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# BIOLOGICAL TRAITS, MORPHOMETRICS AND SUB-LETHAL EFFECTS OF INSECTICIDES ON FALL ARMYWORM *Spodoptera frugiperda* (LEPIDOPTERA: NOCTUIDAE) IN MAIZE

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## ABSTRACT

Maize (*Zea mays* L.) is an important cereal crop globally and in Bangladesh, but its productivity is threatened by the invasive fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae). This study evaluated the morphometrics, feeding behavior, and reproductive performance of *S. frugiperda* on maize, and assessed sub-lethal effects of ten insecticides-Tecorel 18.5 SC, Belt 24 WG, Incipio 20 SC, Delegate 11.7 SC, Vayego 20 SC, Spinomax 44.03 SC, Bio BTK, Biochamak 1% EW, *Beauveria bassiana*, and *Metarhizium anisopliae*-under laboratory conditions. Larvae reared on maize cobs exhibited a shorter pre-oviposition period (2.9 days) than larvae reared on maize leaves (3.6 days). They also developed faster, with the sixth larval instar lasting 4.3 days in larvae reared on maize cobs and 5.6 days in those reared on maize leaves. Larvae fed maize leaves treated with sub-lethal concentrations of Delegate 11.7 SC and Spinomax exhibited prolonged larval durations to 21.2 to 22.1 days and pupal durations to 17.3 to 17.8 days, reduced larval body length to 27.8 to 28.2 mm, adult body length (male 12.4 to 13.5 mm, female 13.1 to 13.7 mm), and wing length (male 12.4 to 13.1 mm, female 14.5 to 14.7 mm), suppressed leaf consumption (0.5 to 0.6 g), egg mass production (5.5 to 6.6 egg masses/female), and shortened oviposition period (2.1 to 2.2 days). Bio BTK, Biochamak 1% EW, *B. bassiana* and *M. anisopliae* caused moderate reductions in larval length (32.4-33.8 mm), adult body size (male 13.5-14.5 mm, female 13.7-16.1 mm), wing length (male 14.1-14.6 mm, female 15.7-16.1 mm), and egg mass production (10.3-10.7), while maintaining longer adult longevity (male 7.5-8.4 days, female 8.9-9.7 days). These results indicate that chemical insecticides strongly reduced growth and reproduction, while biopesticides moderately affected development and maintained adult survival.

**Keywords:** Noctuidae; maize pest; developmental biology; reproductive performance; insecticide exposure; microbial control

## ABSTRAK

Jagung (*Zea mays* L.) merupakan tanaman bijirin yang penting di peringkat global dan di Bangladesh, namun produktivitinya diancam oleh ulat ratus askar invasif, *Spodoptera frugiperda* (Lepidoptera: Noctuidae). Kajian ini menilai morfometrik, tingkah laku pemakanan dan prestasi pembiakan *S. frugiperda* pada jagung, serta menilai kesan subletal sepuluh jenis racun serangga, iaitu Tecorel 18.5 SC, Belt 24 WG, Incipio 20 SC, Delegate 11.7 SC, Vayego 20 SC, Spinomax 44.03 SC, Bio BTK, Biochamak 1% EW, *Beauveria bassiana* dan *Metarhizium anisopliae* di bawah keadaan makmal. Larva yang dipelihara menggunakan tongkol jagung menunjukkan tempoh praoviposisi yang lebih singkat (2.9 hari) berbanding larva yang dipelihara menggunakan daun jagung (3.6 hari). Larva tersebut juga berkembang dengan lebih cepat, dengan instar larva keenam berlangsung selama 4.3 hari pada larva yang dipelihara menggunakan tongkol jagung berbanding 5.6 hari pada larva yang dipelihara menggunakan daun jagung. Larva yang diberi daun jagung yang dirawat dengan kepekatan subletal Delegate 11.7 SC dan Spinomax menunjukkan tempoh larva yang lebih panjang, iaitu 21.2 hingga 22.1 hari, serta tempoh pupa yang meningkat kepada 17.3 hingga 17.8 hari. Rawatan ini juga mengurangkan panjang badan larva kepada 27.8 hingga 28.2 mm, panjang badan dewasa (jantan 12.4 hingga 13.5 mm, betina 13.1 hingga 13.7 mm), panjang sayap (jantan 12.4 hingga 13.1 mm, betina 14.5 hingga 14.7 mm), penggunaan daun (0.5 hingga 0.6 g), penghasilan kelompok telur (5.5 hingga 6.6 kelompok telur/betina), serta memendekkan tempoh oviposisi kepada 2.1 hingga 2.2 hari. Bio BTK, Biochamak 1% EW, *B. bassiana* dan *M. anisopliae* pula menyebabkan pengurangan sederhana pada panjang larva (32.4–33.8 mm), saiz badan dewasa (jantan 13.5–14.5 mm, betina 13.7–16.1 mm), panjang sayap (jantan 14.1–14.6 mm, betina 15.7–16.1 mm), dan penghasilan kelompok telur (10.3–10.7 kelompok telur/betina), di samping mengekalkan jangka hayat dewasa yang lebih panjang (jantan 7.5–8.4 hari, betina 8.9–9.7 hari). Hasil kajian menunjukkan bahawa racun serangga kimia memberi kesan yang ketara terhadap pengurangan pertumbuhan dan pembiakan, manakala biopestisid memberikan kesan sederhana terhadap perkembangan serta mengekalkan kemandirian serangga dewasa.

**Kata kunci:** Noctuidae; perosak jagung; biologi perkembangan; prestasi pembiakan; pendedahan racun serangga; kawalan mikrob

## INTRODUCTION

Maize (*Zea mays* L.) is a highly adaptable crop grown across diverse agro-climatic regions. Globally, over 170 countries produce approximately 1157.9 million metric tons of maize on 191.5 million hectares, with an average yield of 5.95 t $ha^{-1}$ (FAO 2023). It serves multiple purposes, including grain, green cobs, sweet corn, baby corn, and popcorn. In Bangladesh, maize is a key food grain cultivated in both winter and summer, with 514,962 ha producing 4876 thousand metric tons in 2023–2024 (BBS 2024). Despite its importance, maize productivity is constrained by various biotic and abiotic factors, among which insect pests are a major limiting factor. Among these pests, the fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae), has emerged as a major global threat to maize production. Native to the Americas, *S. frugiperda* has spread aggressively to Africa, Asia, and beyond over the past decade, facilitated by its strong migratory ability and adaptability to diverse environments (Tay et al. 2023). This invasive lepidopteran exhibits a broad host range but shows a strong preference and high reproductive success on maize, causing extensive defoliation and damaged reproductive organs that often result in severe yield reductions (Goergen et al. 2016). Its rapid development, high fecundity, and capacity for multiple generations per year make it particularly difficult to manage.

Understanding the biological traits of *S. frugiperda*, including developmental durations, reproductive parameters, longevity, and morphometric characteristics, is vital for predicting population growth and formulating effective control strategies. Morphometric measurements such as larval body length, head capsule width, and adult wing dimensions are linked to nutritional status and overall fitness, and they can provide important indicators of how environmental factors and pest management interventions affect insect performance. Variation in these traits often reflects underlying physiological responses to host quality, stress, and chemical exposure. Although these biological traits have been extensively studied under different host plants and environmental conditions, information on the sub-lethal effects of insecticides on the biological and morphometric characteristics of *S. frugiperda* remains limited.

Insecticides remain a cornerstone in fall armyworm management, but research increasingly shows that sub-lethal exposures-doses that do not cause immediate mortality-can still significantly affect insect biology. Sub-lethal effects may alter feeding behavior, extend developmental periods, suppress fecundity, and reduce reproductive success, all of which influence population dynamics even when direct mortality is moderate (Hasnain et al. 2023). Integrated pest management of *S. frugiperda* requires multiple control approaches, including the conservation and utilization of natural enemies alongside chemical and biological control methods (Tobing et al. 2023). Biological control agents, such as entomopathogenic fungi-including *Beauveria bassiana* and *Metarhizium anisopliae*-offer environmentally sustainable alternatives or supplements to chemical control. These fungi infect host insects through the cuticle and gradually weaken their physiological condition, reducing feeding efficiency, survival, and reproduction without adversely affecting non-target organisms. Studies have demonstrated that both fungi and their secondary metabolites can suppress life history traits in *S. frugiperda* under controlled conditions, although effects often develop more slowly compared to chemical insecticides (Idrees et al. 2021).

Despite the economic importance of maize and the severity of fall armyworm infestations, there is limited information on how sub-lethal doses of both chemical and biological insecticides influence the full spectrum of biological traits and morphometric responses in fall armyworm, particularly under controlled conditions relevant to Bangladesh. This study aims to investigate the biological traits, morphometrics, feeding, and reproduction of fall armyworm on maize, and to evaluate the sub-lethal effects of selected chemical and biological insecticides on its development and fitness, providing insights for sustainable pest management.

## MATERIALS AND METHODS

### Experimental Site and Duration

The study was conducted in the experimental field of the Division of Entomology at Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh, from May 2024 to June 2025. The study site was located in Gazipur, Bangladesh, with coordinates 23°59'30.91"N latitude and 90°24'48.87"E longitude.

**Biology of Fall Armyworm**

The biology of the fall armyworm, *Spodoptera frugiperda*, was studied under laboratory conditions at the Division of Entomology, Bangladesh Agricultural Research Institute (BARI). The experiment was conducted in a completely randomized design (CRD) maintained at 27±2℃ and 70±5% relative humidity (RH). Full grown larvae were initially collected from maize fields in insect tubes and transferred to the laboratory, where they were reared on maize leaves and cobs until adult emergence to study the complete life cycle. Each larva was individually placed in a plastic container containing fresh maize leaves. Upon adult emergence, adults from each dietary treatment (maize leaf and cob) were paired within the same diet. Three translucent mating cages (25 × 20 × 20 cm), which were covered with muslin cloth secured with rubber bands, were established for each dietary treatment (maize leaf and cob), with each cage containing one male and one female moth. The inner surfaces of the cages were lined with dark paper to facilitate easy observation and collection of eggs. A cotton swab soaked in 10% honey solution was provided as a food source for the moths. Egg masses were collected from the dark paper and transferred to clean containers (20 × 4 cm), where fresh tender maize leaves and cobs were provided for hatching. Wet filter paper inside the containers helped maintain leaf freshness.

After hatching, 30 newly emerged first-instar larvae were randomly assigned to two dietary treatments: maize leaves and maize cobs. Each treatment consisted of three biological replicates, with five individually reared larvae per replicate. Fresh maize leaves and cobs were supplied throughout larval development until the sixth instar. Mature sixth instar larvae were transferred to petri dishes (15 cm lower diameter × 15.5 cm upper diameter) for pupation. Pupae were subsequently collected and stored in plastic jars measuring 20 × 10 × 5 cm. The development of each life stage, from egg to adult, was carefully recorded throughout the study. The larval period was recorded from the time of egg hatching until the larvae ceased feeding prior to pupation. The pupal period was recorded from pupal formation until adult emergence. The pre-oviposition period was measured from adult emergence until the female laid her first egg.

The oviposition period was recorded as the duration from the first to the last egg laid by a female. The incubation period was defined as the time from egg laying until hatching of the eggs. Male longevity was recorded as the total lifespan of adult males from emergence until death. Female longevity was recorded as the total lifespan of adult females from emergence until death.

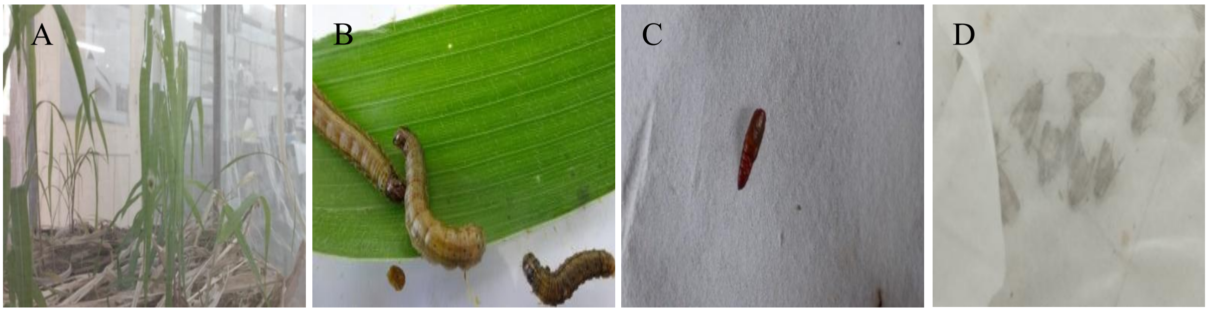


Figure 1. Study on the biology of the fall armyworm. A. Egg mass, B. Larva, C. Pupa and D. Adult fall armyworm

**Morphometric Measurement**

The body length, head width, wing length and wing span of *S. frugiperda* reared on maize leaves and cobs were measured using a stereomicroscope equipped with a digital camera and the images were analyzed using ToupView software. Body length and head width were measured from five individuals per treatment at appropriate developmental stage, wing length and wing span were measured from adult moths. All measurements of larvae and adults were initially recorded in pixel units and subsequently converted to millimeters (mm) for analysis.

**Sub-Lethal Doses of Insecticides on Fall Armyworm**

The experiment on the sub-lethal effects of different insecticides was conducted in the laboratory following a completely randomized design (CRD). Sub-lethal doses of each insecticide were used to evaluate their impact on the development and morphology of fall armyworm larvae. Fresh maize leaves were collected from the field and cut into suitable pieces. These leaf pieces were immersed in the respective insecticide solutions for 30 seconds to ensure complete coverage, then removed and air-dried at room temperature for 10 minutes. Control leaf pieces were immersed in distilled water for 30 seconds and air-dried following the same procedure. After drying. The treated leaves were placed in petri dishes to serve as larval diet.
Sub-lethal doses of the tested insecticides were estimated as approximately 20% of their recommended field doses, following approaches used in previous studies on insect sub-lethal effects (Wu et al. 2022; Zhang et al. 2023a). Specifically, the sub-lethal doses applied for each insecticide were as follows: Tecorel 18.5 SC (0.1 ml/L), Belt 24 WG (0.1 g/L), Incipio 20 SC (0.12 ml/L), Delegate 11.7 SC (0.2 ml/L), Vayego 20 SC (0.1 g/L), Spinomax (0.4 ml/L), Biochamak 1% EW (0.5 ml/L), Bio-BTK (0.2 g/L), *Beauveria bassiana* (1 g/L), and *Metarhizium anisopliae* (0.4 ml/L). Water-dispersible granule (WG) insecticides were measured using a digital weighing balance, while emulsifiable concentrate (EC) insecticides were measured using a micropipette.

Each treatment consisted of three replicate Petri dishes, with each Petri dish containing five healthy third instar larvae, which were provided the treated leaf pieces as their diet. In the untreated control, larvae were supplied with fresh maize leaves only. Mature sixth instar larvae were then transferred to petri dishes for pupation. The insect colony and all laboratory experiments were conducted under prevailing laboratory conditions at 27±2°C and 70±5% relative humidity (RH) and a photoperiod of 12:12 (light: dark). Developmental parameters, including larval duration, pupal duration, and larval body length, were recorded. Leaf consumption by each larva was determined by subtracting the remaining leaf from the initial amount provided. Upon adult emergence, one male and one female moth (1:1 ratio) from each replicate were transferred to translucent mating cages (25 × 20 × 20 cm), covered with muslin cloth and secured with rubber bands. The inner surfaces of the cages were lined with dark paper to facilitate the observation and collection of egg masses. The number of egg mass and oviposition periods were recorded. Adult longevity was determined by recording the number of days from adult emergence until death. Additionally, adult male and female body length and wing length were measured to assess the effects of the insecticides.

**Statistical Analysis**

All experimental data were subjected to one-way analysis of variance (ANOVA) to determine significant differences among treatments. When ANOVA indicated significant effects, treatment means were compared using Tukey's HSD post hoc test at a 5% significance level ($P<0.05$). Independent t-tests were employed for pairwise comparisons during comparing life history traits between maize leaves and cobs. All statistical analyses were conducted using IBM SPSS Statistics version 21.0.

## RESULTS

The life-history traits of fall armyworm, representing the biological trait study, reared on maize leaves and cobs, are presented in Table 1. The pre-oviposition period was significantly longer on leaf (3.6±0.03 days) than on cob (2.9±0.05 days), showing a highly significant difference ($t = 30.2$, $P<0.001$). Similarly, the incubation period was slightly higher on leaf (3.3±0.02 days) compared to cob (3.1±0.05 days). A consistent trend was observed in the larval stages, where all instars reared on maize leaf exhibited longer durations than those reared on cob. The durations of the 1$^{st}$ to 6$^{th}$ instar larvae on maize leaf were 2.8±0.2, 3.2±0.03, 2.4±0.03, 2.7±0.03, 3.4±0.03, and 5.6±0.03 days, respectively.

Table 1. Duration of the life history traits of fall armyworm reared on leaf and cob of maize plants under laboratory condition

| Life History Parameters | Duration (Mean±SE Days) | | t Statistic | | |
|---|---|---|---|---|---|
| | Leaf | Cob | df | t | *P* |
| Pre-oviposition | 3.6±0.03 | 2.9±0.05 | 4 | 30.2 | <0.001 |
| Incubation | 3.3±0.02 | 3.1±0.05 | 4 | 5.7 | <0.005 |
| 1$^{st}$ instar larva | 2.8±0.2 | 1.7±0.05 | 4 | 5.7 | <0.05 |
| 2$^{nd}$ instar larva | 3.2±0.03 | 2.6±0.07 | 4 | 11.6 | <0.001 |
| 3$^{rd}$ instar larva | 2.4±0.03 | 2.1±0.03 | 4 | 1.6 | <0.05 |
| 4$^{th}$ instar larva | 2.7±0.03 | 2.4±0.05 | 4 | 8.5 | <0.05 |
| 5$^{th}$ instar larva | 3.4±0.03 | 2.8±0.05 | 4 | 12.6 | <0.001 |
| 6$^{th}$ instar larva | 5.6±0.03 | 4.3±0.06 | 4 | 14.9 | <0.001 |

df = Degrees of freedom.

The measurements of body length and head capsule width of different larval instars of fall armyworm reared on maize leaves and cobs under laboratory condition (Figure 2). For body length, the lowest value was recorded in the 1st instar (1.7 mm on leaves, 1.8 mm on cobs), while the highest was in the 6th instar (33.3 mm on leaves and 33.5 mm on cobs). Across all instars, cob-fed larvae tended to be slightly larger than leaf-fed ones, except in the 5th instar where the values were equal (19.8 mm). For head capsule width, the smallest measurement occurred in the 1st instar (0.36 mm leaf, 0.38 mm cob), whereas the largest was observed in the 6th instar (2.8 mm leaf, 2.9 mm cob). Differences between leaf and cob-fed larvae were more pronounced in earlier instars but became less distinct in later instars.

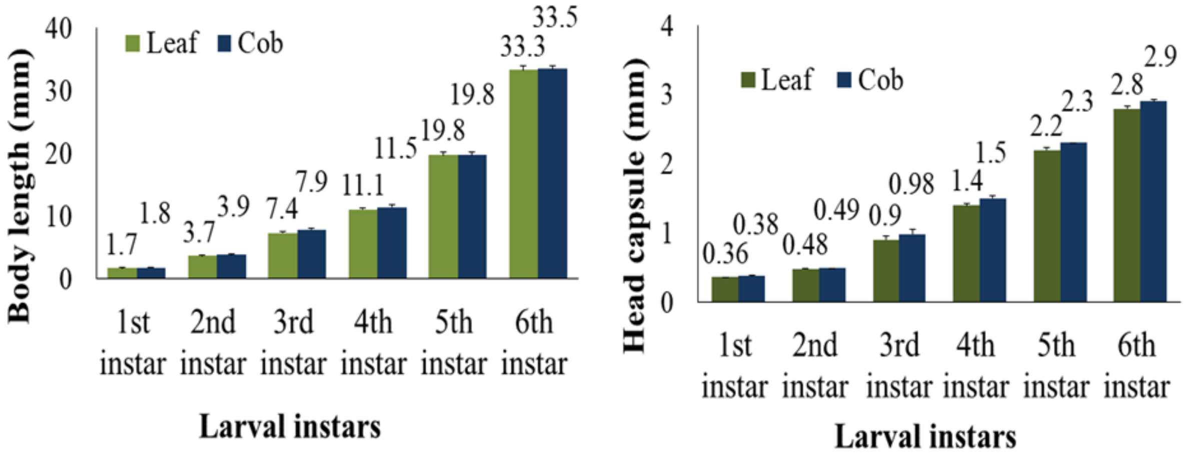


Figure 2. Morphometric measurements of different instars of fall armyworm larvae reared on leaf and cob of maize under laboratory conditions

Significant differences (*P<0.05*) were observed in larval duration, pupal duration, and adult longevity (male and female) across the tested treatments (Table 2). Among the insecticides tested, Spinomax resulted in the longest larval duration (22.1±0.1 days), followed by Delegate 11.7 SC (21.2±0.2 days) and Vayego 20 SC (21.1±0.1 days), while the shortest larval duration was observed in the control group (19.3±0.6 days). Similarly, pupal duration was longest in larvae treated with Delegate 11.7 SC (17.8±0.2 days), followed by Spinomax (17.3±0.1 days) and Vayego 20 SC (16.3±0.1 days), and shortest in the control (12.1±0.06 days). Adult longevity varied with treatment, with males living longest on *Metarhizium anisopliae* (8.1±0.02 days) and females on *Beauveria bassiana* (9.7±0.05 days), while the control group exhibited the longest overall lifespan (males 9.4±0.02 days, females 11.2±0.1 days).

Table 2. Effect of sub lethal doses of different insecticides on the development durations and adult longevity of fall armyworm, when their larvae were reared on maize leaves under laboratory condition

| **Treatment** | **Duration (days)** | | | |
|---|---|---|---|---|
| | **Larva** | **Pupa** | **Male Longevity** | **Female Longevity** |
| Tecorel 18.5 SC | 20.2±0.2bc | 15.2±0.08cd | 7.03±0.03f | 7.8±0.3g |
| Belt 24 WG | 20.1±0.1c | 16.2±0.05bc | 7.1±0.03ef | 8.2±0.5ef |
| Incipio 20 SC | 20.1±0.2c | 15.3±0.1cd | 7.2±0.02d-f | 8.3±0.3e |
| Delegate 11.7 SC | 21.2±0.2ab | 17.8±0.2a | 6.9±0.08f | 7.6±0.08g |
| Vayego 20 SC | 21.1±0.1bc | 16.3±0.1bc | 7.4±0.03c-e | 8.7±0.2d |
| Spinomax | 22.1±0.1a | 17.3±0.1ab | 7.1±0.1f | 7.9±0.1g |
| Bio BTK | 19.5±0.1d | 14.4±0.1d | 7.6±0.03c | 9.1±0.3cd |
| Biochamak 1% EW | 19.6±0.1de | 14.6±0.2d | 7.5±0.03cd | 8.9±0.4d |
| *Metarhizium anisopliae* | 19.6±0.03de | 14.5±0.1d | 8.1±0.02b | 9.4±0.8bc |
| *Beauveria bassiana* | 19.7±0.03de | 14.3±0.1d | 8.4±0.05b | 9.7±0.05b |
| Control | 19.3±0.6e | 12.1±0.06e | 9.4±0.02a | 11.2±0.1a |

Data expressed as mean±SE. Means having same letter(s) in a column are not significantly different at *P<0.05* followed by Tukey's HSD posthoc statistic.

The effects of sub-lethal doses of various insecticides varied significantly (p< 0.05) on the morphometric traits of fall armyworm reared on maize leaves under laboratory conditions (Table 3). The control group exhibited the largest larval body length (35.9±0.2 mm), adult body length (males 14.8±0.3 mm and females 15.4±0.3 mm), and adult wing length (males 15.7±0.1 mm; females 17.4±0.1 mm), indicating normal growth without biological stress. Among the tested insecticides, Delegate 11.7 SC (27.8±0.1 mm), followed by Spinomax (28.2±0.1 mm) and Vayego 20 SC (29.0±0.1 mm) significantly reduced larval body length compared to the control. The smallest adults were observed in the Delegate 11.7 SC treatment, with males measuring 12.4±0.1 mm and females 13.1±0.2 mm, indicating substantial growth suppression compared to the control. Other chemical treatments, including Tecorel 18.5 SC, Belt 24 WG, Incipio 20 SC, and Vayego 20 SC caused moderate reductions in adult size, with male body lengths ranging from 12.7±0.2 to 13.3±0.3 mm and females from 13.3±0.1 to 13.9±0.2 mm. Biopesticides such as Spinomax, Bio BTK, Biochamak 1% EW, *Metarhizium anisopliae*, and *Beauveria bassiana*, had comparatively lesser effects, producing adults with male lengths of 13.5±0.3 to 14.1±0.2 mm and female lengths of 13.7±0.1 to 14.5±0.3 mm. Similarly, adult wing lengths were reduced, with males ranging from 12.4±0.1 mm in Delegate 11.7 SC to 13.9±0.1 mm in Incipio 20 SC and Vayego 20 SC; females ranging from 14.5±0.1 mm in Delegate 11.7 SC to 15.2±0.1 mm in Belt 24 WG and Incipio 20 SC. In contrast, biocontrol agents such as Bio BTK (32.6±0.1 mm), Biochamak 1% EW (32.4±0.1 mm), *Metarhizium anisopliae* (33.1±0.06 mm), and *Beauveria bassiana* (33.8±0.03 mm) also reduced larval and adult sizes relative to the control but to a lesser extent than chemical insecticides. Adult wing lengths for these treatments were moderately higher, with males ranging from 14.1 to 14.6 mm and females from 15.7 to 16.1 mm, indicating that surviving larvae could still develop relatively normally.

Table 3. Effect of sub-lethal doses of different insecticides on the lengths of full grown larvae, and wing of fall armyworm, when their larvae were reared on maize leaves under laboratory condition

| **Treatment** | **Length Of Larvae (Mm)** | **Adult Body Length (Mm)** | | **Adult Wing Length (Mm)** | |
|---|---|---|---|---|---|
| | | **Male** | **Female** | **Male** | **Female** |
| Tecorel 18.5 SC | 29.6±0.06c | 13.1±0.1df | 13.6±0.1df | 13.2±0.1de | 15.1±0.1ce |
| Belt 24 WG | 29.5±0.06c | 13.3±0.2ce | 13.9±0.2ce | 13.6±0.1cd | 15.2±0.1cd |
| Incipio 20 SC | 29.8±0.03c | 12.8±0.2fh | 13.4±0.2eg | 13.9±0.1bd | 15.1±0.03ce |
| Delegate 11.7 SC | 27.8±0.1e | 12.4±0.1h | 13.1±0.2g | 12.4±0.1e | 14.5±0.1e |
| Vayego 20 SC | 29±0.1cd | 12.7±0.2gh | 13.3±0.1fg | 13.9±0.1bd | 15.1±0.03ce |
| Spinomax | 28.2±0.1de | 13.3±0.3ce | 13.5±0.1eg | 13.1±0.2de | 14.7±0.1de |
| Bio BTK | 32.6±0.1b | 13.5±0.3bd | 13.7±0.1df | 14.1±0.1bc | 15.7±0.1bc |
| Biochamak 1% EW | 32.4±0.1b | 13.8±0.3bd | 14.1±0.2bd | 14.6±0.1b | 16±0.06b |
| *Metarhizium anisopliae* | 33.1±0.06b | 13.9±0.3bc | 14.3±0.3bc | 14.4±0.03bc | 15.9±0.06b |
| *Beauveria bassiana* | 33.8±0.03b | 14.1±0.2b | 14.5±0.3b | 14.6±0.03b | 16.1±0.03b |
| Control | 35.9±0.2a | 14.8±0.3a | 15.4±0.3a | 15.7±0.1a | 17.4±0.1a |

Data expressed as mean±SE. Means having same letter(s) in a column are not significantly different at $P<0.05$ followed by Tukey's HSD posthoc statistic.

The effects of sub-lethal doses of various insecticides varied significantly ($P<0.05$) on the leaf consumption (Figure 3). The highest leaf consumption was observed in the control (1.3 g), followed by Biochamak (1.2 g), *Beauveria bassiana* (1.1 g), and *Metarhizium anisopliae* (1.0 g). Moderate levels of consumption were recorded in Bio BTK (0.9 g), Belt 24 WG (0.8 g), Incipio 20 SC (0.8 g), and Spinomax (0.8 g). In contrast, significantly lower leaf consumption was observed in Delegate 11.7 SC (0.6 g) and Vayego 20 SC (0.5 g).

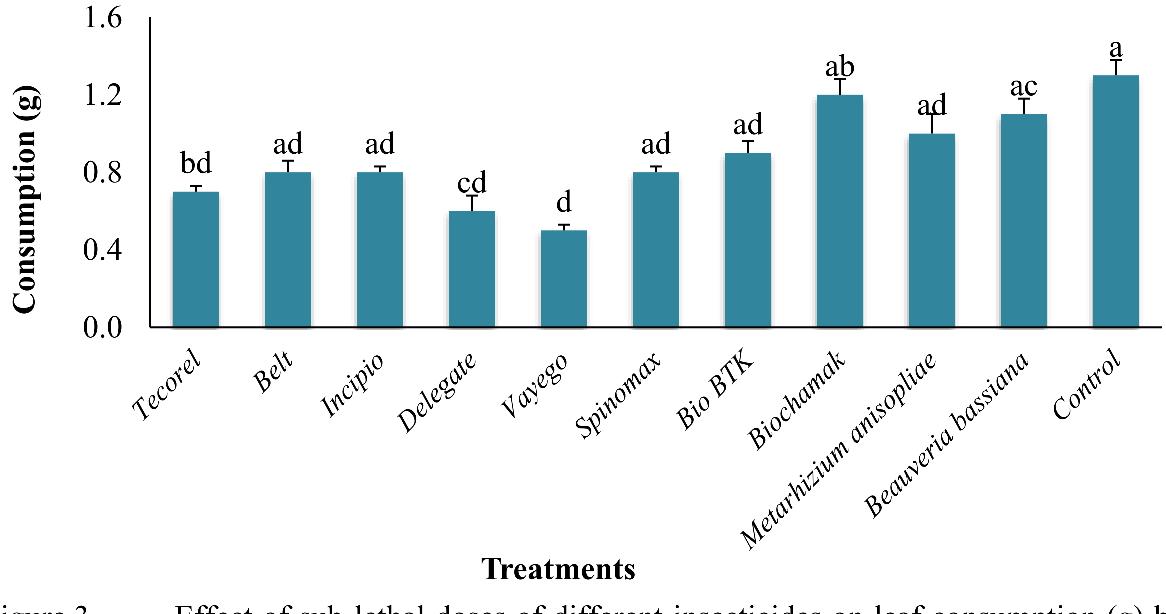


Figure 3. Effect of sub-lethal doses of different insecticides on leaf consumption (g) by fall armyworm larvae under laboratory condition

The number of egg masses produced by *Spodoptera frugiperda* females was significantly influenced by different sub-lethal insecticide treatments (Figure 4). The highest egg mass production occurred in the control (11.2 egg masses female$^{-1}$), followed closely by *Beauveria bassiana* (10.7), *Metarhizium anisopliae* (10.3), Biochamak 1% EW (10.4), and Bio BTK (10.7). These values did not differ significantly from the control, indicating that the tested biopesticides had only a mild impact on oviposition potential. In contrast, several chemical insecticides markedly reduced egg mass production. Delegate 11.7 SC (5.5 egg masses female$^{-1}$) and Spinomax (6.6) were the most suppressive, indicating strong interference with reproductive output. Tecorel 18.5 SC (8.2), Belt 24 WG (9.6), Incipio 20 SC (9.5), and Vayego 20 SC (9.5) also significantly reduced egg mass production compared to the control, though their effects were less severe than Delegate 11.7 SC and Spinomax.

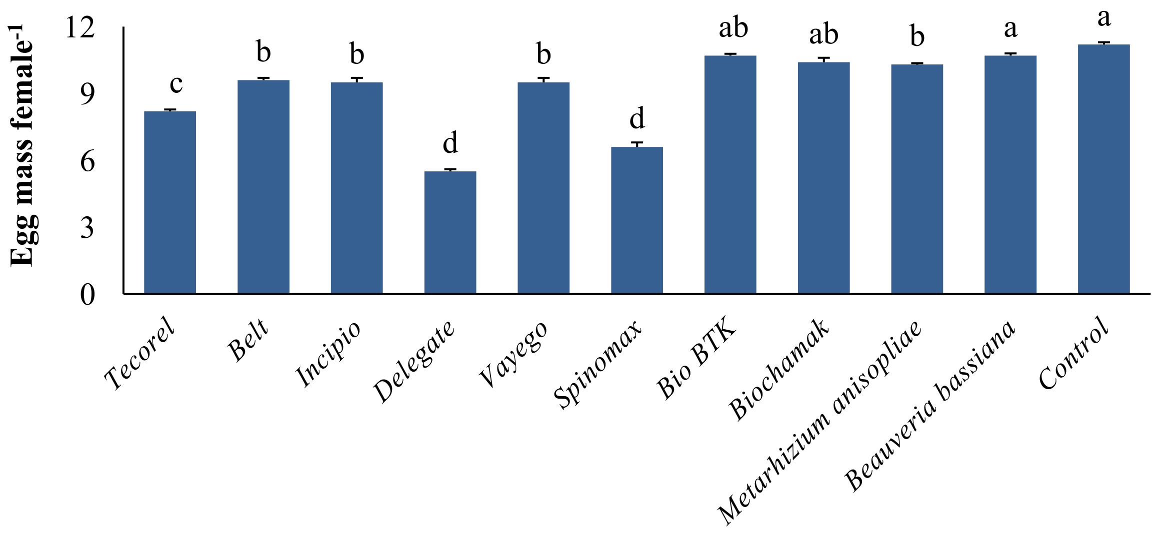


Figure 4. Effect of sub-lethal doses of different insecticides on the number of egg mass production of female fall armyworm under laboratory condition

The oviposition period of *Spodoptera frugiperda* females differed significantly among treatments (*P<0.05*) (Figure 5). The longest oviposition period occurred in the untreated control (6.4 days), whereas Delegate 11.7 SC (2.1 days) had the shortest. Chemical insecticides such as Spinomax (2.2 days), Tecorel 18.5 SC (2.4 days), Belt 24 WG (2.5 days), and Vayego 20 SC (2.6 days) also markedly reduced the oviposition period compared to the control. Incipio 20 SC produced a moderate oviposition period (2.8 days), while biopesticides *Metarhizium anisopliae* (4.1 days) and *Beauveria bassiana* (4.2 days) showed intermediate effects, reducing reproduction less severely than most chemical treatments.

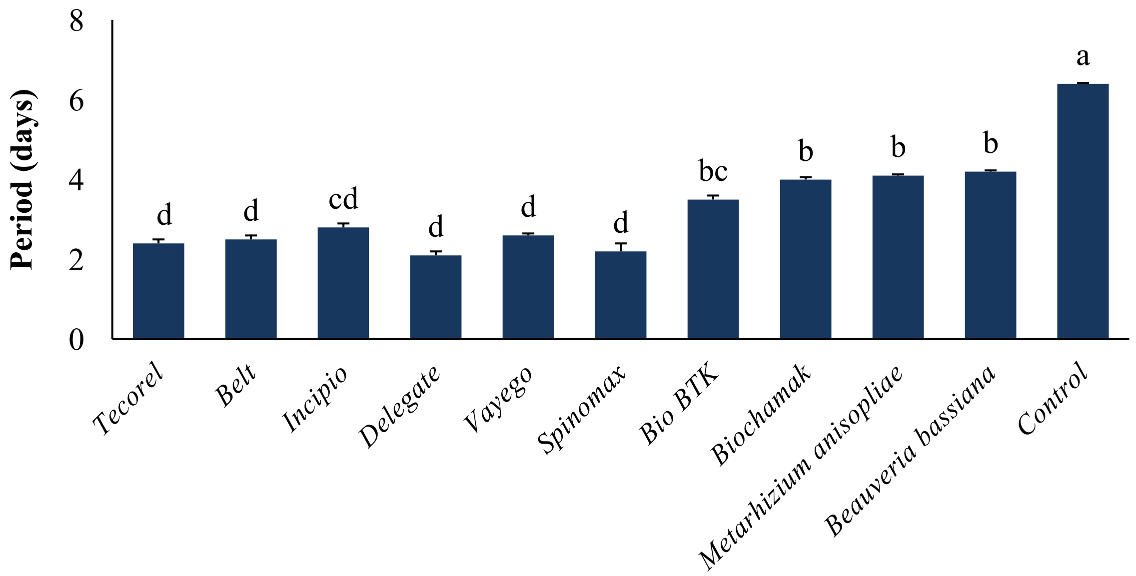


Figure 5. Effect of sub-lethal doses of insecticides on oviposition period (days) of fall armyworm under laboratory condition

## DISCUSSION

This life history pattern suggests that maize cob provided a more favorable substrate for rapid larval growth, due to differences in nutritional quality that enhance feeding efficiency and nutrient assimilation (Mason et al. 2022). In contrast, maize leaves possess structural and biochemical defensive traits that can reduce food utilization and slow larval development (Prasanna et al. 2022). Similar variations in development due to host suitability have been widely reported, where fall armyworm exhibited significantly different growth and reproductive performance across maize types, indicating that nutritional quality plays a critical role in determining developmental rate (Zhang et al. 2025).

The morphometric differences between leaf- and cob-fed larvae indicate that the two maize plant parts differed in their suitability for larval growth. Cob-fed larvae attained slightly greater body lengths and head capsule widths, indicating more efficient growth. Larval size and development in *Spodoptera frugiperda* are strongly influenced by host plant quality, with nutrient-rich tissues promoting faster growth, larger body size, and improved feeding efficiency, while lower nutrient or high-fiber tissues constrain development (Ajmal et al. 2024). The larger dimensions of cob-fed larvae in this study are attributed to the higher nutrient content and softer structure of maize cobs.

The extension of larval and pupal durations under chemical insecticides may result from physiological stress and disruption of normal development, whereas biocontrol agents such as Biochamak 1% EW, Bio BTK, *Metarhizium anisopliae*, and *Beauveria bassiana* not only shortened developmental periods but also supported relatively higher adult longevity, indicating a more balanced effect on the pest's biology. These findings suggest that biocontrol agents may be more effective in integrated pest management by reducing developmental time and potentially limiting population growth without excessively harming adult survival which aligns with the study conducted by Wu et al. (2022).

These reductions in morphometric parameters likely result from physiological stress and sublethal disruption of feeding and nutrient assimilation during larval development, as also reported by Zhang et al. (2023a). Reduced larval and adult size under sub-lethal treatments is typical, as stress from insecticides can disrupt normal physiological processes, interfere with nutrient allocation, and impact hormonal regulation (Gao et al. 2021; Liu et al. 2022).

Chemical insecticides are more effective in reducing feeding activity of fall armyworm larvae compared to biological agents, as they act quickly on the insect's nervous system or gut, causing rapid paralysis, while biological agents work more slowly and depend on infection processes. Similar reductions in feeding activity of *Spodoptera frugiperda* larvae due to synthetic insecticides have been documented, with chlorantraniliprole treatments significantly decreasing food consumption rates relative to controls, and other insecticide chemistries exhibiting strong feeding deterrent effects in larval feeding bioassays (Altaf et al. 2022).

These results align with previous studies showing that sub-lethal exposure to chemical insecticides can impair reproductive physiology in *S. frugiperda*. Sub-lethal doses of chlorantraniliprole and spinetoram have been shown to reduce vitellogenin synthesis, disrupt ovarian development, and suppress fecundity (Wu et al. 2022; Yang et al. 2023). The pronounced reduction in egg mass production observed with Delegate and Spinomax may result from interference with the endocrine system and disruption of energy allocation toward reproduction. On the other hand, the minimal effect of *M. anisopliae* and *B. bassiana* is likely due to their slower mode of action. These fungi gradually weaken hosts by producing secondary metabolites and reducing longevity, rather than directly disrupting hormonal balance, allowing females to retain relatively high egg production potential. The findings suggest that chemical insecticides can strongly reduce egg mass production in *S. frugiperda*, whereas biopesticides allow higher reproductive output but are more environmentally safe.

The significant reduction in oviposition duration under chemical insecticide treatments can be attributed to their physiological impacts on reproductive systems. Sublethal exposure to compounds like emamectin benzoate and chlorantraniliprole has been shown to reduce fecundity and other reproductive parameters in *S. frugiperda*, including effects on life table traits and reproductive capacity, even when adults are not killed outright by the treatments (Zhang et al. 2023b). These chemicals rapidly disrupt hormonal signaling and ovarian function, forcing females to allocate energy toward detoxification and survival rather than egg production. This leads to a compressed reproductive window and accelerated reproductive senescence. In contrast, entomopathogenic fungi such as *M. anisopliae* also induce sublethal effects but generally act more slowly and indirectly. Exposure to fungal agents can alter development and reproductive traits in insects, including reductions in reproductive output and prolongation of developmental times, especially under sublethal conditions (Ullah et al. 2023). Since fungal infections develop slowly, females can continue laying eggs for a period before their physiological condition deteriorates, leading to a moderate decrease in oviposition.

## CONCLUSION

This study demonstrates that the biology, morphometrics, and reproductive performance of fall armyworm are strongly influenced by host plant type and sub-lethal insecticide exposure. Larvae developed faster and attained larger body sizes on maize cobs than on leaves. Chemical insecticides including Tecorel 18.5 SC, Belt 24 WG, Incipio 20 SC, Delegate 11.7 SC, Vayego 20 SC, and Spinomax, significantly suppressed larval growth, reduced leaf consumption (as low as 0.5-0.6 g), shortened oviposition periods (2.1-2.6 days), and decreased egg mass production (5.5-6.6 eggs per female). Biopesticides namely Bio BTK, Biochamak 1% EW, *Beauveria bassiana*, and *Metarhizium anisopliae* moderately reduced growth and reproduction while maintaining adult longevity (up to 9.7 days for females) and relatively high egg production (10.3-10.7 eggs per female). Chemical insecticides strongly suppress fall armyworm, whereas biopesticides offer an eco-friendly option that maintains adult longevity and aids in developing efficient pest management strategies for maize.

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## AUTHORS DECLARATIONS

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**Conflict of Interest**
All authors declare that there is no conflict of interest.

**Ethics Declarations**
Ethics declarations are not applicable for this research.

**Data Availability Statement**
This manuscript has no associated data.

**Authors' Contributions**
P. Roy: Conducting research and writing the draft manuscript; N.K. Dutta: Reviewing and editing the manuscript, M. M. Islam: Reviewing and editing the manuscript, H.B. Aslam: Reviewing and editing the manuscript; M.R. Amin: Designing the experiment, research supervision, reviewing and editing.

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