Plant Archives Vol. 26, Supplement 2, 2026 pp. 1054-1060 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org
DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2026.v26.supplement-2.122

BIOMETRICAL ANALYSIS OF FALL ARMYWORM (*Spodoptera frugiperda* J. E. SMITH) ON MAIZE AND SORGHUM

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(Date of Receiving : 03-03-2026; Date of Revision : 15-04-2026; Date of Acceptance : 08-05-2026)

ABSTRACT

The present study evaluated the biometrical growth of *Spodoptera frugiperda* larvae on maize and sorghum under laboratory conditions. The larvae passed through six instars on both host crops, exhibiting a progressive increase in head capsule width, body length and body width. The head capsule width ranged from 0.360 to 2.564 mm on maize and 0.347 to 2.548 mm on sorghum, while body length increased from 1.505 to 34.451 mm on maize and 1.470 to 33.914 mm on sorghum. Similarly, body width ranged from 0.466 to 4.884 mm on maize and 0.439 to 4.859 mm on sorghum. The progression factors indicated that larval growth followed a geometric pattern on both hosts. Regression analysis showed a strong linear relationship between larval instar and logarithmic measurements, with high coefficients of determination (R^2 > 0.96). The results confirm that the larval development of *S. frugiperda* exhibited a consistent growth trend on both maize and sorghum, showing close agreement with Dyar's law, although minor variations were observed.
Keywords **:** *Spodoptera frugiperda*, maize, sorghum, growth ratio, Dyar's law.

Introduction

Maize (*Zea mays* L.), commonly known as corn, is an important cereal as well as fodder crop cultivated widely in India. It belongs to the family Poaceae and ranks third among major food crops globally after rice and wheat. In India, it occupies the fourth position in terms of area and production, following rice, wheat and sorghum. The crop is grown across diverse agro-climatic regions, including Uttar Pradesh, Bihar, Rajasthan, Himachal Pradesh, Madhya Pradesh and Gujarat, and is known by various regional names such as Makka, Makai and Bhutta.

Maize serves as a staple food and an essential fodder source, especially for dairy animals. The grains are rich in carbohydrates (about 72% starch), along with moderate protein (10%) and fat (4%), making it a good energy source. However, its protein quality is limited due to the dominance of zein, which lacks essential amino acids like lysine and tryptophan. Apart from its nutritional value, maize exhibits natural defense mechanisms against pests. Young plants produce DIMBOA, a biochemical compound that helps protect against insects, fungi and bacteria, thereby enhancing resistance during early growth stages.

Maize production in India has shown a progressive increasing trend in recent years. In 2022–23, the crop was grown over an area of 10.74 million hectares, producing 38.09 million tonnes with a yield of 3545 kg/ha. During 2023–24, the area increased to 11.24 million hectares, with a production of 37.66 million tonnes and a yield of 3351 kg/ha. Further, in 2024–25, the area expanded to 12.09 million hectares, and production rose markedly to 43.41 million tonnes, with a yield of 3590 kg/ha, indicating an overall improvement in productivity (Anon. 2026). With respect to Gujarat, *kharif* maize is grown on approximately 280.97 thousand hectares, producing around 567.79 thousand tonnes with an average productivity of 2020.78 kg/ha (Anon., 2025).

Maize has gained considerable importance as a raw material for various industries, including starch, protein, oil, ethanol (biofuel), poultry feed, and animal feed, as well as specialty products such as quality protein maize, sweet corn, popcorn and baby corn (Anon., 2020). However, its production is influenced by both biotic and abiotic factors. Among these, insect pests constitute a major biotic constraint, causing direct damage to leaves, stems, tassels and cobs, and indirectly affecting crop health by facilitating secondary infections. Severe infestations can result in significant yield losses and reduced grain quality. In India, maize is attacked by a wide range of insect pests, with about 130 species reported to infest the crop at different growth stages (Atwal and Dhaliwal, 2002), posing a continuous challenge to its cultivation and management.

Among the major insect pests of maize, the fall armyworm, *Spodoptera frugiperda*, is an invasive species that has emerged as a serious threat worldwide, causing substantial yield losses. The name “fall armyworm” refers to its gregarious feeding behaviour, where large populations move across fields like an army, rapidly defoliating crops (Smith, 1797). Native to the Americas, it was first recorded in 1797 and later reported in Africa in 2016 (Goergen *et al.,* 2016), from where it spread rapidly to Asia. In India, it was first reported in July 2018 from Karnataka (Sharanabasappa *et al.,* 2018) and subsequently spread to several states including Maharashtra, Gujarat and Chhattisgarh (Chormule *et al.,* 2019; Sisodiya *et al.,* 2018; Deole and Paul, 2018). In Gujarat, its occurrence was confirmed from Anklav village of Anand district (Sisodiya *et al.,* 2018). The pest is highly migratory, capable of travelling up to 500 km before oviposition (Prasanna *et al.,* 2018), and is considered cosmopolitan on maize (Wiseman *et al.*, 1966).

Although maize is its primary host, *S. frugiperda* is highly polyphagous, feeding on more than 80 crops and reported from over 350 host plants (Montezano *et al.*, 2018; FAO, 2020). However, severe damage is mainly observed in maize, rice, sorghum and sugarcane. The species consists of two strains, namely rice and maize strains, differing in host preference (Sparks, 1979). In maize, the pest attacks all growth stages, causing defoliation, destruction of young plants and injury to developing grains, ultimately reducing yield and quality (Peairs and Sanders, 1979). Typical symptoms include irregular, ragged holes on leaves and tassels, resembling hail damage, and severe infestations may lead to significant crop losses (Tiwari, 2020).

In recent years, fall armyworm has emerged as a serious pest of maize in Gujarat. Effective management requires a thorough understanding of its biology and ecology (Wang *et al.*, 2020). Biometrical analysis on different host crops helps in understanding growth and developmental variations, reflecting host suitability and adaptability. Parameters such as head capsule width, body length and body width across instars aid in determining growth patterns and are useful for predicting pest population dynamics and developing appropriate management strategies.

Materials and Methods

The present investigation was carried out in the Biocontrol Laboratory of the Department of Entomology, College of Agriculture, Junagadh Agricultural University, Junagadh. The experiment commenced in February 2025. The crops selected for the study included maize (variety: GAYMH-3) and sorghum (variety: CSV-55).

Rearing of *S. frugiperda*

To establish a uniform culture of *S. frugiperda* under laboratory conditions, at least 100 larvae were collected from maize fields and reared in plastic jars (1 L capacity) on fresh, tender maize leaves. The leaves were washed with sodium hypochlorite solution and rinsed with clean water to minimize contamination. Third instar larvae were transferred individually to separate jars to avoid cannibalism. Fresh maize leaves were provided daily for proper development. Pupae were collected and kept in clean jars for adult emergence. The emerged moths were released into oviposition cages containing 5–8-day-old potted maize plants, and a 10 per cent honey solution was provided as food. Egg masses laid on leaves were collected and transferred to petri plates lined with fresh maize leaves for further use in biometrical analysis studies.

Biometric analysis of *S. frugiperda*

Two hundred newly emerged larvae were transferred individually into separate plastic containers (5 cm × 5 cm) and reared on maize and sorghum. Fresh food was provided every day. To determine the larval instars, individual larvae were observed daily for the exuviae as well as the head capsule. The moulting was confirmed by the presence of cast-off head capsules. Freshly moulted 30 larvae were taken and the head capsule width, body length and body width of each larva were measured with the help of a microscope. The application of Dyar's law (1890) was tested for the number of larval instars when reared on different hosts. For the purpose of assigning single individuals to their respective instars, the regression relationship between instars and the mean head capsule width was tested for the applicability of Przibram and Megusar's rule (1912). The regression relationship between the instars, mean body length and width was also calculated. The regression equation used is as follows:

$$\text{Log}(10Y) = a + bx$$

Where,

Y = body length/width/head capsule width of larva

a = constant

b = logarithm of growth ratio

x = number of instars

Growth ratio, progression factor, differences and difference percent were calculated as per the following equations (Bilapate *et al.*, 1981).

$$\text{Growth ratio} = \frac{\text{Value of succeeding instar}}{\text{Value of preceding instar}}$$

Progression factor = regression co-efficient = b

Difference = Observed values of instar–Estimated values of instar

$$\text{Difference percent} = \frac{\text{Difference}}{\text{Estimated value}} \times 100$$

Multiple correlation and partial regression studies on larval body length, body width and head width were calculated by using the following equation:

$$Y = a + b_1x_1 + b_2x_2$$

Y = Mean width of head capsule

x_1 = Mean larval body length

x_2 = Mean larval body width

a = regression constant

b_1 and b_2 coefficients of partial regression.

The value of a_1, b_1 and b_2 was calculated with the help of the data analysis tool pack in Microsoft Excel.

Results and Discussion

Larval Head Capsule Width on maize and sorghum

The data on larval head capsule width of different instars of *S. frugiperda* when reared on maize and sorghum are shown in Table 1.

The results revealed that the larvae passed through six instars on both hosts. On maize, the larval head capsule width was 0.360 ± 0.025, 0.453 ± 0.186, 0.919 ± 0.185, 1.547 ± 0.017, 2.094 ± 0.020 and 2.564 ± 0.231 mm for I to VI instars, respectively, whereas on sorghum, it was 0.347 ± 0.024, 0.475 ± 0.023, 0.898 ± 0.034, 1.533 ± 0.036, 2.229 ± 0.044 and 2.548 ± 0.047 mm for the corresponding instars. Further, the growth ratio ranged from 1.22 to 2.02 on maize and 1.14 to 1.89 on sorghum, while the mean observed and calculated progression factors were 1.48 and 1.53 on maize, and 1.49 and 1.54 on sorghum, respectively. Moreover, the regression equation for maize was Y = 0.1852x – 0.6324 (R^2 = 0.967), whereas for sorghum it was Y = 0.1879x – 0.6394 (R^2 = 0.9704), indicating a strong relationship between instar and head capsule width on both host crops.

Table 1 : Comparison of observed and estimated values for larval head capsule width of *S. frugiperda* on maize and sorghum

Maize							
Parameter	**Mean larval head capsule width (mm) in different instars**						**Progression Factor**
	I	**II**	**III**	**IV**	**V**	**VI**	
Observed ± SE	0.360 ± 0.025	0.453 ± 0.186	0.919 ± 0.185	1.547 ± 0.017	2.094 ± 0.020	2.564 ± 0.231	
Growth ratio	-	1.25	2.02	1.68	1.35	1.22	1.48
Estimated	0.357	0.545	0.838	1.284	1.967	3.013	1.53
Difference	0.003	-0.093	0.080	0.263	0.126	-0.448	
Difference %	0.80	-17.14	9.64	20.53	6.45	-14.89	
Sorghum							
Parameter	**Mean larval head capsule width (mm) in different instars**						**Progression Factor**
	I	**II**	**III**	**IV**	**V**	**VI**	
Observed ± SE	0.347 ± 0.024	0.475 ± 0.023	0.898 ± 0.034	1.533 ± 0.036	2.229 ± 0.044	2.548 ± 0.047	
Growth ratio	-	1.36	1.89	1.70	1.45	1.14	1.49
Estimated	0.354	0.545	0.840	1.295	1.996	3.077	1.54
Difference	-0.006	-0.070	0.058	0.238	0.233	-0.529	
Difference %	-1.86	-12.91	6.85	18.39	11.68	-17.18	

The biometrical observations of *S. frugiperda* revealed that larval head capsule width increased progressively across successive instars, with variations observed among different host plants. The present findings are in close agreement with earlier studies. Capinera (2017) and Igyuve *et al.* (2018) reported that head capsule width increased from 0.35, 0.45, 0.75, 1.30, 2.00 to 2.60 mm from first to sixth instars. Similarly, Prasanna *et al.* (2018) observed a range from about 0.30 mm in the first instar to 2.60 mm in the sixth instar, while Sharanabasappa *et al.* (2018) recorded values of 0.34, 0.48, 0.81, 1.22 and 1.96 mm across five moults on maize. Further, Assefa and Ayalew (2019) reported head capsule widths of 0.35, 0.45, 0.75, 1.30, 2.00 and 2.60 mm for instars I to VI. In contrast, Manjula *et al.* (2019) recorded comparatively higher values, with head capsule width increasing from 0.16 mm in the first instar to 3.00 mm in later instars. Montezano *et al.* (2019) also observed variations between sexes, with head capsule widths of 0.35, 0.57, 0.87, 1.29, 1.89 and 2.80 mm in females and 0.35, 0.56, 0.87, 1.25, 1.81 and 2.64 mm in males across instars. Ramaiah *et al.* (2020) reported comparatively lower initial values of 0.09 ± 0.01 mm in the first instar, increasing to 2.40 ± 0.23 mm in the sixth instar, and noted that the growth did not follow a strict geometric progression. However, Navasero and Navasero (2020) confirmed a consistent increase from 0.22, 0.35, 0.61, 0.95, 1.46 to 2.03 mm from first to sixth instars, indicating a typical growth pattern. Ahmad *et al.* (2021) recorded head capsule width ranging from 0.18 ± 0.02 mm to 1.98 ± 0.12 mm, while Bhatti *et al.* (2021) observed values from 0.39 ± 0.01 mm to 2.60 ± 0.02 mm across instars. In addition, Neupane *et al.* (2023) reported head capsule width increasing from 0.52 mm to 2.91 mm from first to sixth instars. Similarly, Bankar and Bhamare (2024) reported head capsule width ranging from 0.22 to 2.94 mm on maize and 0.20 to 3.05 mm on sorghum, clearly indicating host-dependent variation, which is in close conformity with the present findings.

Overall, variation in head capsule width may be attributed to differences in host plant, nutrition and rearing conditions; however, a consistent increase across instars was observed in *S. frugiperda*. According to Dyar (1890), head capsule width remains constant within an instar and increases geometrically between instars. Minor deviations may result from moulting dynamics, cuticle formation, instar duration, hormonal regulation and measurement errors. Thus, the results confirm a generally consistent growth pattern with slight biological and environmental variations.

Larval Body Length on maize and sorghum

The data displayed in Table 2 revealed that on maize the larval body length of *S. frugiperda* increased from 1.505 ± 0.095 mm in the first instar to 34.451 ± 0.382 mm in the sixth instar, while on sorghum it ranged from 1.470 ± 0.091 mm to 33.914 ± 0.135 mm for the respective instars. The corresponding values for the second, third, fourth and fifth instars were 3.610 ± 0.190, 6.991 ± 0.382, 11.291 ± 0.374 and 18.198 ± 0.433 mm on maize, and 3.567 ± 0.092, 6.903 ± 0.093, 11.247 ± 0.104 and 19.223 ± 0.116 mm on sorghum, respectively. The growth ratio varied between 1.61 to 2.39 on maize and 1.63 to 2.43 on sorghum, while the mean observed and calculated progression factors were 1.87 and 1.82 on maize, and 1.87 and 1.83 on sorghum, respectively. The regression analysis showed a strong linear relationship between larval instar and logarithm of body length on both crops, represented by the equation $Y = 0.2604x – 0.0064$ ($R^2 = 0.9879$) for maize and $Y = 0.2635x – 0.0182$ ($R^2 = 0.9886$) for sorghum.

Table 2 : Comparison of observed and estimated values for larval body length of *S. frugiperda* on maize and sorghum

Maize							
Parameter	**Mean larval body length (mm) in different instars**						**Progression Factor**
	I	**II**	**III**	**IV**	**V**	**VI**	
Observed ± SE	1.505 ± 0.095	3.610 ± 0.190	6.991 ± 0.382	11.291 ± 0.374	18.198 ± 0.433	34.451 ± 0.382	
Growth ratio	-	2.39	1.93	1.61	1.61	1.89	1.87
Estimated	1.794	3.268	5.953	10.843	19.748	35.967	1.82
Difference	-0.288	0.342	1.035	0.398	-1.445	-1.586	
Difference %	-16.12	10.45	17.43	4.13	-7.85	-4.21	
Sorghum							
Parameter	**Mean larval body length (mm) in different instars**						**Progression Factor**
	I	**II**	**III**	**IV**	**V**	**VI**	
Observed ± SE	1.470 ± 0.091	3.567 ± 0.092	6.903 ± 0.093	11.247 ± 0.104	19.223 ± 0.116	33.914 ± 0.135	
Growth ratio	-	2.43	1.94	1.63	1.71	1.76	1.87
Estimated	1.759	3.227	5.919	10.857	19.916	36.533	1.83
Difference	-0.289	0.340	0.985	0.389	-0.693	-2.619	
Difference %	-16.43	10.54	16.63	3.59	-3.48	-7.17	

The biometrical observations of *S. frugiperda* reared on different cereal hosts revealed that larval body length varied distinctly among host plants. The results of the present investigation are in close agreement with earlier findings. Capinera (2017) and Igyuve *et al.* (2018) documented larval lengths of 1.7, 3.5, 6.4, 10.0, 17.2 and 34.2 mm for instars I to VI at 25°C on maize. Likewise, Prasanna *et al.* (2018) indicated that larval length ranged from about 1 mm in the first instar to 45 mm in the sixth instar. Subsequently, Assefa and Ayalew (2019) described body lengths of approximately 1.7, 3.5, 6.4, 10.0, 17.2 and 34.2 mm for instars I to VI, which are comparable with the present findings. Kalyan *et al.* (2020) further outlined that larval body length ranged from 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 from first to sixth instars on maize. In addition, Navasero and Navasero (2020) demonstrated an increase in larval body length from 1.77 ± 0.09 mm in the first instar to 30.79 ± 3.14 mm in the sixth instar, indicating a consistent growth pattern. Ahmad *et al.* (2021) presented values ranging from 1.68 ± 0.00 mm to 26.98 ± 2.93 mm across instars, whereas Bhatti *et al.* (2021) measured larval length from 2.41 ± 0.09 mm to 33.08 ± 0.67 mm. A similar trend was highlighted by Ojumoola and Omoloye (2022), who noted values from 2.28 ± 0.15 mm to 24.40 ± 0.54 mm across instars. Further, Ai *et al.* (2023) indicated larval body length increasing from 1.38 mm to 30.11 mm, while Neupane *et al.* (2023) documented values ranging from 3.33 mm to 34.56 mm. Furthermore, Bankar and Bhamare (2024) revealed that larval length varied from 1.68 mm to 35.90 mm on maize and reached up to 34.40 mm on sorghum, clearly demonstrating host-dependent variation. In addition, Choudhari *et al.* (2024) estimated larval body length from 0.62 ± 0.012 mm to 30.20 ± 3.599 mm across instars.

However, slight variations in larval body length may be attributed to differences in feeding efficiency and host plant suitability, which influence nutrient assimilation and growth rate. In addition, larval crowding and developmental duration of instars can affect the final body size attained. Such variations may also arise due to differences in experimental handling and stage-specific measurement accuracy.

Larval body width on maize and sorghum

The data in Table 3 indicated that on maize, the larval body width of *S. frugiperda* increased from 0.466 ± 0.045 mm in the first instar to 4.884 ± 0.047 mm in the sixth instar, while on sorghum it ranged from 0.439 ± 0.040 mm to 4.859 ± 0.048 mm for the respective instars. The corresponding values for the second, third, fourth and fifth instars were 0.971 ± 0.044, 1.570 ± 0.045, 2.777 ± 0.046 and 3.132 ± 0.055 mm on maize, and 0.967 ± 0.041, 1.549 ± 0.039, 2.749 ± 0.043 and 3.199 ± 0.043 mm on sorghum, respectively. The growth ratio ranged from 1.12 to 2.08 on maize and 1.16 to 2.20 on sorghum, while the mean observed and calculated progression factors were 1.60 and 1.57 on maize, and 1.62 and 1.59 on sorghum, respectively. The regression analysis revealed a strong linear relationship between larval instar and logarithm of body width on both crops, represented by the equation $Y = 0.1964x - 0.4407$ ($R^2 = 0.964$) for maize and $Y = 0.2008x - 0.4613$ ($R^2 = 0.962$) for sorghum.

Table 3 : Comparison of observed and estimated values for larval body width of *S. frugiperda* on maize and sorghum

Maize							
Parameter	**Mean larval body width (mm) in different instars**						**Progression Factor**
	I	**II**	**III**	**IV**	**V**	**VI**	
Observed ± SE	0.466 ± 0.045	0.971 ± 0.044	1.570 ± 0.045	2.777 ± 0.046	3.132 ± 0.055	4.884 ± 0.047	
Growth ratio	-	2.08	1.61	1.76	1.12	1.55	1.60
Estimated	0.569	0.895	1.407	2.212	3.477	5.466	1.57
Difference	-0.103	0.075	0.162	0.564	-0.345	-0.582	
Difference %	-18.15	8.42	11.55	25.50	-9.92	-10.64	
Sorghum							
Parameter	**Mean larval body width (mm) in different instars**						**Progression Factor**
	I	**II**	**III**	**IV**	**V**	**VI**	
Observed ± SE	0.439 ± 0.040	0.967 ± 0.041	1.549 ± 0.039	2.749 ± 0.043	3.199 ± 0.043	4.859 ± 0.048	
Growth ratio	-	2.20	1.60	1.77	1.16	1.51	1.62
Estimated	0.549	0.872	1.384	2.197	3.489	5.539	1.59
Difference	-0.109	0.095	0.165	0.552	-0.289	-0.680	
Difference %	-19.97	10.91	11.93	25.12	-8.29	-12.28	

The biometrical observations of *S. frugiperda* indicated that larval body width increased progressively across successive instars, with variations evident under different host conditions. The present findings are in close agreement with earlier studies. Navasero and Navasero (2020) demonstrated that body width increased from 0.23 ± 0.30 mm in the first instar to 3.82 ± 1.26 mm in the sixth instar. Likewise, Ahmad *et al.* (2021) presented values ranging from 0.14 ± 0.26 mm to 3.90 ± 0.00 mm across instars, which are in conformity with the present results. A comparable trend with slight variation was noted by Ojumoola and Omoloye (2022), who indicated body width ranging from 0.25 ± 0.02 mm to 3.18 ± 0.07 mm. Similarly, Ai *et al.* (2023) documented an increase from 0.24 mm in the first instar to 5.74 mm in the sixth instar, showing relatively higher values in later instars. Neupane *et al.* (2023) also described values ranging from 0.40 mm to 3.34 mm across instars, which are broadly comparable with the present findings. Further, Bankar and Bhamare (2024) revealed that body width varied from 0.17 mm to 3.95 mm on maize and from 0.19 mm to 3.35 mm on sorghum, clearly indicating host-dependent variation and showing close agreement with the present investigation. In accordance with this, Choudhari *et al.* (2024) estimated larval body width ranging from 0.13 ± 0.007 mm to 2.79 ± 0.083 mm across instars, which also aligns with the observed trend.

However, variations in larval body width may be influenced by gut fullness and feeding status at the time of observation, which can temporarily alter body girth. Additionally, water content and turgidity of larval tissues may contribute to differences in width measurements. Such variation may also result from handling stress and posture of larvae during measurement.

Acknowledgement

The authors are grateful to the Director of Research, Junagadh Agricultural University as well as Professor and Head, Department of Entomology, College of Agriculture, Junagadh Agricultural University for their support and providing the necessary facilities to carry out this research work.

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