, *Spodoptera frugiperda* J.E. Smith (Lepidoptera: Noctuidae). *Science of the Total Environment*, 706, 135872.
- Luginbill, P. (1928). The fall armyworm. USDA Technical Bulletin No. 34, 92 pp.
- Montezano, D.G., Specht, A., Sosa-Gómez, A.D.R., Roque-Specht, V.F., Sousa-Silva, J.C., Paula-Moraes, S.V., Peterson, J.A. & Hunt, T.E. (2018). Host Plants of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in the Americas. *African Entomology*, 26(2), 286–300.
- Montezano, D.G., Specht, A., Sosa-Gómez, D.R., Roque-Specht, V.F., DE Paula-Moraes, S.V., Peterson, J.A. & Hunt, T.E. (2019). Developmental parameters of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) immature stages under controlled and standardized conditions. *Journal of Agricultural Science*, 11, 76–89.
- Odebiyi, J. B. (1981). Studies on the biology of the cowpea pod-borer, *Maruca testulalis* in Kenya— I. Determination of the larval instars. *International Journal of Tropical Insect Science* 1(4), 339–341.
- Ojo, J. A. & Omoloye, A. A. (2015). Life History of the Tamarind Weevil, *Sitophilus linearis* (Herbst) (Coleoptera: Curculionidae), on Tamarind Seed. *Journal of Insects*, 11, 1-5.
- Patel, P. P., Patel, S. M, Pandya, H. V. & Amlani, M. H. (2017). Biology and morphometrics of citrus butterfly *Papilio demoleus* Linnaeus (Lepidoptera: Papilionidae) on *Citrus limon* (L.) osbeck. *International Journal of Chemical Studies*, 5(5), 1413 – 1435
- Porter, J.H., Parry, M.L. & Carter, T.R. (1991). The potential effects of climatic change on agricultural insect pests. *Agricultural and Forestry Meteorology*, 57, 221–240.
- Prasanna, B. M., Bruce, A., Winter, S., Otim, M., Asea, G., Sevgan, S., Ba, M., van den Berg, J., Beiriger, R., Gichuru, L., Trevisan, W., Williams, P., Oikeh, S., Edge, M., Huesing, J.E. & Powell, T. (2018). Host plant resistance to fall armyworm. In B.M. Prasanna, J.E.

- Huesing, R. Eddy, V.M. Peschke (Eds.), *Fall Armyworm in Africa: A Guide for Integrated Pest Management*. Mexico, CDMX, pp. 45–62.
- R Core Team (2021). R: A Language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>
- Rojas, J. C., Kolomiets, M. V. & Bernal, J. S. (2018). Nonsensical choices? Fall armyworm moths choose seemingly best or worst hosts for their larvae, but neonate larvae make their own choices. *PLoS ONE* 13(5), e0197628.
- Rwomushana, I., Bateman, M., Beale, T., Beshe, P., Cameron, K., Chiluba, M., Clotey, V., Davis, T., Day, R., Early, R., Godwin, J., Gonzalez-Moreno, P., Kansiime, M., Kenis, M., Makale, F., Mugambi, I., Murphy, S., Nunda, W., Phiri, N., Pratt, C. & Tambo, J. (2018). Fall armyworm: impacts and implications for Africa. Evidence Note Update (October 2018), CABI, UK. <https://www.invasive-species.org/Uploads/InvasiveSpecies/Faw%20Evidence%20Note%20October%202018%20Final.pdf>
- Sharanabasappa, S. D., Kalleshwaraswamy, C. M., Maruthi, M. S. & Pavithra, H. B. (2018). Biology of invasive fall armyworm, *Spodoptera frugiperda* (J E Smith) (Lepidoptera: Noctuidae) on maize. *Indian Journal of Entomology*, 80(3), 540–543. <https://doi.org/10.5958/0974-8172.2018.00238.9>
- Sparks, A. N. (1979). Review of the biology of the fall armyworm (Lepidoptera, Noctuidae). *Florida Entomologist*, 62, 82–87.
- Stillwell, R. C. & Davidowitz, G. (2010). A developmental perspective on the evolution of sexual dimorphism of a moth. *Proceedings of the Royal Society B*, 277, 2069–2074. <https://doi.org/10.1098/rspb.2009.2277>
- Stillwell, R. C., Blanckenhorn, W. U., Teder, T., Davidowitz, G. & Fox, C. W. (2010). Sex differences in phenotypic plasticity of body size affect variation in sexual size dimorphism in insects: from physiology to evolution. *Annual Review of Entomology*, 55, 227–245. <https://doi.org/10.1146/annurev-ento-112408-085500>
- Tobin, P.C., Nagarkatti, S. & Saunders, M.C. (2003). Phenology of Grape berry moth (Lepidoptera: Tortricidae) in cultivated grape at selected geographic locations. *Environmental Entomology*, 32, 340–346.
- Vickery, R. A. (1929). Studies on the fall armyworm in the Gulf Coast district of Texas. USDA, Washington, DC. Tech. Bull. No. 138. 64 pp.
- Westbrook, J. K., Nagoshi, R. N., Meagher, R. L., Fleischer, S. J. & Jairam, S. (2016). Modeling seasonal migration of fall armyworm moths. *International Journal of Biometeorology*, 60, 255–267.
- Zhou, C., Wang, L., Price, M., LI, J., Meng, Y. & Yue, B. (2020). Genomic features of the fall armyworm *Spodoptera frugiperda* (J.E Smith) yield insights into its defence system and flight capability. *Entomological Research*, 50 (2), 100–112. <https://doi.org/10.1111/1748-5967.12413>