Research Square

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Developmental biology and morphometric traits of fall armyworm Spodoptera frugiperda (J.E. Smith) under controlled environment

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Abstract

Background

The fall armyworm, *Spodoptera frugiperda* (J.E. Smith) is an invasive and destructive pest of maize and several other crops, that causing significant losses worldwide. Understanding its developmental biology and morphometric traits is essential for its accurate identification and effective pest management. This study investigated the lifecycle, developmental duration and morphometric traits of *S. frugiperda* under controlled laboratory conditions.

Results

The study was conducted at Banda University of Agriculture and Technology, Banda, Uttar Pradesh, India at 26 ± 2°C temperature and 75 ± 2% relative humidity. Egg masses collected from maize fields were reared on fresh maize foliage. Females laid 97–392 eggs each (mean 246.1 ± 103.59), preferred upper leaf canopy. Eggs were 0.47 ± 0.04 mm in length and 0.36 ± 0.03 mm in width, hatched within 2–3 days and the hatchability ranging from 86.66 % to 92.56%. Larvae passed six instars in 13–15 days (mean 13.35 ± 0.61 days), showing progressive increases in body size and head capsule width. Sixth instar larvae measured 33.98 ± 1.60 mm in length and 7.88 ± 0.28 mm in width. The pupal period lasted 7–9 days (mean 7.18 ± 0.54 days) and sexual dimorphism was observed in both pupal and adult stages, with males slightly larger than females. Adult females lived longer (8.53 ± 0.79 days) than males (6.52 ± 0.78 days). The total lifecycle duration averaged 30.01 ± 1.10 days for females and 29.06 ± 1.25 days for males. Two braconid parasitoids, *Aleiodes laphygmae*and *Stenobracon deesae*, alongwith one dipteran parasitoid were recorded, caused 3.5% larval parasitism.

Conclusion

The study demonstrated rapid development, high reproductive potential and distinct morphometric variations across developmental stages in *S. frugiperda*. These findings provide baseline information useful for accurate identification and the development location-specific integrated pest management strategies.

Introduction

The fall armyworm (*Spodoptera frugiperda* J.E. Smith (Lepidoptera: Noctuidae)), is an invasive, highly destructive and polyphagous insect pest that has emerged as a significant threat to global food security. Native to tropical and subtropical regions of the Americas, this pest has gained international attention due to its rapid invasion and spread across more than 60 countries in Africa, Asia and Oceania since its first detection in Africa in 2016 (Goergen et al. 2016; Prasanna et al. 2018; Baudron et al. 2019; Yainna et al. 2022). In India, the fall armyworm (FAW) was first noticed in Karnataka in May 2018 (Sharanabasappa et al. 2018) and has since spread across maize-growing regions, causing significant reductions in crop productivity. (Padhee and Prasanna 2019; Suby et al. 2020; Pandey et al. 2022).

The pest is highly polyphagous, attacking more than 350 plant species (Montezano et al., 2018), predominantly maize, rice, sorghum, cotton and sugarcane. Among these, maize is the most preferred host (Baudron et al. 2019; CABI 2020; Abbas et al. 2022). The presence of two genetically distinct strains- the “maize strain” and the “rice strain” (Goergen et al. 2016; Yainna et al. 2022) further enhances its adaptability and complicates management strategies.

The lifecycle of FAW consists of four distinct stages: egg, larva, pupa and adult. The duration, development and survival of each stage are strongly influenced by temperature and relative humidity (Du Plessis et al. 2020). Females lay dome-shaped eggs in clusters of 100–200, and are capable of laying 1,000–1,500 eggs under favorable conditions (Abbas et al. 2022). The eggs are covered with scales from the female’s abdomen and hatch within 2 to 5 days. Larvae are generally greenish to brown, characterized by a distinctive inverted “Y”- shaped marking on the head capsule and longitudinal stripes on the body. They pass through six instars over a period of 14–22 days (Montezano et al. 2018) and may display cannibalistic behaviour (Goergen et al. 2016). This stage is the most destructive as larvae actively feed on plants, causing “windowpane” symptoms and severe defoliation (Tiwari et al. 2024). After complete larval development, mature larvae pupate in the soil at a depth of 3–4 cm, forming loose earthen cocoons for 7–13 days. Adult moths exhibit sexual dimorphism, with males displaying more pronounced markings on the wings than females. Adults live for 10–21 days (Goergen et al. 2016) and under optimal conditions, the entire life cycle can be completed in approximately 30 days, allowing multiple generations within a year (Abbas et al. 2022). Adult moths have strong migratory ability, and can travel several hundred kilometers- facilitated by wind currents, which significantly contributes to its rapid global spread (Yainna et al. 2022).

Considering its invasive nature, high host adaptability and reproductive potential, understanding the biological and morphometric characteristics of *S. frugiperda* under local agroclimatic conditions is essential for its accurate identification and the development of effective management strategies. Therefore, the present study was undertaken to investigate the lifecycle and morphometric features of *S. frugiperda* under laboratory conditions.

Materials and Methods

Study Area

The study was conducted in postgraduate laboratory of department of entomology, college of Agriculture, Banda University of Agriculture and Technology, Banda, Uttar Pradesh, India. This region falls under agro climatic zone VIII (Central Plateaus and Hills Region) of India between latitudes 24º 53' and 25º 55' N and longitudes 80º 07' and 81º 34' E and having an altitude of 168 m above sea level.

Sample Collection and Insect Culture

For the establishment of nucleus culture, freshly laid egg masses of fall army worm, *S. frugiperda* were collected from an untreated maize (*Zea mays* L.) field. Collected egg masses were incubated at room temperature for hatching. Identification of egg masses and neonate larvae was confirmed using standard keys defined by CABI (2019). Fifty neonate larvae were reared on fresh maize leaves in 15 cm diameter Petri dishes until they reached the third instar. Thereafter, larvae were reared individually to avoid cannibalism until adult emergence. The stock culture was maintained under climatic conditions of 26 ± 2°C temperature and 75–80% relative humidity.

Lifecycle Study

Newly emerged adults were paired and placed in an aluminum cage (30 x 21 x 20 cm) covered with fine wire mesh. Fresh maize leaves and moist tissue paper were provided as oviposition substrates, and this setup was replicated 10 times. A 10% honey solution soaked in cotton wool was provided as food for adult moths and replaced daily. Freshly laid egg masses were collected, counted and transferred to a 15 cm diameter Petri dish lined with moist filter paper at the bottom. The dishes were inspected at 12-hour intervals to record egg hatchability. One hundred newly hatched first instar larvae were individually transferred into Petri dishes using a camel hairbrush for life cycle observations. The larvae were fed fresh maize leaves, which were replaced daily to maintain hygiene and prevent fungal contamination. After pupation, pupae were collected, sexed and transferred to another Petri dish for adult emergence. Newly emerged adults were again paired and kept in a rearing cage under similar conditions discussed earlier for oviposition. The procedures for colony establishment and life cycle study were adopted from Wang et al. (2020) with suitable modifications.

The following observations on biological parameters were recorded:

- **Egg stage**: Oviposition period (days), fecundity (eggs per female) and incubation period (days)
- **Larval stage**: Duration of each instar (I–VI) and total larval period (days)
- **Pupal stage**: Pupal duration (days)
- **Adult stage**: Longevity of male and female (days)
- **Total life cycle**: Duration (days) for males and females

Morphometric Study

Specimens were sampled at standardized stages: eggs (< 12 h post-oviposition), each larval instar (I–VI) immediately after molting, sclerotized pupae and adults at 24 h post-emergence to ensure uniform morphometric comparisons. All morphometric measurements were recorded using an ocular micrometer and vernier calipers fitted to a stereoscopic microscope. Head capsules shed during molting were preserved in 70% ethanol for measurement. Pupal measurements were taken when wing pads and locomotory appendages were distinctly visible, while adult measurements were recorded after complete wing expansion. Parameters such as egg dimension, body length, body width of larvae and pupae, width

of head capsule and wingspan were measured and averaged for each developmental stage to develop a comprehensive morphometric profile of *S. frugiperda* under laboratory conditions. All measurements were taken by a single observer and represent the mean of three sets, each consisting of 10 replications for each developmental stage.

Data Analysis

Data on biological parameters and morphometric measurements for each developmental stage of *S. frugiperda* were analyzed and expressed as mean ± standard deviation (SD). All statistical analysis was performed using Hisar Statistical Package for Agricultural Scientists (OPSTAT) software developed by O. P. Sheoran (retrieved on 11 July 2024; http://opstat.somee.com). Stagewise variations in morphometric parameters were also assessed. All experimental procedures were conducted in accordance with the guidelines of Banda University of Agriculture and Technology, Banda, ensuring methodological rigor and reproducibility.

Results

The biological parameters of the fall armyworm, *S. frugiperda* (J. E. Smith) were studied using 50 individuals, focusing on life stage developmental duration (Figs. 1 & 2) and morphometric measurements (**Table 1**) were analyzed and summarized.

Oviposition Behaviour and Eggs

The gravid females began laying eggs within 16–18 hours after mating. The eggs were deposited in masses containing 68 to 200 eggs, covered with dense, grayish-white hairs from the female abdomen, giving them a fuzzy appearance. Eggs were primarily laid on the topmost leaf canopy followed by the middle and lower leaves. Additionally, a few egg masses were laid on glass panes and in the corners of the mating chamber. The oviposition period ranged from 1–3 days, with an average of 1.8 ± 0.63 days.

Fecundity varied widely, ranging from 97 to 392 eggs per female (mean 246 ± 103.59), indicates variability among individuals. The freshly laid eggs were pale white, cylindrical or dome-shaped with a flattened base and uniform in size measuring 0.47 ± 0.04 mm in length and 0.36 ± 0.03 mm in width. The eggs darkened before hatching and the incubation period lasted 2–3 days (mean 2.18 ± 0.39 days), with hatchability ranging from 86.66 to 92.56 percent (mean 89.61 ± 2.95).

Larval Stage

The larval stage consists of six instars and lasted 13–15 days (mean 13.35 ± 0.61 days), with each instar lasted approximately 2–4 days for its development. The developmental duration for each instar was as follows: first instar, 2–3 days (mean 2.06 ± 0.25); second instar, 2–3 days (mean 2.07 ± 0.27); third instar,

2.0 days (mean 2.01 ± 0.17); fourth instar, 2.0 days (mean 2.00 ± 0.14); fifth instar, 2–3 days (mean 2.09 ± 0.30) and sixth instar, 3–4 days (mean 3.08 ± 0.30).

The newly hatched larvae were small, greenish in colour and black headed; they initially fed on their eggshells. First instar larvae measured 1.54 ± 0.16 mm in length and 0.22 ± 0.018 mm in width, with dimensions gradually increasing after each molt. The lengths and widths of the second, third and fourth instars were 3.47 ± 0.23 mm * 0.51 ± 0.02 mm, 6.15 ± 0.35 mm * 1.48 ± 0.02 mm and 10.24 ± 0.62 mm * 3.33 ± 0.38 mm, respectively. Second instar larvae were green with an orangish head, while subsequent instars became olive-green to brown with distinct dorsal and lateral stripes and denser hair. A morphological feature such as trapezoidal black spots was also observed on the fourth instar. Fifth instar larvae were much longer than earlier instars, measuring 17.33 ± 1.45 mm in length and 5.86 ± 0.45 mm in width. The sixth instar was approximately twice as large as the fifth instar, measuring 33.98 ± 1.60 mm in length and 7.88 ± 0.28 mm in width. The head capsule width also increased progressively from 0.34 ± 0.008 mm (first instar) to 2.55 ± 0.08 mm (sixth instar).

Pupa

Pupae were reddish-brown and smooth, showing morphological and morphometric distinctions between males and females. The pupal period lasted 7–9 days (mean of 7.18 ± 0.54 days). Sexual dimorphism was evident: male pupae measured 16.17 ± 1.09 mm in length and 4.81 ± 0.20 mm in width, whereas female pupae were slightly smaller (14.93 ± 0.79 mm in length and 4.38 ± 0.23 mm in width).

Adults

Adults were medium-sized and dusky brown. Males had greyish-brown forewings with distinct triangular white spots near the tip and middle, while females were more uniform, with greyish or finely mottled forewings. Both sexes had silver-white hindwings with a narrow dark border. Females lived longer, 8–11 days (mean 8.53 ± 0.79 days) than males, 5–8 days (mean 6.52 ± 0.78 days). Adults also showed a distinct sexual difference; males had slightly larger body size (15.67 ± 0.44 mm) and wingspan (33.72 ± 1.10 mm) than females, measured 14.28 ± 0.73 mm in length and had a wingspan of 32.59 ± 0.77 mm. The total life cycle duration ranged from 28–33 days in males (mean 29.06 ± 1.25 days) and 30–33 days in females (mean 30.01 ± 1.10 days).

Parasitism

Two hymenopteran braconids *Aleiodes laphygmae* (Viereck, 1912) and *Stenobracon deesae* (Cameron, 1902) and one unidentified diptera were recorded, which parasitized 3.5% of the *S. frugiperda* larval population under the lifecycle study (Fig. 3).

Discussion

The present study provides detailed insights into the lifecycle and stagewise morphometrics of *S. frugiperda*, showing consistency with earlier findings while highlighting minor variations influenced by

environmental and nutritional factors.

Oviposition Behaviour and Eggs

The oviposition period (1–3 days) and fecundity range observed in this study align with Sharanabasappa et al. (2018), Deshmukh et al. (2020), Keerthia et al. (2023) and Sharma et al. (2024), who documented that the *S. frugiperda* oviposition period lasted between 1 and 3 days, indicating that reproductive potential remains stable across different conditions. Wide variability in fecundity suggests that host quality, local climatic factors and genetic variability may significantly influence reproductive potential. The egg morphology and incubation period (2–3 days) observed in the present studies were comparable with earlier studies (Tiwari et al. 2024 and Sharanabasappa et al. 2018), with slight differences in incubation period (3–4 days) recorded by Kalyan et al. (2020). These variations may be attributed to differences in temperature and relative humidity during the studies at different locations. The egg dimension records were also comparable with Capinera (2008), who reported slight variations in egg size that may be attributed to nutritional variability under laboratory conditions. High hatchability upto 90% indicates the suitability of laboratory conditions and strong survival potential of *S. frugiperda*.

Larval Stage

The larval duration (13–15 days) recorded in the present study closely agrees with Pogue (2002), Deshmukh et al. (2020) and Kalleshwaraswamy et al. (2018), who documented that the *S. frugiperda* larval period lasted 14 to 16 days, confirming developmental stability. However, slight variation may be attributed to host nutrition and environmental conditions (Keerthia et al. 2023; Ishwarya et al. 2024). The prolonged duration of later instars, particularly the sixth instar larvae (3–4 days) is consistent with Sharanabasappa et al. (2018), who reported 4.5 days. This supports earlier reports that later instars are more voracious and responsible for maximum crop damage. Larval growth showed a consistent increase; first instar length was 1.54 ± 0.16 mm, whereas sixth instar length was 33.98 ± 1.60 mm, indicating substantial growth before pupation (a 22-fold increase in body length) during development (Biswas et al. 2024; Pathak et al. 2024; Madali et al. 2025). These morphometric measurements were also largely consistent with Sharanabasappa et al. (2018), Deshmukh et al. (2020), Ajmal et al. (2024) and Kumar et al. (2025), who documented that the length of sixth instar larvae ranged from 29 to 35 mm, with differences possibly attributed to host plant quality and rearing conditions. These findings further validate the applicability of morphometric traits, which may also be influenced by geographical conditions (Murugasridevi et al. 2025).

Pupa

The pupal duration (7–9 days) observed in the present study is consistent with that reported by Hogg et al. (1982), Deshmukh et al. (2020) and Sharanabasappa et al. (2018), who found that pupal development lasted 9–12 days. Additionally, many recent studies have reported similar pupal durations, although slight variations may occur due to environmental conditions and host adaptability (Dono et al., 2024). The genital aperture in females was located farther from the anal slit than in males, which aided in sex

identification. The pupal dimensions observed in the present study are in agreement with those records of Hogg et al. (1982). Variation in pupal size between sexes and across studies may be attributed to nutritional availability and environmental conditions.

Adults

Adult longevity patterns, with females (8–11 days) living longer than males (5–8 days), support its previous reports (Pair et al. 1986; Capinera, 2008; Sharanabasappa et al. 2018; Sharma et al. 2024) and indicate an adaptive advantage for FAW reproductive potential and population buildup through extended mating and oviposition periods. The total life cycle duration (28–33 days) is consistent with that reported by Montezano et al. (2018), Kalleshwaraswamy et al. (2018), Dono et al. (2024) and Lakshmi et al. (2024), who found that the life cycle duration of *S. frugiperda* ranges between 25 and 35 days under variable climatic conditions and host quality. This suggests that multiple generations can occur within a single cropping season, contributing to rapid pest outbreaks. The adult stage also showed a distinct difference between sexes. Male adults exhibited slightly larger body length and wingspan than females, and these findings are consistent with Pair et al. (1986), who recorded a wingspan between 32 and 34 mm. Sexual dimorphism with differences in morphometrics and colour pattern was observed in the adult stage in large agreement with Oliver and Chaplin (1981), Khatun et al. (2022), Madali et al. (2025) and Melina et al. (2025), who reported that these variations become more pronounced at later developmental stages. However, Zeeshan (2021) noted a minimal body size variation between sexes, suggesting possible regional or environmental influences on morphometric traits.

Larval parasitism

The recorded parasitism rate (3.5%) in the present study indicates the presence of natural biological control agents, although the relatively low percentage suggests limited effectiveness under the studied conditions. This highlights the potential need for integrated pest management strategies to enhance biological control.

Conclusion

Overall, this study provides a comprehensive account of the biological parameters of *S. frugiperda*, clearly demonstrating its rapid developmental rate, short lifecycle and high reproductive potential, all of which contribute significantly to its damaging capacity. The greater longevity of females, combined with considerable fecundity, further enhances its ability to grow rapidly. The results indicate a steady and significant increase in body size and head capsule width across larval instars, with the sixth instar representing the maximum growth phase, followed by differentiation into pupal and adult stages. The observed variations are minor and can be attributed to differences in environmental conditions, host plants and experimental methodologies. This study provides valuable baseline morphometric data essential for identifying larval instars, understanding growth dynamics, and designing timely and location-specific management strategies against this invasive pest.

Declarations

Competing interest:

The authors declare no competing interests.

Ethics declaration

The present study has not involved any human or animal participants and ethical guidelines for insect research, ensuring minimal harm to insects and natural enemies.

Consent to publish

declaration: Not applicable

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Author Contribution

MKM and RP conceived and designed research. A.K. and SKM conducted experiments. SKM preformed the formal analysis and wrote the original draft. MKM designed the graph and figures and edited the final manuscript. BKS visualized, reviewed and edited the manuscript. All authors read, revised and approved of the manuscript.

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Data availability:

Data can be presented on request to the corresponding author.

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Figures

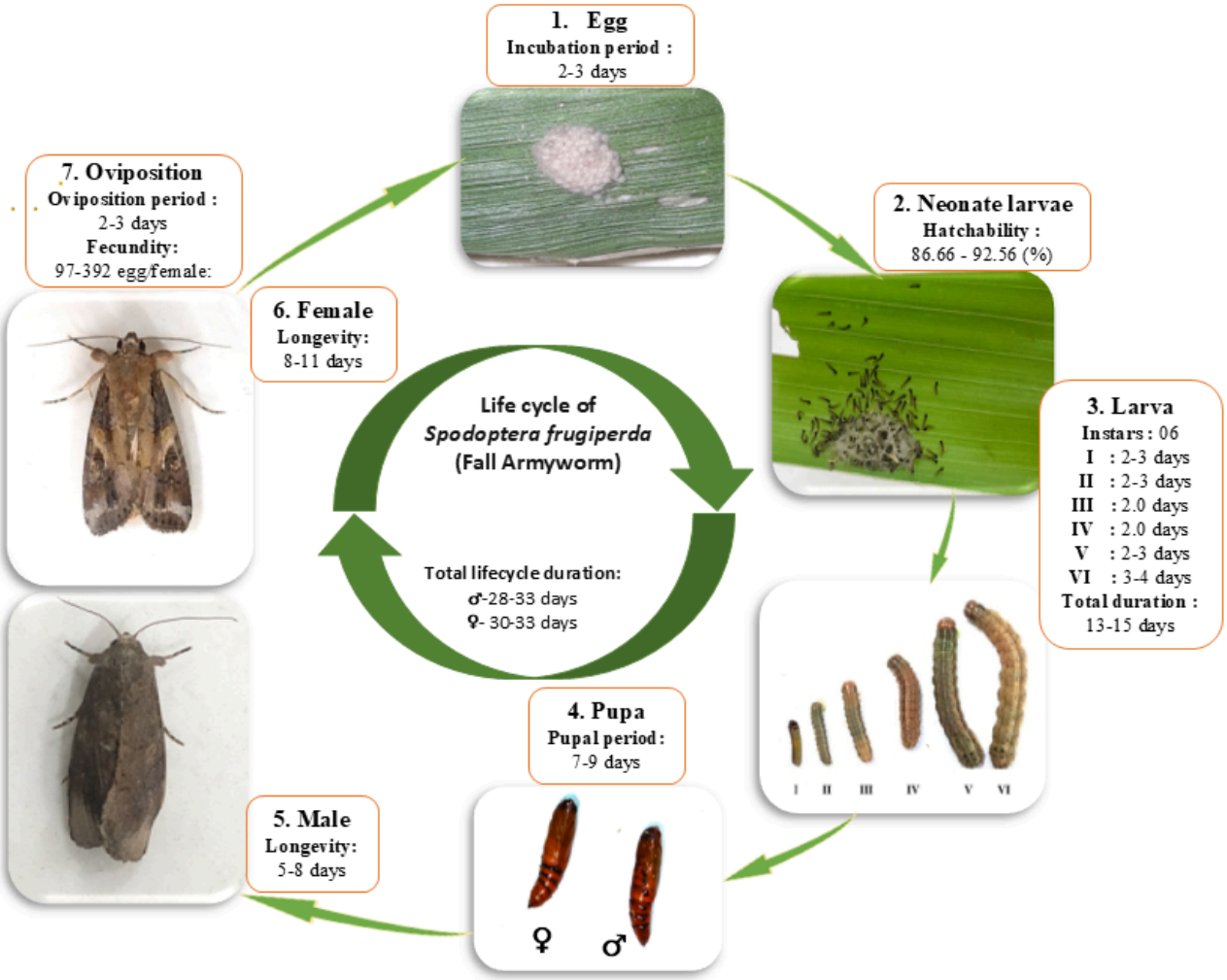


Figure 1

Developmental biology of *Spodoptera frugiperda* (J. E. Smith)

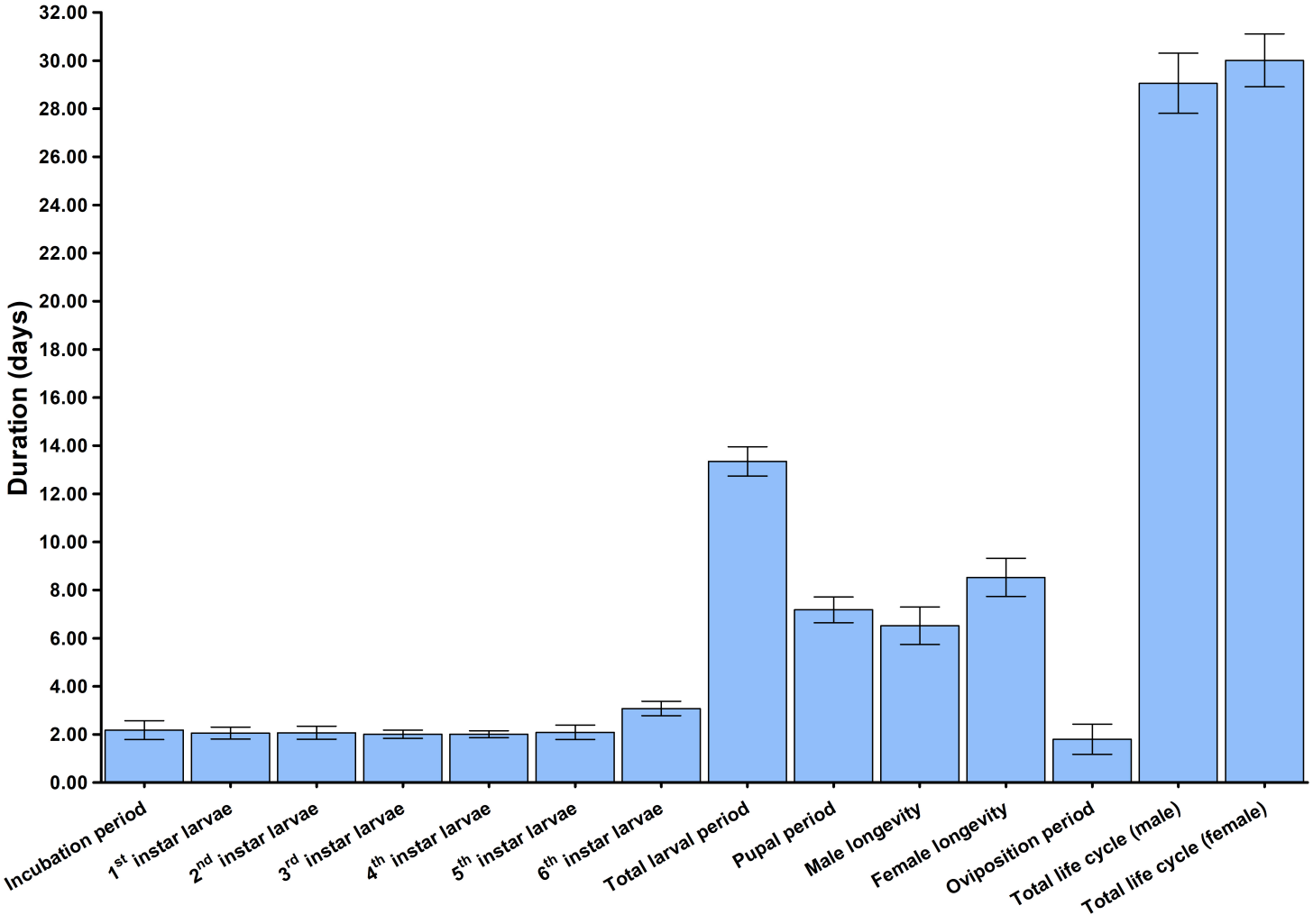


Figure 2

Life stagewise developmental duration of *Spodoptera frugiperda* (J. E. Smith)

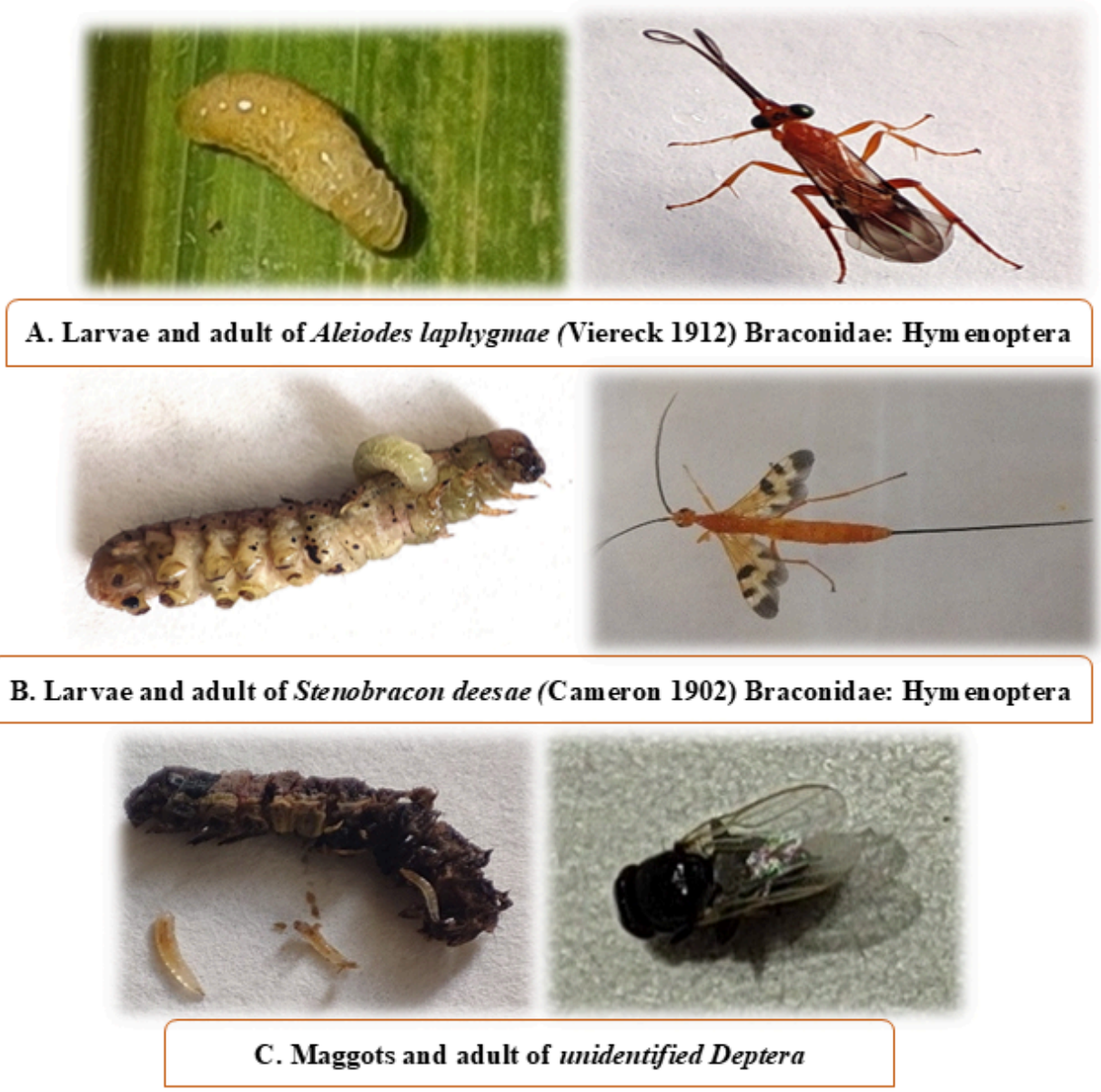


Figure 3

Occurrence of parasitoid species on *Spodoptera frugiperda* larvae

Supplementary Files

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