

Original Research Article

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## Biology and Morphometrics of Fall Armyworm *Spodoptera frugiperda* (J. E. Smith) on Maize

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### ABSTRACT

#### Keywords

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A female fall armyworm, *S. frugiperda* laid 460 to 2424 pale greenish eggs in a mass mostly on the lower surface of maize leaves and covered with light brownish scales. The incubation period, larval period, pupal period and adult period of *S. frugiperda* were 2 to 5, 15 to 24, 8 to 13 and 6 to 15 days, respectively. The forewings of the male moth were greyish brown with a reniform indistinct spot and faintly outlined in black. The forewings of the female moth were ground brown with a mottled coloration of grey and brown markings, whereas the hindwing was silver-white. The developmental period and lifespan of *S. frugiperda* on maize were 28 to 40 and 32 to 59 days, respectively. The emergence of male and female moths from the pupa was 94.73 and 93.75 per cent, respectively.

### Introduction

The name “fall armyworm” originates from their nature of the damage, where infestations sometimes resemble as an army, as they move across large agricultural fields and earned their common name by eating all plant matter, they encounter in their wide dispersals, like a large army (Smith, 1797). Due to its migratory behavior, the fall armyworm is known as a sporadic pest. A new invasive pest, fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith)(Lepidoptera: Noctuidae) attained the status

as a major pest resulting in extensive yield losses of maize all over the world. FAW is a devoring pest native to tropical and subtropical regions of America where it was first detected in 1797 and first discovered in the African continent in 2016 (Goergen *et al.*, 2016) and has reached China, spreading across Africa and Asia continents, west to east, in just three years. Entry of this destructive insect into a portion of Asia is questionable because a majority of people inhabit there and in locations nearby and already a huge pressure is created on food production systems. In India, the occurrence

and prevalence of this invasive pest were noticed for the first time by Sharanabasappa *et al.*, (2018) from Karnataka state which is the first reported infestation in Asia, in July 2018. Subsequently, it spread into the other ten states of India till the middle of March 2019. Later, its existence was confirmed in the states of Maharashtra, Gujarat and Chhattisgarh (Chormule *et al.*, 2019; Sisodiya *et al.*, 2018; Deole and Paul, 2018). It is a cosmopolitan pest of the maize crop (Wiseman *et al.*, 1966). The fall armyworm may travel over 500 km before they start oviposition (Prasanna *et al.*, 2018). The study of the biology of fall armyworm as occurring in Gujarat is very much important for identifying the life stages and finding out the weaker stage of the pest which provides the basis for management strategies. Keeping this in view present studies were carried out.

## **Materials and Methods**

### **Nature of damage of fall armyworm**

The infestation of *S. frugiperda* was studied in field conditions on the GAYMH-1 variety of maize during the summer, 2022. Symptoms of the damage from the vegetative stage to the immature cob stage were recorded at periodic intervals.

### **Biology of fall armyworm, *S. frugiperda***

The GAYMH-1 variety of maize was grown at College Farm of NM College of Agriculture, NAU, Navsari and the larvae of fall armyworm were collected from a pesticide-free field and brought to the laboratory for further rearing at room temperature.

They were reared separately on the maize leaves in the Petri dish. The larva was fed on tender portions of maize leaves, which were soaked overnight in water for maintenance of turgidity before being provided as food to the larva. Till attaining the pupal stage, fresh maize leaves were provided daily in each Petri dish. A biological study was carried out on the second-generation population. The sexual

dimorphism of each pupa was examined by the position of the end distance between anal and genital slits under the binocular microscope. Emerged male and female adults were kept in a glass jar (21×15 cm).

They were allowed to lay eggs on maize leaves. The honey solution was provided as food for the adults by dipping a piece of cotton in the solution. The cotton swab was changed daily. Every morning from 8.00-9.00 o'clock the leaves, muslin cloth and cage were observed to check the egg laying. These eggs were used as nucleus culture for mass rearing and were utilized for the study of the biology of *S. frugiperda*.

### **Egg**

To study the shape and size of eggs, freshly laid eggs were collected in a Petri dish with the help of a fine camel brush. Fifty eggs were examined, subsequently their length and breadth were measured under the stereo zoom microscope.

During the study, the incubation period was recorded for 71 freshly laid eggs till hatching. The hatching percentage was also worked out.

### **Larva**

The color, size and larval duration of 50 larvae were recorded. The 1<sup>st</sup> to 3<sup>rd</sup> instar larvae were measured under a stereo zoom microscope and the 4<sup>th</sup> to 6<sup>th</sup> instar larvae were measured with the help of a standard scale. The head capsule casted off by each instar during changing of the larval instar was collected with a camel hair brush and measured individually.

The duration of each larval instar was determined by recording days between two moltings. The molting was confirmed by casting off the head capsule and increasing the size of the larva of subsequent instar every day between 08:00 to 09:00 o'clock. The total larval period was calculated from the date of egg hatching to the date of formation of pre-pupa.

### **Pre-pupa**

The length and breadth of a 50 pre-pupal stage were recorded with the help of a ruler. The color of the pre-pupal stage was also observed.

When a full-grown larva stops feeding, contracts in size and becomes sluggish in movement, it was considered to be the pre-pupal stage. The period of the pre-pupal stage was considered between the initiation of the pre-pupal stage to complete the conversion of a pupa. A total of 51 pre-pupae was observed for prepupal duration.

### **Pupa**

The length and breadth of 27 male and 23 female pupae were measured under a stereo-zoom microscope. The pupae were weighed in analytical and precision weighing machine. The data of weight of male and female were recorded separately. The change in color of the pupal stage was recorded daily until the distinctive color change ended.

The pupal period for 18 male and 30 female pupae was determined by considering the duration between formation of the pupa to emergence of the adult.

### **Developmental period**

The developmental period of 18 males and 30 females was calculated in days from the date of egg laying to the date of adult emergence from the pupa.

### **Adult**

Adults emerged from pupae were observed under a microscope for their size and sex differences. The female was distinguished from the male by the color differentiation of wings. The length of 20 adults was measured from the head to the tip of the abdomen and breadth was measured in the thorax region. The measurement of wing expansion of 16 males and 28 females was made from the wing attached to the body to an apical margin of the wing, whereas breadth was measured from an apical angle to an

anal angle. For the measurement of the length of the antennae of the same adults, the antennae of both male and female moths were separated from the body with the help of forceps and then measured with the help of a ruler.

### **Pre-oviposition, oviposition and post-oviposition period**

The pre-oviposition, oviposition and post-oviposition periods of 20 female moths were recorded. The pre-oviposition period was considered from the time of the emergence of an adult female to the time of commencement of the egg laying. The oviposition period was calculated from the date of commencement of the egg laying to the ceasing of egg laying by an individual female. The post-oviposition period was measured from the time of the ceasing of egg laying to the death of the female.

### **Fecundity**

Twenty gravid females were separately observed for fecundity. The number of eggs laid by a single female was recorded daily till the death of the female.

### **Adult longevity**

The longevity of twenty-twenty of males and females was recorded in days from the date of adult emergence from pupa to its death.

### **Adult emergence**

The number of adults emerged from the pupa was separately recorded for male and female. Finally, the adult emergence in terms of percentage was worked out.

### **Mating Behavior of Adult**

For the study of mating behavior, freshly emerged as well as around three-hour old female was separately kept for pairing. The pairing of such females with males was done by releasing them in a glass jar (21

× 15 cm). The observation of the female's calling behavior of mating with a male was recorded during dawn (07:00 to 08:00 o'clock) and dusk (17:00 to 20:00 o'clock). Ten per cent of honey solution swabbed cotton was placed inside each jaras feeding to the moth. The mouth of the glass jar was closed with muslin cloth with the help of a rubber band.

### **Sex ratio**

To determine the sex ratio (male: female) 48 adults were allowed for the emergence of males and females. The male and female were identified based on morphological features. Based on the emergence of males and females the sex ratio was worked out.

### **Life span**

The total life span of twenty-twenty males and females was recorded in days from the date of egg laying to the date of the respective adult's death.

### **Results and Discussion**

The biology and morphometrical study of fall armyworms were conducted under laboratory conditions at  $23.34\pm 1.52^{\circ}\text{C}$  morning,  $23.33\pm 1.32^{\circ}\text{C}$  afternoon temperature and  $57\pm 0.075$  per cent morning,  $57\pm 0.078$  per cent afternoon relative humidity during January-February, 2022. The results thus obtained are presented in Tables 1 to 3.

### **Eggs**

Adult females deposited their eggs in a mass in a single-tier fashion on an upper and lower surface of leaves but mostly preferred a lower surface as well as whorls. In the laboratory female deposited her eggs on muslin cloth and honey-swabbed cotton too. The eggs were occasionally deposited in two to three tiers style too. A gravid female laid six to seven egg masses and was sparsely covered from the abdominal tip with light brownish scales and this gave a moldy appearance. The eggs were flattened dorso-ventrally in shape; initially pale green which turned to golden yellowish after one day and at last

turned to blackish in color before hatching and after hatching of eggs the shell was a golden yellowish color. The average incubation period was  $3.06\pm 0.45$  days along with minimum and maximum periods of 2.00 and 5.00 days, respectively (Table 1).

The length of eggs varied from 0.47 to 0.60 mm with an average of  $0.54\pm 0.03$  mm, whereas the breadth varied from 0.45 to 0.60 mm with an average of  $0.54\pm 0.03$  mm. The average hatchability was  $73.23\pm 6.72$  per cent. However, minimum and maximum egg hatching was 65.79 and 94.20 per cent, respectively (Table 1).

More or less similar observations were also reported by Sisodiya *et al.*, (2018) who showed a mass of fall armyworm eggs deposited in layers and covered with greyish color scales. However, Siddhapara *et al.*, (2021) reported that the eggs were laid in clusters and the egg mass was covered with a layer of scales, sometimes not covered with scales. They reported 72.00 to 95.54 per cent hatchability which is very close to present findings but Gamil (2020) and Vinay *et al.*, (2022) reported higher hatchability up to 97.33 and 96.26 per cent, respectively.

Sharanabasappa *et al.*, (2018) also reported similar results in the incubation period ranging from 2 to 3 days with a mean of 2.50 days as well as a similar egg-laying pattern. The result confirmed the finding of Kranthi *et al.*, (2022) who reported a 2 to 3 days incubation period of eggs with an average of  $2.58\pm 0.098$  days. Prasanna *et al.*, (2018) reported a 0.4 mm diameter and 0.3 mm height of the egg which is close to the present finding. Siddhapara *et al.*, (2021) recorded the egg length as  $0.43\pm 0.01$  mm and breadth as  $0.42\pm 0.03$  mm which gave close conformity to the present finding.

### **Larva**

#### **First instar**

The soft-bodied neonate larva hatched out from the egg by making a hole in the surface of eggshell. Neonate larvae were very tiny relatively with a large

black head. The body of larvae was pale green to yellowish in color with two black-colored setae per segment. The length of the first instar larva varied from 0.54 to 1.16 mm with an average of  $0.94\pm 0.13$  mm and breadth varied from 0.13 to 0.29 mm with an average of  $0.24\pm 0.03$  mm (Table 2). The length and breadth of the head capsule of the first instar larvae varied from 0.18 to 0.98 mm and 0.02 to 1.00 mm with an average of  $0.62\pm 0.25$  mm and  $0.56\pm 0.28$  mm, respectively (Table 2). The duration of the first instar larvae was noted as 2 to 3 days with an average of  $2.47\pm 0.50$  days (Table 1). The larvae started to move from the lower surface of the leaf to the upper surface of the leaf. Initially, the first instar larvae consumed the leaf tissue from one side, leaving the opposite epidermal layer intact. Feeding by neonate caterpillars on the leaves resulted in semi-transparent patches, called a 'window pan'.

More or less similar observations were recorded by Kalyan *et al.*, (2020) on maize crop. The length and breadth are fairly lower as compared to the report of Sharma *et al.*, (2022) (1.51 mm length), Vishwakarma *et al.*, (2022) (1.67 mm length and 0.33 mm width) and Reddy *et al.*, (2021) ( $1.42\pm 0.28$  mm length). However, Manjula *et al.*, (2019) recorded 0.71 mm length and 0.16 mm width of the first instar larva, which is in agreement with the present work. The average width of the head capsule of the first instar was  $0.18\pm 0.02$  and  $0.34\pm 0.01$  mm reported by Ahmad *et al.*, (2021) and Sharanabasappa *et al.*, (2018), respectively. The results are in close confirmation to the results of Reddy *et al.*, (2021), who recorded 2 to 3 days (average  $2.6\pm 0.51$  days) duration of first instar larvae.

### **Second instar**

After completion of the first molting, the larvae become dark and appeared greenish brown in color. Two to four setae were sparsely on the dorsal side of each segment with a black head. Three pairs of thoracic legs developed on ventral side of the body. The faint white dorsal and sub-dorsal lines also

developed on the body at this stage. They were also increased in length as well as in breadth. The length of second instar larvae varied from 3.31 to 5.33 mm with an average of  $4.21\pm 0.49$  mm and breadth varied from 0.36 to 0.95 mm with an average of  $0.63\pm 0.11$  mm (Table 2). The length and breadth of the head capsule varied from 0.76 to 1.32 mm and 0.74 to 1.25 mm with an average of  $1.00\pm 0.16$  and  $0.96\pm 0.15$  mm, respectively (Table 2). The duration of second instar larvae ranged from 2 to 3 days with an average of  $2.22\pm 0.42$  days (Table 1).

The feeding behavior of the second instar larvae was mostly similar to that of the first instar larvae but the larval mass was scattered and individual larva lives separately. Larvae make tiny holes in leaves and eat from the edge of the leaves inward.

The similar body color of the second instar of *S. frugiperda* on maize crop was noted by Sharanabasappa *et al.*, (2018). Vishwakarma *et al.*, (2022) reported 3.81 mm and 1.14 mm mean body length and width, respectively. The results of the present findings are in corroboration with the report of Reddy *et al.*, (2020) and Reddy *et al.*, (2021). The results of the head capsule measurement are in contradiction with the work of Manjula *et al.*, (2019) who measured 3.5 to 4.0 mm length and 0.5 mm width of the head capsule of the second instar. Very close conformity of results accomplished by Reddy *et al.*, (2020) and Reddy *et al.*, (2021) who also reported 2 to 3 days larval period of second instar.

### **Third instar**

The dorsal surface of the body of the third instar larvae was brownish and lateral three white lines began to form. The dorsal and sub-dorsal white lines were plainly visible and the black spots became prominent.

On head, the Y-shape yellow colored epicranial suture was observed. The head and first thoracic segments were black. The two spots on the posterior lateral were larger in size. The dorsal surface of each segment of the abdomen has a characteristic crescent

shape (semi-circle) made up of four spots with larger middle spots. Up to the penultimate segment of the abdomen, the big spots were dark.

The length and breadth of third instar larvae varied from 4.00 to 9.00 mm and 0.56 to 2.00 mm, with an average of  $6.35\pm 1.27$  and  $0.97\pm 0.27$  mm, respectively (Table 2). The length and breadth of the head capsule of third instar larvae varied from 1.11 to 1.85 mm and 1.07 to 1.55 mm with an average of  $1.33\pm 0.16$  and  $1.29\pm 0.14$  mm, respectively (Table 2). The third instar larval period ranged from 2 to 4 days with an average of  $2.28\pm 0.86$  days (Table 1). The third instar larvae were mostly observed in the vegetative portion of the plant, leaves with a series of shot holes and eaten from the edge of the leaves inward. A more or less similar observation was made by Ahmad *et al.*, (2021). Siddhapara *et al.*, (2021) showed  $2.43\pm 0.50$  days larval period of the third instar, Vinay *et al.*, (2022) noted 2-3 days with an average of  $2.20\pm 0.41$  days.

#### **Fourth instar**

Brownish black body with reddish pigmentation was noticed in the fourth instar. The larvae mottled with the white-brownish body had three white dorsal lines and an alight lateral line. The front of the head was white. An inverted “Y” shaped epicranial suture distinctively appeared. The elevated dark-colored black spots with spines were observed on the dorsal side of the abdomen. The dorsal surface of each segment of the abdomen has a characteristic crescent shape (semi-circle) made up of four spots with larger middle spots. However, on the posterior segment of the abdomen, the inverted shape of the crescent has formed. The typical trapezoidal shape of four black spots was surrounded by two crescents of the last two abdominal segments. The rough or granular textured epidermis of the larvae was noticed. The head and first thoracic segment were black while the second thoracic segment was lighter black in color. All the spots were arranged as in the case of the third instar with the increase in size and darkness. The spiracles on the prothorax and eighth abdominal segments were elliptical while the rest

were circular. Molting of larva from the third to fourth instar was observed. The length of the fourth instar larvae was noticed from 7.00 to 14.00 mm which with an average of  $10.09\pm 1.96$  mm, whereas breadth was from 0.89 to 2.30 mm which averaged out to  $1.32\pm 0.37$  mm (Table 2). The length and breadth of the head capsule of fourth instar larvae varied from 1.31 to 2.04 mm (average  $1.56\pm 0.20$  mm) and 1.29 to 1.90 mm (average  $1.53\pm 0.16$  mm), respectively (Table 2). The duration of the fourth instar larvae was recorded between 2 to 5 days with an average of  $2.98\pm 0.86$  days (Table 1). A similar type of feeding behavior was observed in the fourth instar larvae as in the third instar. It feeds on leaves with a series of shot holes and severely cuts the whorls.

Identical results were observed by Sharanabasappa *et al.*, (2018) and Siddhapara *et al.*, (2021) who reported that fourth instar larvae were brownish-black and had three white dorsal lines and an alight lateral line. Reddy *et al.*, (2020) mentioned an inverted ‘Y’ shaped marking on the head and the arrangement of four black spots in a square on the dorsal surface of the 8<sup>th</sup> abdominal segment. The result reported by Sharma *et al.*, (2022) was quite similar to the present observation in which they reported 11.6 mm of the average length of 4<sup>th</sup> instar larvae. However, Siddhapara *et al.*, (2021) recorded  $13.94\pm 1.09$  mm length and  $0.84\pm 0.02$  mm width. Sharma *et al.*, (2022) reported a  $1.37\pm 0.006$  mm width of the head capsule of the fourth instar, whereas Sharanabasappa *et al.*, (2018) reported a  $1.22\pm 0.05$  mm (1.17 to 1.30 mm) width which was somewhat similar to present findings. Tiwari and Deole (2021) reported  $2.10\pm 0.06$  days (2 to 3 days) period, whereas Vinay *et al.*, (2022) reported  $2.27\pm 0.47$  days larval developmental period of the fourth instar.

#### **Fifth instar**

The color of the fifth instar larvae was yellowish to cream. A white line was noted in the mid-dorsal area of the body but was interrupted. Yellowish flecking was present on the ventral surface of the abdomen.

Larvae also possessed a distinct pattern of four “dots” on the eighth abdominal segment. Elevated typical dark spots with setae occurred dorsally on the body. The head was reddish brown, mottled with white color.

Molting of larva from the fourth to fifth instar was observed. The length of fifth instar larvae varied from 16.00 to 27.00 mm with an average of  $21.29 \pm 2.64$  mm and breadth was varied from 1.50 to 4.00 mm with an average of  $2.58 \pm 0.53$  mm (Table 2). The length and breadth of the head capsule of the fifth instar larvae were from 2.13 to 2.86 mm and 2.02 to 2.56 mm with an average of  $2.33 \pm 0.16$  mm and  $2.24 \pm 0.13$  mm, respectively (Table 2). The duration of the fifth instar larvae was noted as 3 to 6 days with an average of  $3.67 \pm 0.95$  days (Table 1). The matured leaves with a series of differently shaped shot holes and severely cut whorls (Like cut with a sickle or grazed by an animal) like characteristic damage by fifth instar larvae was observed. The fifth instar larvae were found to scrape on older leaves too. Reddy *et al.*, (2020) noted the color of fifth instar larvae as brownish black with three distinct dorsal lines. The present finding agreed with the finding of Ahmad *et al.*, (2021) and Vishwakarma *et al.*, (2022) who reported  $19.32 \pm 1.65$  and  $2.87 \pm 1.54$ ; and 18.81 mm and 3.45 mm body length and width, respectively. Ahmad *et al.*, (2021), Sharma *et al.*, (2022) and Sharanabasappa *et al.*, (2018) noted  $1.10 \pm 0.13$ , 2.11 and  $1.96 \pm 0.06$  mm average width of the head capsule of fifth instar larvae, respectively.

Tiwari and Deole (2021) reported  $2.10 \pm 0.06$  days (2 to 3 days) period. More or less similar to the results of Sharma *et al.*, (2022) who reported  $2.63 \pm 0.076$  days larval duration of the fifth instar.

### **Sixth instar**

The sixth instar larvae were most stout and bulged with somewhat cylindrical in shape. Their body was smooth with clear and distinct segmentation. The head was dark brown and slightly bilobed. The body was reddish cream, the head was brown, and the first

thorax was light brown. Dorsal lines and lateral dark areas became light. Spots became black in color, surrounding areas reduced in size, the ring was black and the surrounding area was light in color. On the first thoracic segments, spots were very small. On the abdomen and on the 2<sup>nd</sup> thoracic segment, the spots were large. Spiracles were found very black in light brown lateral areas. The key identification characters *viz.*, inverted “Y” shaped epicranial suture on the head and the four spots arranged in an exact square on the 8<sup>th</sup> abdominal segment were very clearly seen in all the instars of the larva. The length of sixth instar larvae in the range from 25.00 to 36.00 mm with an average of  $29.08 \pm 2.47$  mm, whereas breadth in range from 2.00 to 5.00 mm with an average of  $3.52 \pm 0.67$  mm (Table 2). The length and breadth of the head capsule of the sixth instar larvae varied from 2.92 to 3.44 mm and 2.78 to 3.68 mm with an average of  $3.17 \pm 0.14$  mm and  $3.23 \pm 0.19$  mm, respectively (Table 2). The duration of sixth instar larvae ranged from 4 to 8 days which averaged out to  $4.63 \pm 0.87$  days duration (Table 1). The feeding behavior of sixth instar larvae was mostly similar to that of fifth instar larvae. Similar observations were made by Babu *et al.*, (2019) who observed the larva was dark brown with a reddish-brown head marked with an inverted ‘Y’ shape on the head with elevated distinct dark-colored black spots on the whole body which bore spines. Results of Ahmad *et al.*, (2021) and Reddy *et al.*, (2021) were nearly similar for length and width of sixth instar larvae as they measured  $26.98 \pm 2.93$  and  $3.90 \pm 0.00$  mm as well as  $33.6 \pm 1.67$  mm and  $5.90 \pm 0.26$ , respectively. Very close conformity of present result supported by report of Vishwakarma *et al.*, (2022) who measured 3.01 mm width of the head capsule, whereas  $2.70 \pm 0.013$  mm width was measured by Sharma *et al.*, (2022). However, the present result is more or less in agreement with the work carried out by Vishwakarma *et al.*, (2022) who reported 3.01 days sixth instar period.

### **Total larval period**

The total larval period varied from 15 to 24 days with an average of  $18.84 \pm 1.90$  days under laboratory

conditions (Table 1). The results of present findings are more or less in agreement with the work carried out by Ramzan *et al.*, (2021) who reported 14 to 16 days total larval developmental period and Kalyan *et al.*, (2020) reported average period of 16.97 days.

### **Cannibalism behaviour**

The cannibalism was observed in first to third instar larvae, which was observed higher in fourth to sixth instar larvae. The present observations are similar to the observations made by Chapman *et al.*, (1999) and Andow *et al.*, (2015), who reported that cannibalism occurs in equal-aged larvae.

### **Pre-pupal**

When the larvae completed its development, they ceased feeding, became sluggish, darker and wrinkled, contracted their body and reached to the pre-pupal stage. The length of pre-pupa was varied from 12.00 to 22.00 mm with an average of  $17.04 \pm 2.33$  mm, whereas breadth was 2.00 to 4.50 mm with an average of  $3.32 \pm 0.61$  mm (Table 2). The duration of pre-pupa varied from 1 to 2 days with an average of  $1.57 \pm 0.50$  days (Table 1).

Similar observation was also made by Sharanabasappa *et al.*, (2018) and Vishwakarma *et al.*, (2022) who also reported cessation of feeding and color changing from greenish to the bright brown.

In contradiction to present findings, Tiwari (2020) showed the length and breadth of the pre-pupae ranging from 19 to 22 mm with an average of  $20.0 \pm 0.11$  mm and 2.7 to 3.2 mm with an average of  $3.08 \pm 0.02$  mm, respectively. Inconsistency in prepupal duration with longer prepupal period between 2 to 3 days was reported by Tiwari and Deole (2021) as well as Kranthi *et al.*, (2022) with an average of  $2.10 \pm 0.06$   $2.55 \pm 0.054$  days, respectively. The controversial results might be due to change of maize varieties as previous work was carried out on nutritious varieties and under higher temperature and relative humidity in *kharif* season.

### **Pupa**

The larvae of *S. frugiperda* pupated in Petri dish under laboratory condition. However, the full-grown larva pupated in the soil under field conditions at a depth of 2 to 8 cm, moreover, larvae were also found to pupate in cob. Newly formed pupae of *S. frugiperda* were brownish green and static movement of pupae was observed in this condition. After 12-14 hours, the pupa was changed to a dark reddish-brown color. Identification of sex in the pupal stage was done by observing at the genital opening. The pupa was broadly rounded from the anterior side and tapered from the posterior side. The pupa was an obtect type. They had a typical cremaster with two spines.

The length of the pupa was ranging from 14.98 to 18.39 mm with an average of  $16.60 \pm 0.82$  mm, whereas breadth was ranging from 4.57 to 5.65 mm with an average of  $5.05 \pm 0.23$  mm (Table 2). The length of male pupa varied from 15.87 to 18.39 mm with an average of  $16.99 \pm 0.66$  mm, whereas breadth varied from 4.57 to 5.65 mm with an average of  $5.06 \pm 0.26$  mm (Table 2). The length and breadth of male pupa was larger than female. The length of female pupa was varied from 14.98 to 17.67 mm with an average of  $16.17 \pm 0.75$  mm, whereas breadth of pupa was varied from 4.60 to 5.40 mm with an average of  $5.03 \pm 0.22$  mm (Table 2). The pupa required 8 to 13 days to complete this stage and average duration was  $9.24 \pm 1.60$  days. The duration of male pupa was varied from 8 to 12 days with an average of  $9.15 \pm 0.93$  days. The duration of female pupa was varied from 8 to 13 days with an average of  $9.15 \pm 1.69$  days (Table 1). The weight of male pupa was varied from 86.40 to 187.50 mg and the average weight was  $151.65 \pm 23.40$  mg, whereas female pupa was varied from 49.10 to 139.60 mg with an average of  $108.21 \pm 22.92$  mg. The female pupa weight was less than male pupa. Siddhapara *et al.*, (2021) observed the pupation mostly in the soil up to 2-5 cm deep in moist soil and within oval earthen cell. The result provided close conformity with report of Reddy *et al.*, (2021) and Prasanna *et al.*, (2018).



**Table.1** Biological parameters of fall armyworm, *S. frugiperda*

Life stage	Min. (Days)	Max. (Days)	Mean± SD (Days)
<b>1. Egg period</b>			
Incubation period	2	5	3.06±0.45
<b>2. Larval period</b>			
I instar	2	3	2.47±0.50
II instar	2	3	2.22±0.42
III instar	2	4	2.88±0.86
IV instar	2	5	2.98±0.86
V instar	3	6	3.67±0.95
VI instar	4	8	4.63±0.87
Total larval period	15	24	18.84±1.90
<b>3. Pre-pupal period</b>			
<b>4. Pupal period</b>			
Male	8	12	9.15±0.93
Female	8	13	9.15±1.69
<b>5. Developmental period</b>			
Male	30	37	32.25±1.89
Female	28	40	32.25±3.20
<b>6. Adultperiod</b>			
Pre-oviposition period	1.50	7	3.08±1.24
Oviposition period	3	7	5.15±1.22
Postoviposition period	0.29	5	1.22±1.52
<b>7. Longevity</b>			
Male	6	14	9.95±1.96
Female	8	15	11.30±2.34
Fecundity	460	2424	1272.88± 503.15
<b>8. Life span</b>			
Male	32	58	41.00±5.14
Female	34	59	43.50±4.82
<b>9. Hatching %</b>			
<b>10. Sex ratio (Male:Female)</b>			
		1:1.67	
<b>11. Adult emergence</b>			
Sex	Total		% emergence
Male	19		94.73
Female	32		93.75

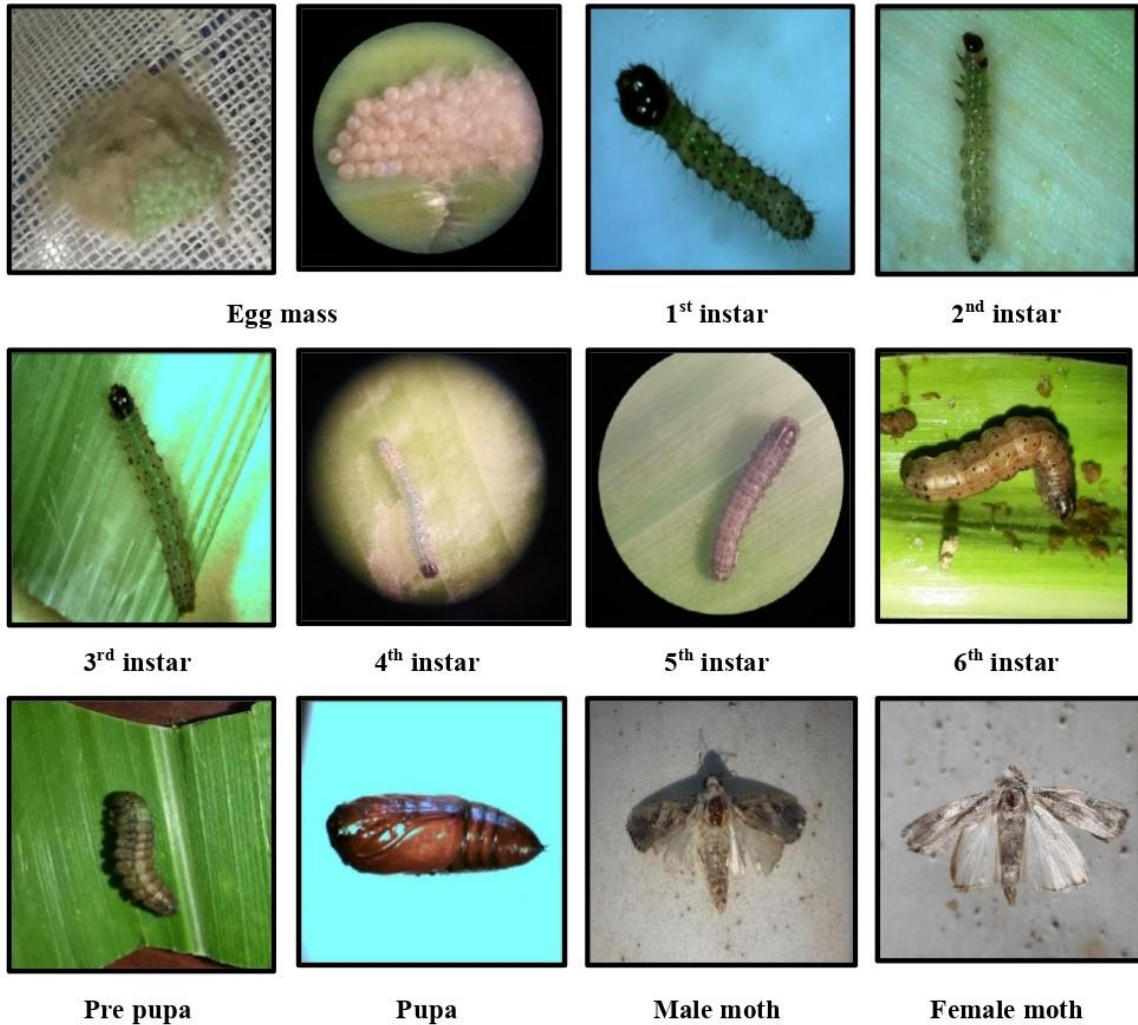
**Table.2** Measurement of different immature life stages of fall armyworm

Life stage	Particulars	Min.	Max.	Mean±SD
Eggs (mm)	Length	0.47	0.60	0.54±0.03
	Breadth	0.45	0.60	0.54±0.03
<b>Body of larva (mm)</b>				
I instar	Length	0.54	1.16	0.94±0.13
	Breadth	0.13	0.29	0.24±0.03
II instar	Length	3.31	5.33	4.21±0.49
	Breadth	0.36	0.95	0.63±0.11
III instar	Length	4.00	9.00	6.35±1.27
	Breadth	0.56	2.00	0.97±0.27
IV instar	Length	7.00	14.00	10.09±1.96
	Breadth	0.89	2.30	1.32±0.37
V instar	Length	16.00	27.00	21.29±2.64
	Breadth	1.50	4.00	2.58±0.53
VI instar	Length	25.00	36.00	29.08±2.47
	Breadth	2.00	5.00	3.52±0.67
<b>Head capsule of larva (mm)</b>				
I instar	Length	0.18	0.98	0.62±0.25
	Breadth	0.02	1.00	0.56±0.28
II instar	Length	0.76	1.32	1.00±0.16
	Breadth	0.74	1.25	0.96±0.15
III instar	Length	1.11	1.85	1.33±0.16
	Breadth	1.07	1.55	1.29±0.14
IV instar	Length	1.31	2.04	1.56±0.20
	Breadth	1.29	1.90	1.53±0.16
V instar	Length	2.13	2.86	2.33±0.16
	Breadth	2.02	2.56	2.24±0.13
VI instar	Length	2.92	3.44	3.17±0.14
	Breadth	2.78	3.68	3.23±0.19
Pre-pupa (mm)	Length	12.00	22.00	17.04±2.33
	Breadth	2.00	4.50	3.32±0.61
Pupa (mm)	Length	14.98	18.39	16.60±0.82
	Breadth	4.57	5.65	5.05±0.23
Male	Length	15.87	18.39	16.99±0.66
	Breadth	4.57	5.65	5.06±0.26
Female	Length	14.98	17.67	16.17±0.75
	Breadth	4.60	5.40	5.03±0.22
<b>Weight of pupa (mg)</b>				
Male		86.40	187.50	151.65± 23.40
Female		49.10	139.60	108.21± 22.92

**Table.3** Measurement of adult body, wings and antenna of fall armyworm, *S. frugiperda*

Particulars	Male			Female		
	Measurement (mm)			Measurement (mm)		
	Min.	Max.	Mean±SD	Min.	Max.	Mean±SD
Length of body	13.00	21.00	16.62±1.66	13.00	19.00	14.76±1.58
Breadth of body	3.00	5.10	4.32±0.50	3.00	4.50	3.76±0.45
Forewing expanse (length)	12.50	15.00	13.66±0.75	12.00	15.00	13.93±0.94
Forewing expanse(breadth)	5.00	6.00	5.50±0.52	4.00	7.00	5.61±0.78
Hindwing expanse (length)	10.00	13.00	11.19±0.91	10.00	13.00	11.11±0.92
Hindwing expanse (breadth)	6.00	9.00	7.03±0.83	5.00	8.00	6.39±0.99
Antennae length	7.00	9.00	8.00±0.80	5.00	9.00	7.21±0.96

**Fig.1**



### **Difference between male and female pupa**

Pupal sexing was done by looking at the genital opening. The distance between the genital opening and the anal slot was used to distinguish the female and male pupa. In females, the distance between the genital opening and anal slot was more compared to the male.

### **Developmental period**

The period from egg to adult emergence was considered as developmental period. The developmental period for males was 30 to 37 days with an average of  $32.25 \pm 1.89$  days, whereas it was noticed between 28 to 40 days with an average of  $32.25 \pm 3.20$  days for females (Table 1).

The results are more or less in agreement with the results of Sharanabasappa *et al.*, (2018); Rajisha *et al.*, (2022) and Vinay *et al.*, (2022).

### **Adult emergence**

About 94.73 and 93.75 per cent healthy male and female moths were successfully emerged from the pupa, respectively. (Table 2).

### **Adults**

The forewings of the male moth were greyish brown with a reniform blurry spot, faintly outlined in black, with a small V-shaped mark; a pale brown orbicular spot, somewhat oval and oblique in shape and a white patch at the apical margin of the wing. The hindwings were silver-white with a narrow dark border in males.

The forewings of the female were grey and brown in color *i.e.*, with a mottled coloration of grey and brown, with brown markings and without a white patch near the apical margin of the wing.

The hindwing was silver-white with a narrow dark border in females. The length of male moths ranged from 13 to 21 mm with an average of  $16.62 \pm 1.66$

mm; while breadth ranged from 3.00 to 5.10 mm with an average of  $4.32 \pm 0.50$  mm (Table 3). The length of female moths ranged from 13 to 19 mm with an average of  $14.76 \pm 1.58$  mm; while breadth ranged from 3.00 to 4.50 mm with an average of  $3.76 \pm 0.45$  mm (Table 3).

The results of present findings are more or less similar to work of Manjula *et al.*, (2019) and Maurya *et al.*, (2019).

### **Forewing and hindwing expanse**

The length of the male forewing varied from 12.50 to 15.00 mm with an average of  $13.66 \pm 0.75$  mm and the breadth varied from 5.00 to 6.00 mm with an average of  $5.50 \pm 0.52$  mm; while the male hindwing length varied from 10.00 to 13.00 mm with an average of  $11.19 \pm 0.91$  mm, whereas breadth varied from 6.00 to 9.00 mm with an average of  $7.03 \pm 0.83$  mm (Table 3).

The length of the forewing of female varied from 12.00 to 15.00 mm with an average of  $13.93 \pm 0.94$  mm and the breadth varied from 4.00 to 7.00 mm with an average of  $5.61 \pm 0.78$  mm; while the length of the hindwing varied from 10.00 to 13.00 mm with an average of  $11.11 \pm 0.92$  mm and breadth varied from 5.00 to 8.00 mm with an average of  $6.39 \pm 0.99$  mm (Table 3).

### **Length of antennae**

The length of antennae of male moths varied from 7.00 to 9.00 mm with an average of  $8.00 \pm 0.80$  mm. In the case of female moths, the length of antennae varied from 5.00 to 9.00 mm with an average of  $7.21 \pm 0.96$  mm (Table 3).

### **Longevity of moth**

The duration of male and female moths varied from 6 to 14 and 8 to 15 days with an average of  $9.95 \pm 1.96$  and  $11.30 \pm 2.34$  days, respectively. More or less similar results were noted by Deole and Paul (2018) and Sharanabasappa *et al.*, (2018).

## Mating behavior of adult

It was observed that the freshly released female couldn't attract a male partner for mating, but around three-hour old female showed her calling behavior of mating to a male partner through its mating attraction. Mostly the mating was shown at dusky times. The mating was not seen during sunny times, but on cloudy days adults were observed to mate during day time also.

## Pre-oviposition, oviposition and post-oviposition period

The pre-oviposition, oviposition and post-oviposition periods of female moths varied from 1.5 to 7, 3 to 7 and 0.29 to 5 days with an average of  $3.08 \pm 1.24$ ,  $5.15 \pm 1.22$  and  $1.22 \pm 1.52$  days, respectively (Table 1). The average  $1272.88 \pm 503.15$  eggs were laid by a single female with a minimum egg laying of 460 to a maximum of 2424 eggs. The sex ratio (male: female) was 1:1.67. The results of the present experiment corroborate with the work of Ashok *et al.*, (2020); Ahmad *et al.*, (2021) and Siddhapara *et al.*, (2021).

## Life span

The lifespan of male *S. frugiperda* was recorded in the range between 32 to 58 days with an average of  $41.00 \pm 5.14$  days (Table 1). The lifespan of females varied from 34 to 59 days with an average of  $43.50 \pm 4.82$  days (Table 1). Similar results were reported by Sharanabasappa *et al.*, (2018); Kalyan *et al.*, (2020) and Ahmad *et al.*, (2021). Contradictorily, total lifespan of female and male was reported with an average of  $36.0 \pm 0.75$  days and 28 to 41 days with an average of  $33.1 \pm 0.69$  days respectively, by Tiwari and Deole (2021). The prolongation of lifespan might be due to lower temperature during study period.

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