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Biology and life tables of invasive fall armyworm *Spodoptera frugiperda* on sunflower, *Helianthus annuus*

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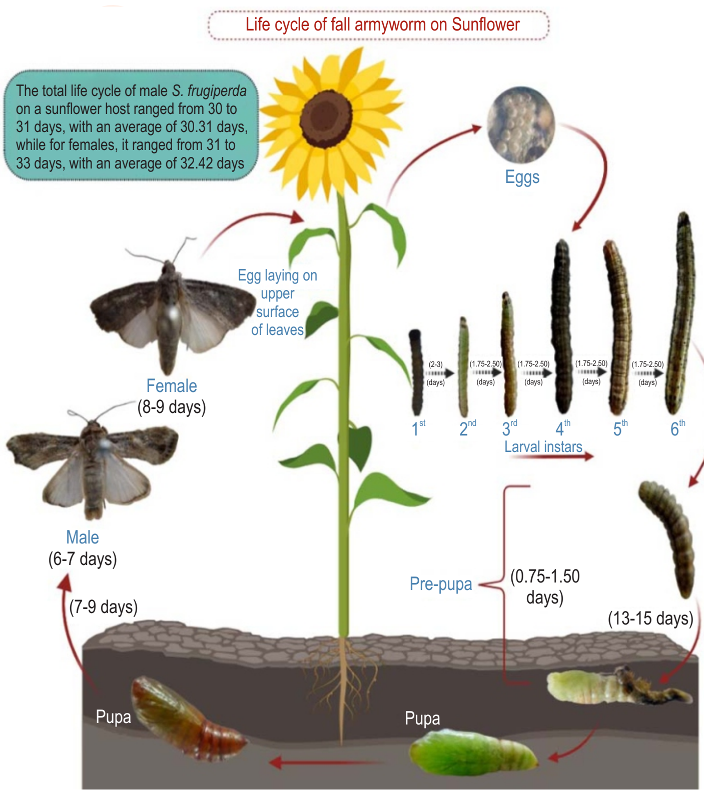
Abstract

Aim: To investigate the biology, growth and development, morphometrics and population life tables of invasive fall armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith) on sunflower, *Helianthus annuus* (L.).

Methodology: The study was conducted in a controlled environment with regulated temperature (27±2°C), humidity (75±5%) and a photoperiod of L12:D12. Sunflower plants were grown as host following recommended agricultural practices, excluding specific plant protection measures. All the observation were taken using standard procedures and protocols.

Results: Female moths laid an average of 691.60 eggs with a hatch ability percentage of 94-98% and an incubation period of 2-3 days. Larval and pupal periods was 13.74 and 7.55 days. The total life cycle was 30.82 days for males and 32.42 days for females. Morphological measurements showed incremental growth in larval head capsule width, length and weight across in stars. Pupal lengths15.92 mm for males and 16.40 mm for females with corresponding weights of 198.31 mg and 210.60 mg. Population parameters revealed a mean length of generation (Tc) of 30.42 days, an intrinsic rate of increase of 0.185 females female^{-1} day^{-1}, a mean generation time (T) of 30.29 days, a finite rate of increase in numbers (λ) of 1.53 females female^{-1} day^{-1} and a corrected innate capacity for increase in numbers (rm) of 0.186 females female^{-1} day^{-1}.

Interpretation: This study provides valuable insights into the life cycle and basic biology of fall armyworm on sunflower as well as critical information about population dynamics to develop strategies to mitigate its impact on agriculture.



Key words: Biology, Life tables, *Spodoptera frugiperda*, Sunflower

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Introduction

The fall armyworm, scientifically known as *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae), previously identified as *Laphygma frugiperda,* traces its first recorded presence back to the United States in 1797 (Johnson, 1987). This highly migratory and polyphagous herbivore, native to tropical and subtropical America (Luginbill, 1928; Sparks, 1979), has rapidly spread across the globe, earning a classification as a level A1 threat. Its short development cycle (Sharanabasappa *et al.,* 2018), wide host range (Montezano *et al.,* 2018), prolificacy (Sparks, 1979) and remarkable dispersal ability (Westbrook *et al.,* 2016; Rose *et al.,* 1975) render it a significant threat to subsistence and cash crops worldwide. A part from America, the invasion of *S. frugiperda* was first observed in Central and Western Africa in early 2016 (Goergen *et al.,* 2016), followed by its widespread presence in sub-Saharan Africa (Day *et al.,* 2017) and confirmed in over 44 countries. Concerningly, South and South-east Asia as well as Australia are deemed highly susceptible to fall armyworm spread (Early *et al.,* 2018), posing a significant threat to food security and the livelihoods of millions of smallholder farmers. In India, the invasion of *S. frugiperda* was initially documented in May 2018 on maize in Shivamogga, Karnataka (Sharanabasappa *et al.*, 2018).

By August 2018, the pest had spread across maize-growing regions of South India, including Maharashtra (Sharanabasappa *et al.,* 2018) becoming a severe menace to maize crops in Vidarbha, Khandesh, Marathawada and Western Maharashtra regions. Beyond maize, the pest has also been reported on sugarcane, sorghum and sweet corn in districts such as Sangali, Kolhapur, Solapur and Pune (Chormule *et al.,* 2019). Given its polyphagous nature, *S. frugiperda* poses a threat to a wide array of crops, attacking 353 plant species of 76 families, with a preference for crops belonging to family Poaceae, Asteraceae and Fabaceae (Montezano *et al.,* 2018). Besides maize, it also reported to feed on economically important crops such as rice, sorghum, sugarcane, cabbage, sunflower, beet, peanut, soybean, alfalfa, onion, cotton, pasture, grasses, millets, potato and tomato (Montezano *et al.,* 2018). In response to the rapid global spread of *S. frugiperda* significant research has focused on the pest's behavior, host preference and ecological impacts across diverse environments. Historically, *S. frugiperda* has been well-documented in maize, its primary host, where its destructive larval stage causes significant yield losses.

However, recent studies reveal the pest's adaptability to non-traditional hosts such as sunflower, which poses a new challenge in agricultural management (Montezano *et al.,* 2018). Sunflower (*Helianthus annuus* L.) a globally significant oilseed crop plays an essential role in agricultural economies, particularly in the production of vegetable oils and livestock feed. Its vulnerability to fall armyworm infestation exacerbates the challenges faced by farmers, especially in regions already struggling with pest management. While research has established the pest's impact on maize and other Poaceae family members, studies on *S. frugiperda's* interactions with sunflower remain limited necessitating in-depth exploration of its biology and lifecycle on this host. Understanding *S. frugiperda's* growth and development on sunflower is critical for predicting potential outbreaks and formulating effective management strategies. Given the pest's adaptability, it is imperative to assess its life cycle parameters, fecundity and survival rates on sunflower to adapt integrated pest management (IPM) strategies. This study, therefore, aims to address these gaps by exploring the pest's biology on sunflower under controlled laboratory conditions. The findings will inform future efforts to mitigate the threat posed by *S. frugiperda* to sunflower crops, ultimately contributing to better pest control practices across various cropping systems.

Materials and Methods

The experiment was carried out in an insect rearing laboratory under controlled laboratory setting with consistent conditions of temperature (27± 2°C), humidity (75 ± 5%) and a photoperiod of L12 : D12. The objective was to investigate the biology, morphometrics and life tables of *S. frugiperda* on a sunflower host. Host plant (Sunflower) was cultivated using standard agronomic practices as per recommended by VNMKV, Parbhani University, excluding any plant protection measures during 2021 on the Research Farm, Department of Entomology, College of Agriculture, Latur, Maharashtra, India.

Laboratory culture of fall armyworm: The laboratory culture of fall armyworm, *S. frugiperda* (J.E. Smith) (Noctuidae: Lepidoptera), was initiated by collecting large-sized larvae from sunflower crops cultivated on the research farm. These larvae were individually reared in clean round plastic vials (3.5 cm diameter × 4 cm height), with the vials being cleaned daily. Each day, the larvae were fed with unsprayed field-collected leaves of sunflower during morning hours until pupation. Upon pupation, the sexes of the pupae were determined based on the distance between the two apertures. Male pupae typically exhibited a shorter distance between the genital and anal apertures, while female pupae showed a greater distance (Fig. 1) (Luginbill, 1928). Upon emergence, the adult moths from the same day were separated. One male and one female adult were then paired together in an oviposition cage for copulation and egg-laying. A cotton swab dipped in 50% honey solution was provided as food for the adults in the oviposition cage. Fresh leaves, delicate stems and heads of sunflower were also provided as an oviposition substrate. Every 24 hours, the leaves were examined for the presence of eggs or egg masses and replaced with fresh ones. Freshly laid eggs were further selected for investigating the biology, morphometrics and population life tables of invasive fall armyworm *S. frugiperda.*

Biology of *S. frugiperda*: A total of 100 eggs of *S. frugiperda* were used with 20 eggs in each replication. Upon hatching, each larva was individually reared on fresh sunflower leaves, tender stems and heads. Fresh food was provided daily throughout the larval stage. The observations were recorded on larval duration, pupation percent, pupal duration, growth index, adult emergence percent, adult longevity and duration of life-cycle. Following emergence, male and female adults were paired in oviposition cages for mating and egg collection. The adults were supplied with a cotton swab dipped in 50% honey solution as a food source. (Bankar and Bhamare, 2023a). The growth index was calculated by using Howe's (1953) formula:

$$\text{Growth Index} = \frac{\text{\% larvae pupated}}{\text{Mean larval duration (days)}}$$

Morphometrics of *S. frugiperda*: For the morphometrics study, observations on exuviae casting were conducted under a microscope. After each larval instar, immediately following molting, measurements were taken for head capsule width, head capsule length, body length, width and weight of each larva using ocular and stage micrometres (Olympus ocular micrometer and Am Scopestage micrometer) with precision to the nearest value of 0.1053 mm. Dyar's rule (1890) was applied to determine the number of larval instars fed on sunflower. To assess the relationship between instar and the mean value of head capsule width, a regression analysis was performed using the formula Log 10 Y = a + bx, where Y represents the mean head capsule width of the larva, a is the constant, b is the logarithm of growth ratio and x is the number of instars. The growth ratio was computed by dividing the mean value of head capsule width by the mean value of head capsule width of larva of the preceding instar. Measurements of pupal morphometrics were also recorded, including width, length and weight of ten pupae with each measurement replicated five times.

Life tables of *S. frugiperda*: The life-fecundity tables of *S. frugiperda* on sunflower were established through the observation of 100 eggs across 20 per replication. Each egg was delicately affixed to white tissue paper using a soft, damp camel hair brush and then placed in a petri dish to facilitate hatching observations. Upon hatching, all larvae were individually reared on fresh sunflower leaves, tender stems and heads. Fresh food was provided daily throughout the larval stage. Daily observations were conducted on hatching, larval development, pupal development, successful emergence of adults, fecundity and age-specific mortality in eggs, larvae, pupae and adults. The emerged adults from each batch were transferred to separate cages at a ratio of 3:1 (male: female) to determine age-specific fecundity. Fresh, healthy leaves from the corresponding host plant were provided in the cage for egg laying. Additionally, a cotton swab soaked in 50% honey solution was provided daily as a food source for the moths in the oviposition cage. Following Southwood's method (1968), the number of female births (mx) was calculated by dividing the number of eggs laid per female by two, considering a sex ratio of 1:1. The life-fecundity tables under laboratory conditions were constructed by using the following column headings proposed by Birch (1948), elaborated by Howe (1953) and Atwal and Bains (1974).

x = Pivotal age in days
l_x = Survival of females at age 'x'
m_x = Age schedule for female births at age 'x'

The value of 'x', 'lx' and 'mx' was calculated from the data on life-tables.

Net reproductive rate: The sum of products '$l_x m_x$' is the net reproductive rate represented by R_o (Lotka 1925). The net reproductive rate in each generation was measured in terms of females multiplied per generation was calculated by the following formula: $R_o = \Sigma\, l_x m_x$

Mean generation time: The precise value of cohort generation time (T_c) is the mean age of mothers in a cohort at the birth of female off springs. It was calculated as follows.

$$T_c = \frac{\Sigma\, l_x m_x X}{R_o}$$

Innate capacity for increase in numbers: The numbers of individuals survived and mean number of female offspring's produced at each age interval were recorded and the arbitrary value of innate capacity for increase in number r_c was calculated by the formula given by Loughlin (1965).

$$r_c = \frac{\mathrm{Log}_e R_o}{T_c}$$

Intrinsic rate of increase (r_m): It is calculated from the value of arbitrary 'r_m' by taking three trial values arbitrarily selected on either side of it differing in second decimal place by interpolation with formula given by Birch (1948) and Watson (1964).

$$\Sigma\, e^{7-rmx} l_x\, m_x = 1096.6$$

Table was then constructed with column 'X' and '$l_x m_x$' for each trial 'r_m'. The three trial values of $\Sigma\, e^{7-rmx} l_x\, m_x$ were then plotted on the horizontal axis against their respective arbitrary 'r_m' on the vertical axis. The points were joined to give a line which intersected a vertical line drawn from the desired values of $\Sigma\, e^{7-rmx} l_x\, m_x = 1096.6$. The point of intersection gave the value of true 'r_m' accurate to three or four decimal places. The precise generation time (T) was calculated from the equation

$$T = \frac{\mathrm{Log}_e R_o}{r_m}$$

The finite rate of natural increase: The finite rate of natural increase (λ) i.e. females female^{-1} day^{-1} were calculated as: λ= anti $\log_e r_m$.

Stable age-distribution: The stable age-distribution was worked out with the value of 'r_m' and the age-specific mortality of immature as well as mature stages. The l_x (life-table age-distribution) was calculated from the 'l_x' table with the formula given below:

$$l_x = \frac{l_x + (l_x + 1)}{2}$$

The l_x was multiplied with $e^{-rm(x+1)}$ and the percentage distribution of each pivotal age (x) was worked out. By putting

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Table 1: Biology of *S. frugiperda* on sunflower

Parameters		Range		Mean± SD
		Minimum	Maximum	
Fecundity/female (no)		400	1000	691.60±28.11
Egg hatching (%)		94	98	96.40±1.81
Incubation period (days)		2.00	3.00	2.60±0.41
Larval period (days)		13.00	15.00	13.74±0.43
I instar (days)		2.00	3.00	2.74±0.51
II instar (days)		1.75	2.50	2.00±0.02
III instar (days)		1.75	2.50	2.00±0.04
IV instar (days)		1.75	2.50	2.00±0.03
V instar (days)		1.75	2.50	2.00±0.02
VI instar (days)		1.75	2.50	2.00±0.03
Pre-pupal period(days)		0.75	1.50	1.00±0.01
Pupal period (days)		7.00	9.00	7.55±0.11
Pupation (%)		88	95	92±0.46
Adult emergence (%)		94	98	96±0.31
Pre-oviposition period (days)		3.00	4.00	3.16±0.20
Oviposition period (days)		1.00	2.00	1.84±0.33
Post- oviposition period (days)		3.00	4.00	3.53±0.23
Adult longevity (days)	Male	6.00	7.00	6.92±0.13
	Female	8.00	9.00	8.52±0.31
Total life cycle (days)	Male	30.00	31.00	30.81±0.46
	Female	31.00	33.00	32.42±0.41
Sex ratio	-	-	1:1.02	
Growth index	-	-	6.69	

together, the percentage under each pivotal age for respective stages *viz.,* egg, larva, pupa and adult, the expected percentage distribution of each stage in a stable age-distribution was calculated (Andrewartha and Birch, 1954).

Data analysis: For the study on the biology, morphometrics and population life tables of *S. frugiperda* feeding on sunflower under laboratory conditions, the data analysis was conducted by above mentioned formulae using Microsoft Excel. Specific formulae and built-in functions were utilized to process and analyze the data efficiently.

Results and Discussion

Table 1 provides a detailed account of biological parameters of *S. frugiperda* reared on sunflower under laboratory conditions offering insights into its reproductive and developmental biology. The fecundity of female *S. frugiperda* ranged between 400 to 1000 eggs per female with a mean fecundity of 691.60 ± 28.11 eggs. This relatively high fecundity coupled with high egg hatching percentage (96.40%) indicates significant reproductive potential which can contribute to rapid population growth in the field on sunflower. This highlights the importance of early detection and intervention to control the pest at its early stages before the population escalates. The incubation period of the eggs ranged from 2 to 3 days with a mean of 2.60 ± 0.41 days, which is consistent with the rapid embryonic development typical of *S. frugiperda* under favorable conditions. The high egg hatching rate combined with a short incubation period suggests that the pest is well-adapted to sunflower crops and can initiate infestations rapidly, underscoring the need for continuous monitoring during early stages of crop growth. The larval stages panning approximately 13.00 to 15.00 days with a mean of 13.74 ± 0.43 days consists of six distinct instars. The first instar lasted 2.74 ± 0.51 days whereas the subsequent instars from second to sixth each recorded approximately 2.00 days with minimal variation. This consistency in larval development suggests a predictable pattern that can be exploited in pest management strategies, such as timing insecticide applications to target specific larval instars. The relatively short larval period, especially in the later instars implies that *S. frugiperda* can rapidly transition to the next developmental stage reinforcing the need for timely control measures.

The pre-pupal stage was brief, ranging between 0.75 to 1.50 days with an average of 1.00 ± 0.01 days. This stage marks the transition between larval and pupal forms during which the larvae cease feeding and prepare for pupation. The pupal period ranged from 7.00 to 9.00 days with an average 7.55 ± 0.11 days. These stages are critical in the life cycle of pest, as pupae are less vulnerable to above-ground interventions, and successful pupation rates (92%) indicate that most larvae are successfully transitioning into adult stage. The effectiveness of pest management at these stages might require soil-based treatments

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or biological controls targeting pupating larvae. The adult emergence rate was also notably high (96%) suggesting a successful transition from pupae to adult moths. The longevity of adult males and females varied slightly with males life span between 6.00 to 7.00 days (mean: 6.92 ± 0.13 days) and females life span between 8.00 to 9.00 days (mean: 8.52 ± 0.31 days). The pre-oviposition period recorded 3.16 ± 0.20 days followed by an oviposition period of 1.84 ± 0.33 days and a post-oviposition period of 3.53 ± 0.23 days. This indicates that female moths spend a significant portion of their adult life engaged in reproductive activities rendering multiple opportunities for egg-laying and population expansion. The total life cycle duration from egg to adult ranged from 30 to 31 days for males and 31 to 33 days for females with mean duration of 30.81 ± 0.46 and 32.42 ± 0.41 days, respectively. This relatively short life cycle combined with high reproductive rate and survival rates emphasizes the *S. frugiperda's* capacity for rapid population turnover, which poses a serious threat to sunflower crops if left unmanaged.

The sex ratio observed in the study was approximately 1:1.02, indicating a near-equal proportion of males and females in the population. This balanced ratio suggests that the reproductive potential of the population was maximum as there were sufficient numbers of both sexes for successful mating. The growth index of 6.69 further supports the pest's high reproductive and developmental efficiency allowing for multiple generations within a single growing season, which could exacerbate infestations in the absence of timely and effective control measures. The biological parameters presented in this study highlight the significant threat posed by *S. frugiperda* to sunflower crops due to its high fecundity, rapid life cycle, and successful pupation and adult emergence rates. The consistent and predictable development through larval instars provides an opportunity for targeted control measures, particularly during the most destructive larval stages. High egg hatching and adult emergence rates emphasize the need for ongoing surveillance and early intervention to reduce the pest population before it reaches the reproductive adult stage.

Table 2: Morphometrics of *S. frugiperda* on sunflower

Larval head capsule width			
Larval Instars	**Estimated (mm)**	**Observed (mm) ± SE**	**Growth ratio**
I	0.19	0.19±0.003	-
II	0.19 × 1.48 =0.28	0.51±0.007	2.68
III	0.28 × 1.48 =0.41	0.79±0.04	1.55
IV	0.41 × 1.48 =0.61	1.13±0.01	1.43
V	0.61 × 1.48 =0.90	1.69±0.06	1.50
VI	0.90 × 1.48 =1.33	2.87±0.02	1.70
Mean growth rate=			1.48
Larval head capsule length			
I	0.20	0.20 ±0.04	-
II	0.20 × 1.49 = 0.30	0.55 ±0.03	2.75
III	0.30 × 1.49 = 0.45	0.82 ±0.03	1.49
IV	0.45 × 1.49 = 0.67	1.23 ±0.02	1.50
V	0.67 × 1.49 = 0.99	1.98 ±0.01	1.61
VI	0.99 × 1.49 = 1.47	3.16 ±0.06	1.60
Mean growth rate =			1.49
Morphometrics			
Stages	**Length (mm) mean ± SE**	**Breadth (mm) mean ± SE**	**Weight (mg) mean ± SE**
Egg mass (diameter)	-	5.13±0.02	-
I	1.63±0.06	0.20±0.004	0.58±0.02
II	5.20±0.26	1.00±0.01	2.07±0.28
III	10.40±0.20	1.55±0.07	12.90±0.82
IV	15.10±0.31	2.45±0.08	66.20±1.71
V	23.30±0.47	2.85±0.09	193.13±9.12
VI	42.17±0.33	4.21±0.30	413.40±11.08
Pupa			
Male	15.92±0.17	3.70±0.18	198.31±0.08
Female	16.40±0.26	3.90±0.23	210.60±0.29
Adults	**Body length (mm)**	**Wing span (mm)**	
Male	15.32±0.37	41.17±0.51	
Female	13.41±0.42	43.09±0.33	

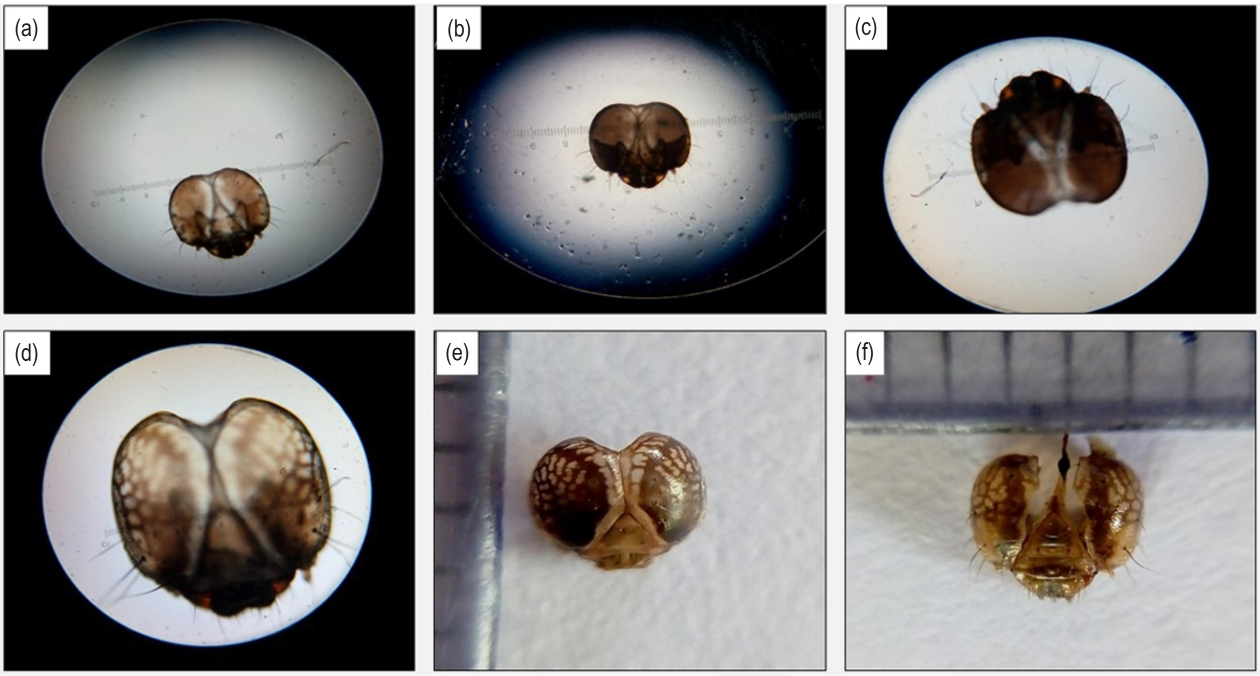

Fig. 1: Head capsules of 1st to 6th instar of *S. frugiperda* larvae on sunflower.

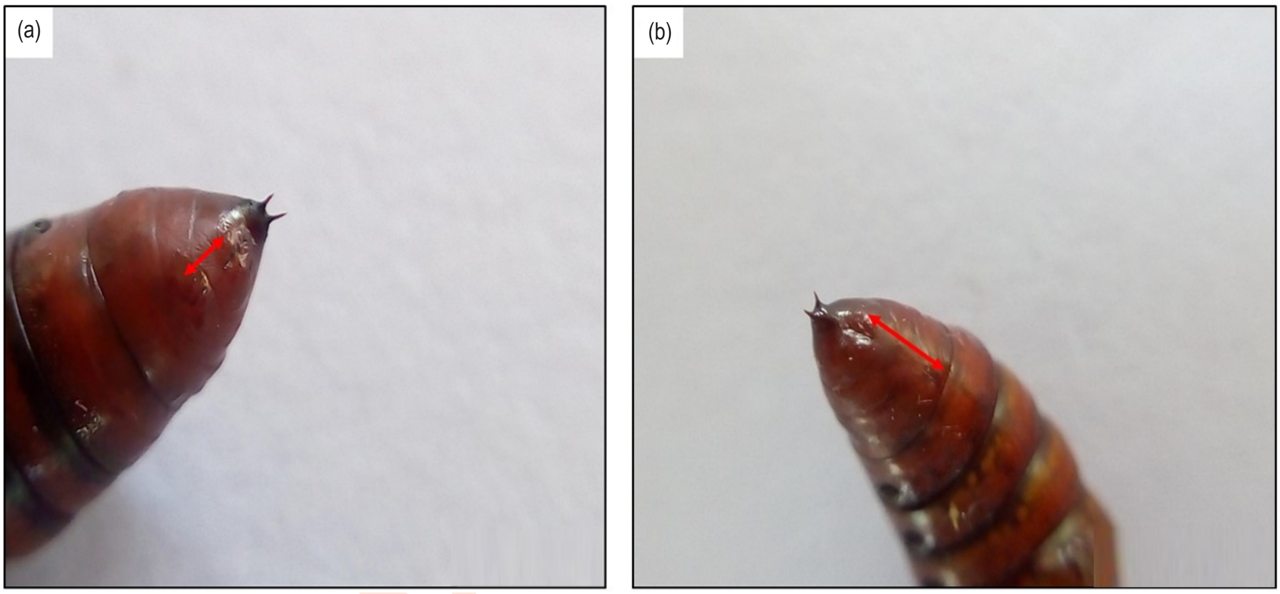

Fig. 2: (a) Male and (b) female pupa of *S. frugiperda* on sunflower.

Integrated pest management strategies should focus on reducing the reproductive potential of the pest by using biological control agents, egg parasitism, or timely application of insecticides. Additionally, cultural practices such as crop rotation and the use of pest-resistant sunflower varieties may help reduce the overall pest pressure. Overall, the biological data obtained from this study provide essential insights for the development of more effective pest management strategies to mitigate the impact of *S. frugiperda* on sunflower crops. This discussion connects the biological parameters from the table to potential control strategies, providing a comprehensive understanding of how the pest's life cycle can inform management efforts in

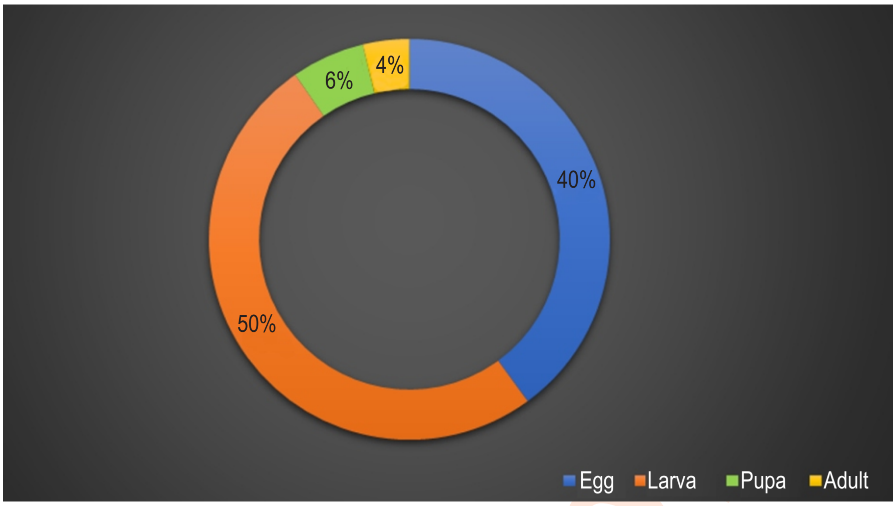

Fig. 3: Stable age-distribution of population of *S. frugiperda* on sunflower

Table 3: Survival of life-stages of *S. frugiperda* on sunflower

Number of eggs observed	Number of survived life-stages				
	Eggs (0-3 days duration)	Larvae (4-18 days duration)	Pupae (19-26 days duration)	Adults	
				Male	Female
20	19	18	17	8	9
20	20	17	16	8	8
20	20	19	18	10	8
20	19	17	17	6	11
20	18	17	15	9	6
100	96	88	83	41	42

sunflower cultivation. These results are consistent with the reports of Li-mei *et al.* (2021), who recorded the incubation period of *S. frugiperda* on sunflower as 3.00 days with a larval period of 21 days spanning 7 larval instars. The duration of first to seven instars were reported as 3.2, 2.0, 2.5, 2.8, 3.8, 6.7 and 5.5 days, respectively. The pupal period lasted 10.3 days and the adult stage persisted for 10.3 days as well. Additionally, the percent of pupation, adult emergence, per cent hatching and sex ratio were reported as 82.56, 74.81, 73.54 per cent and 1:0.89, respectively. Recently, by Bankar and Bhamare (2023a), reported an incubation period of 2.00 and 2.26 days *S. frugiperda* infesting maize and sorghum. The larval and pupal periods were 12.58 and 6.74 days in maize and 15.93 and 7.99 days in sorghum. The percent of egg hatching, pupation and adult emergence were 94, 88 and 92 per cent on maize and 89, 91 and 91 per cent in sorghum. The total life cycle duration of male and female was 27.61 and 31.31 days in maize and 29.78 and 32.52 days in sorghum. Additionally, the growth index and sex ratio were 6.99 and 1:1.20 on maize and 5.71 and 1:1.131 on sorghum respectively.

The results of morphometrics analysis of *S. frugiperda* reared on sunflower (Table 2; Fig. 1) indicated that the larval head capsule width increased progressively from I to VI instars measuring 0.19, 0.51, 0.79, 1.13, 1.69and 2.87 mm. The mean growth rate (progression factor) calculated from these measurements was 1.48, aligning with Dyar's rule, which approximately predicts a constant growth ratio of 1.4 (Dyar, 1890). Similarly, the larval head capsule length showed an increasing trend from I to VI instars, measuring 0.20, 0.55, 0.82, 1.23, 1.98 and 3.16 mm, respectively, with a mean growth rate of 1.49 mm. These findings are consistent with the result of Ramaiah *et al.* (2020), who observed similar trends in head capsule width of *S. frugiperda* larvae fed on artificial diet across the first six instars with ratio close to 1.94. Furthermore, Bankar and Bhamare (2023b) investigated the morphometrics of *S. frugiperda* across various cereal crops and reported head capsule width measurements for I to VI instars as follows: in maize (0.22, 0.42, 0.71, 1.13, 1.29 and 2.94 mm), in sorghum (0.20, 0.41, 0.67, 1.06, 1.24 and 3.05 mm), in pearl millet (0.19, 0.29, 0.52, 0.83, 1.23 and 2.80 mm) and in sugarcane (0.22, 0.43,

Table 4: Life-table and age-specific fecundity of *S. frugiperda* on sunflower

Pivotal age in days	**Survival of females at different age intervals**	**Age schedule for female birth**		
X	**l_x**	**m_x**	**$l_x m_x$**	**$l_x m_x X$**
0-26	0.83	Immature stages		
27-29	0.83	Pre-oviposition period		
30	0.81	199	161.19	4835.70
31	0.81	147	119.07	3691.17
32	0.52	00	0.00	0.00
33	0.37	00	0.00	0.00
34	0.24	00	0.00	0.00
35	0.18	00	0.00	0.00
36	0.00	00	0.00	0.00
			$\sum l_x m_x$ or (R_o)= 280.26	$\sum l_x m_x X$= 8526.87

Table 5: Population growth statistics of *S. frugiperda* on sunflower

Parameters	**Sunflower**
Mean length of generation, (T_c); (days)	30.42
Innate capacity for increase in numbers (r_m); (females/female/day)	0.185
Corrected r_m $\sum^{7\text{-}e r_m x} l_x m_x$ = 1096.60 (females/female/day)	0.186
Corrected generation time (T); (days)	30.29
Finite rate of increase in numbers (λ); (females/female/day)	1.53

0.67, 0.94, 1.22 and 2.70 mm) for I to VI instars, respectively. These observations indicated the consistency of head capsule width across different food sources for the larvae.

The morphometric analysis revealed that diameter of egg mass measured 5.13 mm. The length of larvae in the first six instars were 1.63, 5.20, 10.40, 15.10, 23.30 and 42.17 mm whereas the larval breadth in these instars measured 0.20, 1.00, 1.55, 2.45, 2.85 and 4.21 mm. Additionally, the weight of larvae in these instars were recorded as 0.58, 2.07, 12.90, 66.20, 193.13 and 413.40 mg, respectively. These findings corroborate with the results of Kalyan *et al.* (2020) who reported varying lengths of (1.5-2.0, 3.0-4.0, 5.5-6.5, 9.0-10.5, 15.0-18.0 and 32.0-36.0 mm) *S. frugiperda* larvae in the first six instars whereas the breadth larval body of *S. frugiperda* in maize was 0.17, 1.02, 1.55, 3.05, 3.3 and 3.95 mm for instars I to VI. Furthermore, Maruthadurai and Ramesh (2020) recorded larval body weight of *S. frugiperda* as 0.46, 0.39, 0.34 and 0.23 g on fodder maize, green amaranth, para grass and guinea grass, respectively, providing additional insights into larval weight variations across different host plants.

The morphometric analysis of *S. frugiperda* pupae revealed that the length of male and female pupae as 15.92 and 16.40 mm breadth of 3.70 and 3.90 mm and weight 198.31 and 210.60 mg, respectively. These findings are consistent with Kalyan *et al.* (2020), who observed pupal lengths of *S. frugiperda* ranging between 14.0 to 19.0 mm on maize. Similarly, Tendeng *et al.* (2019) reported pupal lengths varying between 14 to 18 mm. Recently, Bankar and Bhamare (2023b) documented pupal measurements on various hosts, reporting pupal length on maize, sorghum, pearl milletand sugarcane to be 15.10, 14.20, 12.30 and 13.10 mm whereas pupal breadth was 4.00, 3.70, 3.05 and 3.30 mm pupal weight was 185.90, 144.40, 104.70 and 124.80 mg, respectively. These consistent findings across different studies underscore the reliability of the reported morphometric measurements for *S. frugiperda* pupae. The body length of adult male and female *S. frugiperda* was 15.32 and 13.41 mm whereas the wing span of male and female individuals was 41.17 and 43.09 mm, respectively. These results align with Helen *et al.* (2021) who reported the mean body length of male and female *S. frugiperda* to be 15.99 and 15.16 mm. Similarly, the average wing span of male and female was reported to be 31.95 and 30.82 mm, respectively. Furthermore, Bankar and Bhamare (2023b) provided additional insights, noting that the average body length of adult male *S. frugiperda* on maize, sorghum, pearl millet and sugarcane was 13.50, 13.10, 12.50 and 12.60 mm, respectively. For adult female the body lengths were recorded as 12.20, 11.90, 11.50 and 11.70 mm on the respective hosts. Additionally, the wing spans of adult male and female were 37, 35, 32 and 34 mm and 39, 37, 34 and 36 mm, respectively. These findings across studies provide valuable information on the morphometric characteristics of adult *S. frugiperda*.

In a cohort of 100 eggs reared on sunflower (Table 3), *S. frugiperda* exhibited survival rates of 96, 88 and 83 per cent in the egg, larval and pupal stages, respectively. Successful emergence resulted in 41% male and 42% female adults, maintaining a near equal sex ratio with a male to female ratio of 1:1.02. Survival analysis of immature stages (lx) of *S. frugiperda* on sunflower revealed a survival rate of 0.83 individual^{-1} within a pivotal age of 26 days. The pre-oviposition period ranged from 27 to 29 days of pivotal age (Table. 4). The number of eggs laid/female/day was halved to calculate the number of female births (m_x). The highest number of eggs laid by females (mx=199.00) was noticed on the first day of oviposition at 30th day of pivotal age, followed by a gradual decline. Female mortality began on the 32nd day of pivotal age (lx=0.52), with subsequent mortality increasing gradually. Females laid eggs for a duration of 2 days. The net reproductive rate (R_o), indicating the total female births/female/generation, was 280.26. Therefore, the population of *S. frugiperda* has the potential to increase at a rate of 280.26 females/female/ generation on sunflower. The mean length of generation (T_c) was determined to be 30.42 days. An arbitrary value for intrinsic rate of increase (r_c) was calculated as 0.185 females/female/day (Table 5).

The precise generation time (T) was estimated to be 30.29 days, while the finite rate of increase in numbers (λ) was recorded as 1.53 females/female/day. Additionally, the corrected innate capacity for increase in numbers (rm) was calculated as 0.186 females/female/day. The findings of the present study in line with Guo *et al.* (2020) who reported intrinsic rates of increase (r) of 0.1681, 0.0738 and 0.0270 per day; finite rates of increase (λ) of 248.3584, 19.3282 and 3.3757 off spring/female and mean generation times (T) of 32.7882, 39.9029 and 41.1053 days on maize, potato and tobacco, respectively. Similarly, Bankar and Bhamare (2023b) recorded mean generation times on maize and sorghum as 27.42 and 31.45 days, innate capacities for increase in numbers on maize and sorghum to be 0.185 and 0.113 females/ female/day and finite rates of increase to be 1.20 and 1.12, respectively. In their subsequent study (Bankar and Bhamare, 2023c), the life-fecundity tables of *S. frugiperda* on pearl millet and sugarcane showed mean generation times of 31.35 and 35.42 days, innate capacities for increase in numbers of 0.104 and 0.123 females/female/day and finite rates of increase of 1.11 and 1.13, respectively. It is apparent from Fig. 3 that there is a reduction in the stable age distribution of *S. frugiperda* population on sunflower across various stages: egg, larval, pupal and adult (including pre-oviposition, oviposition and post-oviposition). Specifically, the distribution is as follows: 39.95% in the egg stage, 50.38% in the larval stage, 5.91% in the pupal stage and 3.74% in the adult stage.

In conclusion, this study provides a basic understanding of the biology of fall armyworman invasive alien insect pest in India. Notably, it provides the first comprehensive analysis of fall armyworm biology in laboratory conditions with a focus on sunflower. The fall armyworm has a significant impact on maize, which is India's main staple food crop. Therefore, understanding its biology on alternative hosts such as sunflower is critical. With the potential for fall armyworm damage to worsen as global temperatures rise, early implementation of compatible integrated pest management techniques is critical to mitigate the potential impact of pest's.

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