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Research Article

Developmental Biology and Morphometric Studies of Fall Armyworm (*Spodoptera frugiperda*) on Cotton under Laboratory Conditions

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Abstract: The life cycle and morphometric characteristics of fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae), on cotton were studied under laboratory conditions at the Stored Grain Research Laboratory, Department of Entomology, Faculty of Crop Protection, Sindh Agriculture University, Tandojam. Ten individuals of each stage, i.e., egg, six larval instars, pupae, and adults (males and females) were observed to observe their development duration and record various morphometric parameters which were then presented as mean ± SE calculated using MS-Excel. The obtained results indicated that the mean egg hatching period was recorded as 2.33 ± 0.05 days. The mean developmental duration of six larval instars was recorded as 5.11 ± 0.30, 6.17 ± 0.27, 5.81 ± 0.21, 5.78 ± 0.26, 5.63 ± 0.27, and 4.53 ± 0.27 days, respectively, with total larval development completed in 32.06 ± 0.21 days. The mean pupal period was 9.63 ± 0.23 days, as the total life cycle of *S. frugiperda* was completed in 43.92 ± 0.72 days. Mean adult longevity of males was recorded as 7.90 ± 0.29 days and 9.60 ± 0.19 days for females. Mean fecundity of *S. frugiperda* was recorded as 407.50 ± 13.76 eggs per female. The lengths of the six larval instars were 1.68 ± 0.05, 3.32 ± 0.07, 6.94 ± 0.07, 12.87 ± 0.46, 19.78 ± 0.34, and 31.95 ± 0.27 mm, respectively, while their mean width was 0.30 ± 0.01, 0.60 ± 0.02, 1.43 ± 0.06, 1.91 ± 0.04, 3.26 ± 0.11, and 4.41 ± 0.07 mm, respectively. The head capsule radius of all six instars was recorded as 0.14 ± 0.01, 0.23 ± 0.01, 0.37 ± 0.01, 0.76 ± 0.01, 1.02 ± 0.02, and 1.83 ± 0.03 mm. The mean larval weight from the 3rd to 6th instars and pupa was 0.08, 0.14, 0.23, 0.42, and 0.15 g, respectively. Therefore, obtained results clearly indicated that *S. frugiperda* has the potential to survive and grow on cotton, a major cash crop in Pakistan. Therefore, it is recommended that appropriate measures should be taken to restrict its spread on key crops of Pakistan, i.e., cotton, to reduce economic losses.

Keywords: Fall Armyworm, Invasive Insect Pest Species, Morphometrics, Cotton Crop.

1. INTRODUCTION

Fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) has recently emerged as one of the most destructive insect pests of maize and other important crops [1, 2]. *Spodoptera frugiperda* is a polyphagous pest, damaging different crops such as maize, millet, cotton, rice, sorghum, sugarcane, and more than 80 other crops in subtropical and tropical regions [3-5]. *Spodoptera frugiperda* is capable of feeding on almost all above-ground plant components of its hosts. On immature corn, larvae eat on the surface of the leaves, leaving behind just white papery areas known as windowpanes. Older larvae devour more tissues, have stronger mandibles, and cut huge parts of plant tissues with high silica content, such as seedlings, leaves, tassels, cobs, husks, and

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developing kernels [6]. Adults of *S. frugiperda* can travel 100 kilometers in a single night, hence contribute to its spread and invasiveness. The presence of this migratory pest also spread in Africa and Australia in 2016 and 2020 in Asia. In Asia, it causes more damage and becomes a major pest of maize [3].

Temperature has a significant impact on growth as the Fall armyworm completes its life cycle in one month during the summer at a temperature of 28 °C, it takes between 60 and 90 days throughout the spring, fall, and winter months [7]. *Spodoptera frugiperda* has four life stages, i.e., egg, larva, pupa, and adult. The female lays 100-200 eggs in clusters during its whole life span on the underside or surface of the leaf, as well as on the top apex of the leaf and on other surfaces such as stems [7]. Duration of egg stage is only 2–3 days during warm conditions. Newly hatched larvae consume little amount of food but when they reach at fifth to sixth larval stage, they consume large amount of food [8]. Constant pest fecundity under favorable environmental conditions is expected to cause significant crop damage [6]. The larvae are the most harmful stage of *S. frugiperda* because early first and second instars eat on one side of the leaves, skeletonizing them, whereas final instars feed on all above-ground parts of their hosts [3]. *Spodoptera frugiperda* do the most harm between stages 3 and 6 of maize, when they reach the whorls' protective zones. Feeding in the early stages destroys the growth points, resulting in no further leaf or cob development. Normally, one or two larvae feed in a whorl as larger larvae might feed on smaller larvae to lessen competition [9].

Fall armyworms can quickly destroy a crop, causing significant economic damage to farmers. The fall armyworm is a very damaging pest of many economically essential crops throughout the world [9]. In 2018, *S. frugiperda* caused a massive loss in maize for the first time in India [10]. *Spodoptera frugiperda* can cause huge profit losses in various economically important crops as a notorious pest. Bannor *et al.* [11] observed that corn plant is favorite of *S. frugiperda* and normally causes 15-73% yield losses in maize; they concluded that the decrease in maize yield by *S. frugiperda* is about 8.3 to 20.6 million tons annually. Mostly soft leaf parts are eaten by fresh caterpillars, creating holes in leaves; this is the characteristic loss sign of *S. frugiperda* [12]. All six instars of *S. frugiperda* caterpillars are the harmful stage for their host. The initial two instars of the caterpillar generally eat from the sides of the leaves and empty them, and the final instars eat all parts of their host's plant [11]. Despite its importance, there is still a lack of knowledge on its biology and life cycle, which hampers the development of effective management strategies [13]. The life cycle of *S. frugiperda* is comprised of egg, six larval instars, pupa, and adult male and female, which make their effective management more difficult [7]. Therefore, continuous research on the various biological aspects and management options of *S. frugiperda* could be very helpful in its effective management [14].

Morphometrics analysis can reveal important information about the growth and development of insects [15]. The length and width of the head capsule of an insect can provide an estimate of its age and nutritional status, while the length and weight of the body segments can indicate the rate of growth and development [16]. *S. frugiperda*, previous studies have shown that the morphometrics of larvae can be influenced by various factors, such as temperature, humidity, and host plants [17]. As *S. frugiperda* is a highly polyphagous pests that can survive on alternate hosts in absence of its primary host (maize), therefore, this study was conducted to understand its life cycle parameters and morphometric on cotton, a cash crop of Pakistan under laboratory conditions. The obtained results could help to take appropriate measures to prevent *S. frugiperda* losses to cotton that is already vulnerable to many insect pests, and the same can result in improved cotton yield.

2. MATERIALS AND METHODS

The research work was carried out at the Stored Grain Research laboratory, located within the Department of Entomology, Faculty of Crop Protection at Sindh Agriculture University in Tandojam during 2023-24.

2.1. Rearing and Handling of *Spodoptera frugiperda*

The initial culture of *S. frugiperda* was obtained by collecting larvae from a field near Tandojam. The culture was carefully collected from the growing maize in the field, put in plastic jars covered with

a fine mesh net, and brought into the laboratory. In the lab, the larvae were shifted into plastic bowls provided with freshly cut cotton leaves as food till the pupation. After pupation, the pupae were transferred into a glass cage covered with a net for adult emergence. The laboratory was maintained at a temperature of 28 ± 2 °C and a relative humidity of 75 ± 5% throughout the process [18]. After the emergence of adults, the adults were placed in an insect cage along with fresh cotton leaves for egg laying, whose petiole was surrounded with wet cotton to retain their freshness, and a 10% honey mixed with water solution was given to the adults as food. On a daily basis, the eggs deposited on cotton leaves were separated and placed in a petri dish for hatching. This process has been used to rear the culture of *S. frugiperda* [19].

2.2. Experimental Set-up and Data Collection

The bunch of eggs was kept in a Petri dish at a laboratory-maintained temperature until they hatched. When the eggs hatched, the 1st instar larvae were counted and then placed in a Petri dish and given soft cotton leaves regularly to eat until they reached the 3rd instar. After reaching the 3rd instar, all the larvae were separated and put in plastic bowls separately to avoid cannibalism. All the life cycle parameters, i.e., hatching period, development period of larvae and pupae, along with longevity of adults (male and female) were observed. Ten individuals of respective *S. frugiperda* stages were observed to record various morphometric parameters, i.e., length, width, and head capsule radius. After adult emergence, the 10 pairs of *S. frugiperda* adults were kept in glass cages, and observed regularly to recorded data regarding pre-oviposition, oviposition, and post-oviposition period along with fecundity per female on cotton.

2.3. Egg Duration

The bunch of 370 eggs was kept in a petri dish at a controlled laboratory temperature of 28 ± 2 °C and humidity of 75 ± 5% for 2-3 days. The eggs were observed daily. After three days, the eggs were hatched, and the larvae were counted to determine the percentage of hatching. Then they were given soft cotton leaves as food for eating for their further development [18].

2.4. Larval Duration and Development

Ten fall army larvae were separately placed in plastic bowls with small holes in the bowls for aeration. They were fed fresh cotton leaves on a daily basis until they reached the pupal stage [3]. During the larval period, changes in shape and weight were recorded throughout six larval stages. The weight of 3rd to 6th larval instars was measured on an electronic weight balance; the weight of 1st and 2nd instars was not taken in this study because of their minimal weight, as the same was not possible using the available balance. The length and width of the 1st to 3rd instars were taken using a digital USB microscope. While the length and width of 4th-6th instar larvae were measured using a digital Vernier caliper. The head capsule's radius was also measured using a digital USB microscope. Additionally, ten pre-pupae were placed in separate pupal glass containers to monitor the percentage of pupation, and their progress was observed for adult emergence [20].

2.5. Pupal Duration and Development

The newly developed pupae were placed inside a glass cage and observed until adult moths emerged. The time period between pupation and adult emergence was noted. The weight of pupae was measured on an electronic weight balance, and the pupal length and width were measured and recorded.

2.6. Adult Longevity

Adult male and female moths (with a ratio of 1 male to 1 female) were placed in a glass cage. A cotton ball soaked in a 10% honey solution was given as food for eating. The number of male and female moths that died in each cage was recorded daily until the last adult in the cage had died. This data was utilized as an indicator of the adult moths' lifespan [21].

2.7. Data Analysis and Presentation

MS-Excel was used to determine the mean and standard error values of the various recorded parameters [22].

3. RESULTS AND DISCUSSION

3.1. Life Cycle of *Spodoptera frugiperda* on Cotton Crop

3.1.1. Development period of various life stages of Spodoptera frugiperda on cotton crop

Table 1 shows the results regarding the development period of various life stages of *S. frugiperda* on cotton. The data on the hatching period of *S. frugiperda* eggs indicated that they have an average hatching period of 2.33 ± 0.05 days, with the lowest and highest hatching intervals recorded as 1.85 and 2.80 days, respectively. *Spodoptera frugiperda* larval development consists of six instars, each of which has a different color, shape, and size. The 1st instar larvae of *S. frugiperda* were greenish with a black head and body covered with tiny hairs, as its average development duration was recorded as 5.11 ± 0.30 days with a minimum and maximum developmental duration of 3.55 and 5.11 days, respectively. The 2nd instar larvae of *S. frugiperda* have shown morphological features like a yellow-white body and brownish-colored head with inverted Y-line on frons which is the main character for its identification. The mean development period of 2nd instar larvae was observed as 6.17 ± 0.27 days with minimum and maximum duration of 4.98 and 7.56 days, respectively. The 3rd instar *S. frugiperda* larvae was active having four black spots on its body, as it completed its development in mean duration of 5.81 ± 0.21 days as its minimum and maximum development durations were recorded as 4.55 and 6.43 days, respectively. Similarly, minimum and maximum development durations of 4th instar *S. frugiperda* larvae were recorded as 3.93 and 6.21 days, respectively, with mean development period of 5.78 ± 0.26 days. A change in color was observed in 5th instar which become greyish brown as its minimum and maximum development were completed within 4.23 and 6.54 days, respectively, whereas its mean period of development was observed as 5.63 ± 0.27 days. The final 6th instar larvae were flashy and cylindrical in shape which completed their development within mean duration of 4.53 ± 0.27 days, whereas their minimum and maximum development periods were observed as 3.12 and 5.97 days, respectively. Overall, the entire larval period of *S. frugiperda* on cotton leaves was recorded as 32.06 ± 0.21 days. The newly developed pupa of *S. frugiperda* was soft and greenish in color, later it changed to dark brown color till the emergence of the adult. The observed data showed that the minimum and maximum durations of the pupal stages varied from 8.45 to 10.55 days, respectively, with a mean duration of 9.63 ± 0.23 days. Thus, the total life cycle (egg to adult) of *S. frugiperda* was noted as 43.92 ± 0.72 days (Table 1).

3.1.2. Adult longevity (male and female) of Spodoptera frugiperda on cotton crop

The results regarding the adult longevity of *S. frugiperda* feeding on cotton are given in Table 2. It was observed in the study that female adults lived comparatively a little longer than males. The forewing of the male is shaded with gray and brown, with a triangular white patch at the apical region and a circular spot at the center of the wing. The mean observation longevity of *S. frugiperda* male

Table 1. Development period of various life stages of *Spodoptera frugiperda* on cotton.

Developmental period	Days		
	Minimum	Maximum	Average
Hatching Period	1.85	2.80	2.33 ± 0.05
1st instar Larva	3.55	5.11	5.11 ± 0.30
2nd instar Larva	4.98	7.56	6.17 ± 0.27
3rd instar Larva	4.66	6.77	5.81 ± 0.21
4th instar Larva	4.55	6.43	5.78 ± 0.26
5th instar Larva	4.23	6.54	5.63 ± 0.27
6th instar Larva	3.12	5.97	4.53 ± 0.27
Total Larval Duration (six instars)	-	-	32.06 ± 0.21
Pupal Period	8.45	10.55	9.63 ± 0.23
Total Life Cycle (egg to adult)	-	-	43.92 ± 0.72

Table 2. Adult longevity of *Spodoptera frugiperda* on cotton.

Life stage	Days		
	Minimum	Maximum	Average
Male	6.55	9.12	7.90 ± 0.29
Female	8.77	10.56	9.60 ± 0.19

adults was recorded as 7.90 ± 0.29 days, whereas its lowest and highest intervals were recorded as 6.55 and 9.12 days, respectively. The forewing of the female is uniform grayish brown to a fine mottling of gray and brown. The hind wing is silver, white with a narrow dark border in both male and female. The result showed that *S. frugiperda* female adult's minimum and maximum longevity intervals was observed as 8.77 and 10.56 days respectively, and its mean longevity was recorded as 9.60 ± 0.19 days.

3.2. Morphometric Parameters of *Spodoptera frugiperda* on Cotton Crop.

3.2.1. Morphometric of various larvae instars and pupae of Spodoptera frugiperda on cotton crop

Table 3 describes the results of various morphometric parameters of *S. frugiperda* larval instars and pupa when reared on cotton. According to the results of the study, minimum and maximum lengths of 1st, 2nd, 3rd, 4th, 5th, and 6th instar larvae were recorded as 1.44 and 1.91 mm, 3.11 and 3.71 mm, 6.54 and 7.25 mm, 11.20 and 15.50 mm, 17.60 and 21.10 mm, and 30.40 and 33.10 mm, respectively. The average length of *S. frugiperda* larvae from 1st to 6th instars were recorded 1.68 ± 0.05, 3.32 ± 0.07, 6.94 ± 0.07, 12.87 ± 0.46, 19.78 ± 0.34, and 31.95 ± 0.27 mm, respectively. Moreover, the mean width of *S. frugiperda* larvae from 1st to 6th instars were also recorded as 0.30 ± 0.01, 0.60 ± 0.02, 1.43 ± 0.06, 1.91 ± 0.04, 3.26 ± 0.11, and 4.41 ± 0.07 mm, respectively. The minimum width of *S. frugiperda* larvae from 1st to 6th instars were recorded as 0.28, 0.49, 1.15, 1.7, 2.6 and 4.2 mm, respectively. The maximum width of *S. frugiperda* larvae from 1st to 6th instars were observed as 0.34, 0.70, 1.71, 2.11, 3.9 and 4.9 mm, respectively. The lowest and highest length of *S. frugiperda* pupae was recorded as 11.50 and 14.80, whereas their minimum and maximum widths were observed as 3.20 and 4.20 mm, respectively. Moreover, the average length and width of the pupae were recorded as 12.87 ± 0.31 and 3.81 ± 0.10 mm, respectively.

3.2.2. Morphometrics of eggs and various larval instars and heads of Spodoptera frugiperda on cotton crops

During the studies, the radius of *S. frugiperda* eggs and larval instars was also observed and are given in Table 4. It was observed that the minimum and maximum radius of *S. frugiperda* eggs were recorded as 0.13 and 0.15 mm, respectively, with an average radius of 0.14 ± 0.00 mm. Moreover, the minimum radius of *S. frugiperda* larvae head from 1st to 6th instars were observed as 0.10, 0.19, 0.32, 0.69, 0.93, and 1.65 mm, respectively. Moreover, the maximum radius from 1st to 6th instars was recorded as 0.18, 0.26, 0.41, 0.81, 1.13, and 1.97 mm, respectively. The mean radius of *S. frugiperda* larvae heads from 1st to 6th instars were observed as 0.14 ± 0.01, 0.23 ± 0.01, 0.37 ± 0.01, 0.76 ± 0.01, 1.02 ± 0.02, and 1.83 ± 0.03 mm, respectively.

Table 3. Morphometrics of various larval instars and pupae of *Spodoptera frugiperda* on cotton.

Life stage	Length (mm)			Width (mm)		
	Minimum	Maximum	Average	Minimum	Maximum	Average
1st instar	1.44	1.91	1.68 ± 0.05	0.28	0.34	0.30 ± 0.01
2nd instar	3.11	3.71	3.32 ± 0.07	0.49	0.70	0.60 ± 0.02
3rd instar	6.54	7.25	6.94 ± 0.07	1.15	1.71	1.43 ± 0.06
4th instar	11.20	15.50	12.87 ± 0.46	1.70	2.11	1.91 ± 0.04
5th instar	17.60	21.10	19.78 ± 0.34	2.60	3.90	3.26 ± 0.11
6th instar	30.4	33.10	31.95 ± 0.27	4.20	4.90	4.41 ± 0.07
Pupae	11.50	14.80	12.87 ± 0.31	3.20	4.20	3.81 ± 0.10

Table 4. Radius of *Spodoptera frugiperda* eggs and head of larval instars on cotton.

Life stage	Radius (mm)		
	Minimum	Maximum	Average
Eggs	0.13	0.15	0.14 ± 0.00
1st instar	0.10	0.18	0.14 ± 0.01
2nd instar	0.19	0.26	0.23 ± 0.01
3rd instar	0.32	0.41	0.37 ± 0.01
4th instar	0.69	0.81	0.76 ± 0.01
5th instar	0.93	1.13	1.02 ± 0.02
6th instar	1.65	1.97	1.83 ± 0.03

3.2.3. Weight of various larval instars and pupae of Spodoptera frugiperda on cotton crop

During the research work, the weight of *S. frugiperda* larvae instars and pupae was recorded in grams (g). Only the 3rd, 4th, 5th, and 6th instar larvae and pupae weights were recorded and given in Table 5. It was observed that the minimum weight of *S. frugiperda* larvae in the 3rd to 6th instars was recorded as 0.06 g, 0.11 g, 0.19 g, and 0.36 g, respectively. The maximum weight of *S. frugiperda* larvae from 3rd to 6th instars were observed as 0.10 g, 0.17 g, 0.30 g, and 0.50 g, respectively. Moreover, the average weight of *S. frugiperda* larvae from 3rd to 6th instars were also observed as 0.08 ± 0.00 g, 0.14 ± 0.01 g, 0.23 ± 0.01 g, and 0.42 ± 0.01 g, respectively. The weight of *S. frugiperda* pupa was also recorded as its minimum and maximum weight was recorded as 0.09 and 0.19 g, respectively, whereas its average weight was observed as 0.13 ± 0.01 g.

Table 5. Weight of various larvae instars and pupae of *Spodoptera frugiperda* on cotton crop**.**

Life stage	Weight (g)		
	Minimum	Maximum	Average
3rd instar	0.06	0.10	0.08 ± 0.00
4th instar	0.11	0.17	0.14 ± 0.01
5th instar	0.19	0.30	0.23 ± 0.01
6th instar	0.36	0.50	0.42 ± 0.01
Pupae	0.09	0.19	0.13 ± 0.01

3.2.4. Various ovipositional parameters of Spodoptera frugiperda on cotton crop

During the study, pre-oviposition, oviposition, post-oviposition period, and the average number of eggs were also recorded and given in Table 6. It was observed that *S. frugiperda* females, on average, started their oviposition on 3.33 ± 0.21 days, with a maximum and minimum interval of 4 and 3 days, respectively. The mean oviposition period of *S. frugiperda* females was recorded with a minimum and maximum interval of 3 and 4 days, with an average of 3.33 ± 0.21 days. After completion of egg laying, the *S. frugiperda* female lived an average of 2.33 ± 0.21 days, with a minimum and maximum interval of 2 and 3 days, respectively. The egg-laying capacity of females varied from 360 to 449 eggs, with an average of 407.50 ± 13.76 eggs per female recorded during the study.

4. DISCUSSION

Fall Armyworm is one of the most important invasive polyphagous pests due to its transcontinental migration, highly destructive nature, and adaptability to a wide host range of about 353 plant species [23]. In this study, the life cycle and morphometric parameters of *S. frugiperda* were examined on cotton to understand the behavior of the pest, which enables it to feed on so many plants of economic importance, and the same will be helpful to design an effective control strategy. It was observed in our studies that cotton greatly affected the developmental period of *S. frugiperda* as compared to its preferred host maize, as it took a longer time to complete the development of various life stages.

During the present study, it was observed that the mean developmental time of six instars of *S. frugiperda* was recorded much higher than those observed by Sharma *et al.* [20], who observed much lower developmental duration of all six

Table 6. Various ovipositional parameters of *Spodoptera frugiperda* on cotton.

Life stage	Days		
	Minimum	Maximum	Average
Pre-oviposition period	3 days	4 days	3.33 ± 0.21 days
Oviposition period	3 days	4 days	3.33 ± 0.21 days
Post-oviposition period	2 days	3 days	2.33 ± 0.21 days
Eggs per female	360 eggs	449 eggs	407.50 ± 13.76 eggs

instars of *S. frugiperda* when reared on maize as the developmental time from 1st to 6th larvae instars were noted as 2.98 ± 0.37, 2.90 ± 0.39, 1.98 ± 0.021, 2.19 ± 044, 2.63 ± 0.076, and 3.63 ± 0.048 days, respectively, whereas, the total larval developmental of *S. frugiperda* on maize was recorded as 16.31 ± 0.205 days.

Keerthi *et al.* [24] studied the larval developmental duration of *S. frugiperda* on sorghum from the 1st to 6th larval instars, which were recorded as 2.26 ± 0.11, 2.00 ± 0.08, 1.95 ± 0.20, 2.05 ± 0.05, 2.28 ± 0.20, and 4.79 ± 0.73 days, respectively. While the larval development of *S. frugiperda* on maize from 1-6 larval instars was recorded as 2.40 ± 0.36, 2.11 ± 0.36, 2.00 ± 0.05, 2.00 ± 0.00, 2.21 ± 0.29, and 5.08 ± 0.74 days, respectively. The larval developmental period on artificial diet was recorded as 2.54 ± 0.22, 2.31 ± 0.35, 2.25 ± 0.33, 2.38 ± 0.40, 2.56 ± 0.10, and 5.88 ± 0.58 days, respectively. Moreover, the overall larval development was recorded as 13.88 ± 0.76, 14.04 ± 0.25, 16.07 ± 1.66 days on sorghum, maize, and artificial diet, respectively. In addition, Praveen and Mallapur [25] also studied various hosts; the entire larval developmental duration of *S. frugiperda* was recorded as 28.40 ± 0.51, 18.51 ± 1.19, 19.80 ± 1.31, 29.40 ± 0.51, and 21.00 ± 1.05 days on cotton, sorghum, maize, cabbage, and wheat, respectively. The results of Keerthi *et al.* [24] and Praveen and Mallapur [25] showed variance between our findings and their results, the genetic strain, the environment they grow in (such as temperature and laboratory techniques), the food they consume (nutrition and plant defenses), and the experiences of their mother all influence the surprisingly different larval development times of *Spodoptera frugiperda*. For instance, the high protein and low fiber content of maize promotes growth, whereas cotton or cabbage slows it down, and warmer, ideal temperatures (27 ± 2 °C) further accelerate development.

Moreover, the pupal period was also influenced by the cotton, as larvae reared on the cotton had a longer pupal period, it takes 9.63 ± 0.23 days on cotton. However, the results of Sharma *et al.* [20] are almost similar to our findings; they recorded 9.69 ± 0.145 days on maize. Bankar and Bhamare [26] found the lowest pupal duration while reared on various hosts; the pupal duration of *S. frugiperda* was recorded as 6.76 ± 0.44, 7.99 ± 0.24, 7.61 ± 0.38, and 8.49 ± 0.42 days on maize, pearl millet, sorghum, and sugarcane, respectively. In addition, Praveen and Mallapur [25] also studied various host crops, the pupal period of *S. frugiperda* on cotton, maize, and sorghum was mostly similar to our findings, it was recorded as 9.00 ± 0.00, 9.00 ± 0.00, and 8.00 ± 0.00 days, respectively. However, the results of pupal duration on wheat and cabbage were much higher compared to our findings on cotton. Pupal period of *S. frugiperda* on wheat and cabbage was recorded as 13.00 ± 0.00 and 12.00 ± 0.00 days, respectively.

The mean hatching period was observed 2.33 ± 0.05 days; when compared with the recent studies on different host crops, the number of *S. frugiperda* eggs laid on cotton was much lower. The mean egg laying capacity in the present study was recorded as 407.50 ± 13.76 eggs per female. Keerthi *et al.* [24] observed variation in the fecundity period of *S. frugiperda* reared on maize and sorghum. It was much higher and recorded as 1009.24 ± 133.31 eggs on maize, and 1086.6 ± 188.13 eggs on sorghum. However, Bankar and Bhamare [26] noted almost similar results of *S. frugiperda* fecundity on maize, which was recorded as 436.44 ± 22.44 eggs. In addition, Praveen and Mallapur [25] experimented on various host crops, as she noted 650.45 ± 88.53, 680.54 ± 91.52, 565.23 ± 27.78 eggs on sorghum, maize, and wheat, respectively. Such huge variation in the fecundity in the fecundity of *S. frugiperda* observed in above-mentioned studies may be attributed to different host plants used in the studies, experimental conditions, and the insects used in the study. Moreover, the results of Acharya *et al.* [27] were very low, with a record of 231.54 ± 28.48 eggs on potato. The reasons behind the highest and lowest fecundity on different hosts can be due to the fact that some host plants may not provide the nutritional requirements required for growth and development, thereby resulting in decreased fecundity. As we know, maize, sorghum, millet, and some other fodder crops are the favorites of *S. frugiperda*; on these hosts, their egg laying capacity was much better compared to sugarcane and potato.

Regarding morphometrics, various stages of *S. frugiperda* larvae instars and pupae were observed on the cotton crop. The morphometric analysis revealed that diet did significantly affect the radius of *S. frugiperda* eggs on cotton as the mean radius of eggs were recorded as 0.14 ± 0.00

mm. Navasero and Navasero [28] observed much higher radius and diameter of eggs on maize than our findings, as she noted 0.195 ± 0.00 and 0.39 ± 0.00 mm, respectively. However, it did influence the weight of various *S. frugiperda* larvae instars and pupae. The result showed that the mean length of *S. frugiperda* larvae from 1st to 6th instars was recorded as 1.68 ± 0.05, 3.30 ± 0.07, 6.94 ± 0.07, 12.87 ± 0.46, 19.78 ± 0.34, and 31.95 ± 0.27, mm, respectively. The measurement of width was also noted; it was observed as 0.30 ± 0.01, 0.60 ± 0.02, 1.43 ± 0.06, 1.91 ± 0.04, 3.26 ± 0.11, and 4.4 ± 0.07 mm, respectively. The present results are in line with the findings of Sharma *et al.* [20] on maize, as they observed that the mean length of *S. frugiperda* larvae from 1st to 6th instars was recorded as 1.5 ± 0.013, 3.56 ± 0.017, 7.12 ± 0.052, 11.60 ± 0.181, 18.5 ± 0.212, 34.39 ± 0.351 mm, respectively. The mean width of *S. frugiperda* larvae from 1st to 6th instars was observed shortened on maize, noted 0.35 ± 0.011, 0.47 ± 0.03, 0.80 ± 0.04, 1.37 ± 0.06, 2.11 ± 0.13, and 2.70 ± 0.13 mm, respectively. In addition, Navasero and Navasero [28] observed that the mean length of *S. frugiperda* larvae from 1st to 6th instars was recorded as 1.77 ± 0.49, 2.79 ± 0.35, 7.41 ± 0.58, 14.57 ± 2.09, 21.25 ± 1.47, and 30.79 ± 3.14 mm, respectively. The mean width was observed 0.23 ± 0.30, 0.35 ± 0.05, 0.89 ± 0.28, 1.86 ± 0.18, 2.99 ± 1.47, and 3.82 ± 0.26 mm, respectively. Some variance can be observed in the 2nd, 4th, 5th, and 6th instars' length with our findings, whereas width was also observed shorter in the 2nd, 3rd, 5th, and 6th instars with our results.

Moreover, the weight of various *S. frugiperda* larvae instars was measured on cotton, during study mean weight of 3rd, 4th, 5th, and 6th instars was recorded as 0.8 ± 0.00, 0.14 ± 0.01, 0.23 ± 0.01, and 0.42 ± 0.01 g, respectively. The observations of previous studies also supported our findings as the weight of the 3rd instar larvae of *S. frugiperda* when fed on corn was recorded as 0.08 g [29]. Similarly, Firake and Behere [30] found that the larval weight of the final instar was recorded as 0.42 g. Furthermore, the mean weight of *S. frugiperda* pupae was also observed on cotton, and it was recorded as 0.13 ± 0.01 g. The results of Sari *et al.* [31] showed that the pupal weight of *S. frugiperda* was directly affected by the host plant cotton. As he noted 0.16 g on corn and 0.18 g on mustard, respectively.

The findings of this study have shown that *S. frugiperda* is capable of feeding and successfully completing its various life stages on cotton and the same highlighted the importance of the host feeding in controlling the duration of the various life stages, i.e., larvae, pupae, and adult longevity of both males and females [31]. Accordingly, such findings could provide a base for its proper management because it confirmed the significant role of host range in feeding, development, and population dynamics of *S. frugiperda* [32].

Besides its main host maize, recent studies have shown that *S. frugiperda* is also capable of feeding and developing on cotton, hence confirming its polyphagous feeding niche [33]. Despite the minimal development duration of larvae, highest survival of various life stages, and relatively higher fecundity was recorded on maize; Ahmad *et al.* [33] confirmed that cotton and sorghum can also support significant growth, survival, and reproduction of *S. frugiperda*. In another comparative study regarding biological parameters of tow armyworm species, i.e., *S. littoralis* and *S. frugiperda* on cotton, maize, coriander, and tomatoes, coriander was found to be the preferred host for both the species as it causes lowest larval mortality along with shortest development period, maximum pupal weight, highest fecundity and net reproductive rate [34]. All the observed parameters of *S. littoralis* and *S. frugiperda* were not significantly different from those recorded on maize, their main host. Moreover, cotton was also found suitable for the growth and reproductive parameters of *S. frugiperda* and *S. littoralis*, whereas tomato was found to be the most unfavorable host [34]. Additionally, exploring the specific nutritional components of the natural diet that contribute to the observed effects on the biological parameters of *S. frugiperda* could be valuable for understanding the underlying mechanisms driving these differences and can be exploited for its adequate management [35].

5. CONCLUSIONS

Life cycle and morphometrics data generated from the present study confirm that the pest can shift to other hosts in the absence of its main host, i.e., maize, to continue its survival. The average incubation period was 2.33 ± 0.05 days, larval duration from 1st to 6th instars was 32.06 ± 0.21 days, and pupal development was 9.63 ± 0.23 days,

whereas the entire life cycle was completed in 43.92 ± 0.72 days. Adult longevity was 7.90 ± 0.29 (for males) and 9.60 ± 0.19 days (for females), whereas the mean fecundity was 407.50 ± 13.76 eggs. The results of this study are useful for designing the *S. frugiperda* management strategy.

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7. ETHICAL STATEMENT

This study was conducted in accordance with the ethical guidelines of Sindh Agriculture University, Tando Jam. All procedures involving *Spodoptera frugiperda* were performed with care to minimize unnecessary harm to the insects. No endangered or protected species were involved in the research.

8. CONFLICT OF INTEREST

The authors have no conflicts of interest.

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