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Differential effect of temperatures on the biological attributes of the fall army worm, *Spodoptera frugiperda* (Smith) under laboratory conditions

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ABSTRACT

An experiment was conducted to assess the influence of different temperatures on the growth and development of fall armyworms under laboratory conditions at the Institute of Agriculture Sciences, SOADU, between the year 2022-2023. This study examined the biological stages of fall armyworm under four distinct constant temperatures: 20 °C, 25°C, 30 °C, and 35 °C, all maintained at a constant relative humidity of 65 ± 5% within a BOD incubator. Observations revealed that the duration of the life stages decreased as the temperature increased from 20 °C to 35 °C. The egg period reduced from 6.08±0.06 days at 20°C to 2.36±0.05 days at 30 °C, while the larval period similarly shortened from 25.14±0.06 days at 20°C to 9.54±0.06 days at 35 °C. The development duration of the pupa also significantly decreased from 17.2±0.07 days at 20 °C to 6.50±0.07 days at 35 °C. Notably, the male pupae took a longer time to develop compared to female pupae. The adult lifespan of both males and females decreased with increasing temperatures from 20 °C to 35 °C. The study revealed that females generally lived longer than males. Egg hatchability was highest at 25 °C (94.20±0.5) and lowest at 35 °C (48.40±0.67). The survival percentage of larvae was highest at 30 °C (95%) followed by 89% at 25 °C. The findings of the study indicated that temperature ranges between 25 °C and 30 °C were favourable for the growth and development of fall armyworms, while extremes of 20 °C and 35 °C were not suitable for proper development.

Key words: *Fall armyworm, Temperature, Developmental period, Pupa, Hatchability, Larval survivability.*

Introduction

Maize, also known as *Zea mays* L., holds a significant position in India, ranking third after wheat and rice. It plays a vital role in the country's agricultural landscape, contributing significantly to food security and economic growth. It is widely cultivated across diverse agro-climatic zones, serving as a staple food, fodder, and industrial raw material. Its adaptability, high yield potential, and versatility make it a key crop in India's agricultural sector. Maize cultivation in India spans three seasons: Kharif, Rabi, and Spring. Kharif, which is characterized by high temperatures exceeding 35 °C and rainfall, is the primary season for maize planting. Rabi is the second most significant season, contributing approximately 15% of the total corn acreage. The climate plays a crucial role in maize production.

The presence of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) was first identified in Africa in 2016, causing substantial damage to maize crops before spreading across Asia, including India in

2018. The insect's growth and development are significantly influenced by temperature, an essential abiotic factor according to Denlinger and Yocum (1998). The relationship between temperature and growth rate impacts pest biology, distribution, and abundance, with insects favoring specific temperature ranges for reproduction. Deviations from the optimal temperature range can affect growth pace. Temperature not only affects the duration and number of instars but also influences various aspects of insect reproduction, including pre-oviposition, oviposition, post-oviposition, egg viability, and total fecundity per female.

This study aims to assess the developmental pace of *S. frugiperda* at different temperatures, providing insights into the time required for each stage of its development. Such information is crucial for the formulation of effective pest management strategies by scientists and for guiding maize farmers in adapting to future cultivation challenges influenced by temperature variations.

Materials and Methods

Source of FAW culture

The Fall armyworm larvae (F0 generation) were collected from naturally infested maize fields from the Agriculture Research Station, Institute of Agriculture Sciences, SOA University in Khordha District of Odisha. The collected larvae were reared in well aerated plastic containers (10x12 cm) on natural diet (maize leaves) under constant laboratory conditions *i.e.* 26 ± 1 °C, 65±5% RH and 14L:10D photoperiod till pupation was achieved. Maize leaves provided as food were replaced at every two days interval and the jar was cleaned to avoid contamination Then pupae were separated on the basis of their sexes and kept in oviposition cage along with a cotton swab dipped in 5% honey solution as food for adults. Two maize (30 days old) seedlings along with pots were placed inside the cage as a oviposition substrate and the eggs collected from this culture were used in the experimental set up.

Rearing in Laboratory under different temperatures

In this experiment, five homogeneous batches, each comprising approximately 100 eggs (F1 generation), derived from a stock culture, were stored in BOD incubators. These batches were subjected to constant temperatures, namely 20 °C, 25 °C, 30 °C, and 35 °C, until the completion of their progeny. Daily examinations under an optical stereo microscope were conducted to record hatchability and hatching time. Eggs that successfully hatched were categorized as hatched eggs, while those that did not hatch by the end of the experiment were considered dead. Key parameters such as the number of hatched eggs, incubation period length, and hatching percentage were calculated.

Following the emergence of first instar larvae, as per the methodology outlined by DuPlessis *et al.* (2020), they were individually transferred to petri dishes and fed with a natural diet (Maize leaves). A total of 100 larvae were reared at each temperature, with 20 in each replication. Daily observations, facilitated by an optical stereo microscope, were conducted to measure the length of the first, second, third, fourth, fifth, and sixth larval instars, continuing until pupation, as evidenced by the observation of head capsules and exuviae. Upon pupation, pupae were collected, and gender determination was made based on size, with males being smaller and females being longer. The pupal lifespan was monitored until adulthood.

Subsequently, ten pairs from the emerging population of the aforementioned progeny were placed in oviposition cages and maintained at four different temperatures, with their durations recorded.

Treatment details

The experiment was carried out at 65 ± 5% relative humidity and a 14:10 h (L: D) in BOD incubator.

Treatment No.	Temperature
T_1	20 °C
T_2	25 °C
T_3	30 °C
T_4	35 °C

Data Analysis

The mean developmental duration of each stage of the FAW life cycle at different temperatures was analysed using one-way analysis of variance (ANOVA) (through IBM SPSS version 28) followed by Duncan's Multiple Range Test (DMRT) to separate the means (through R- software).

Results

The current study demonstrated a significant influ-

ence of temperature ranging from 20 °C to 35 °C on various biological parameters of *S. frugiperda*.

Biological growth stages of fall armyworm under different constant temperatures

Egg Period and Hatchability

The recorded observations indicate a decrease in the egg developmental period with an increase in temperature, ranging from 6.08±0.06 days at 20°C to 2.36±0.05 days at 30°C, as shown in Table.1. However, at 35°C, the incubation period slightly increased to 2.76±0.05 days compared to 30°C. At 25°C, the recorded egg period was 3.40±0.07 days. Significant differences were noted among the egg periods at different temperatures (20°C, 25°C, 30°C, and 35°C), and the relationship between these temperatures and the egg period is illustrated in Fig. 1.

The highest number of successfully hatched eggs was observed at 25°C (94.2±0.49), followed by 30°C (89.2±0.45) (Table 2). The minimum hatchability was recorded at 35°C (48.4±0.54), and at 20°C, it was 52.2±0.47. In line with the experiment's findings, it is evident that the developmental period of FAW eggs decreased, while hatchability increased with rising temperatures, up to 30°C.

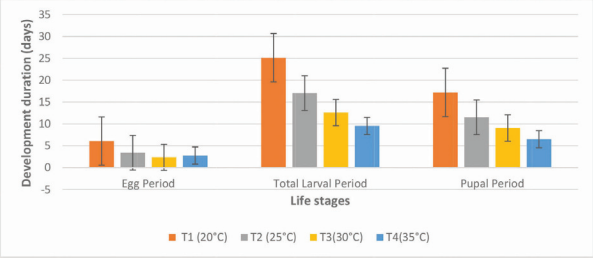

Fig. 1. Development of life stages of Fall Armyworm at different constant temperature under laboratory condition

Larval Period and Larval Survivability

The overall developmental period of larvae exhibited an inverse relationship with temperature increments from 20°C to 35°C. The larval period displayed a linear response, demonstrating a reduction in developmental duration for all instars with an increase in temperature. Noteworthy differences were observed in the mean larval duration at four constant temperatures: 20°C, 25°C, 30°C, and 35°C. The maximum larval duration occurred at 20°C, recording 25.14±0.06 days, while the minimum duration was noted at 35°C, measuring 9.54±0.06 days.

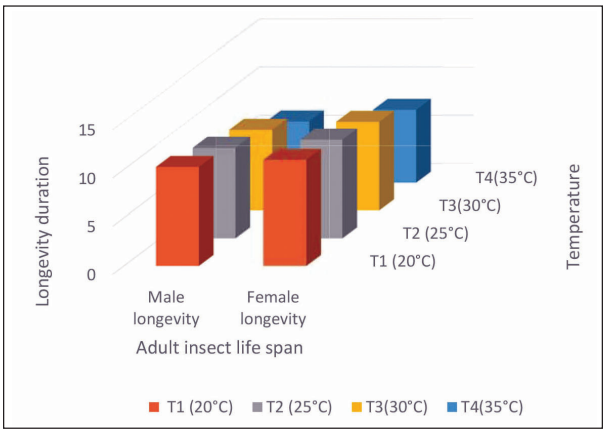

Fig. 2. Adult male and female longevity of Fall Armyworm at different constant temperature under laboratory condition

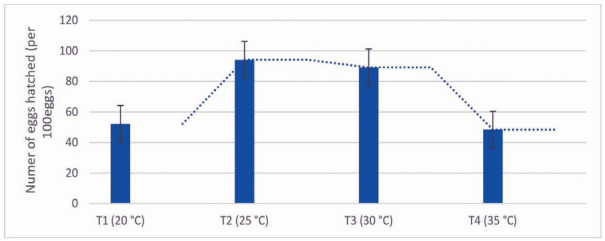

Fig. 3. Hatchability of eggs of Fall Armyworm at different constant temperature under laboratory condition

Larval periods at 25 °C and 30 °C were 17.06±0.07 and 12.60±0.06 days, respectively. Although fall armyworm (FAW) larvae completed development at all four temperatures, their development was less robust at 20°C and 35 °C compared to 25 °C and 30°C.

Larval survivability at various temperatures (20°C, 25 °C, 30 °C, and 35 °C) is detailed in Tables 2 and 3. The minimum larval survivability was observed at 20°C, with a rate of 10.4±0.24 (52%), followed by survivability at 35 °C, recorded at 13.4±0.50 (67%). The highest larval survivability was documented at 30°C, reaching 19±0.31 (95%), followed by 25 °C with 16.8±0.37 (84%).

Pupal Period

The development of the pupal stage displays an inverse relationship with temperature escalation (Table 1). The pupal period exhibited a range from 17.2±0.07 days (at 20 °C) to 6.50±0.07 days (at 35°C), which aligns with the range of 6.6–30.4 days at 32–18°C reported by Busato *et al.*, 2005. Specifically, a pupal development period of 11.52±0.03 days was

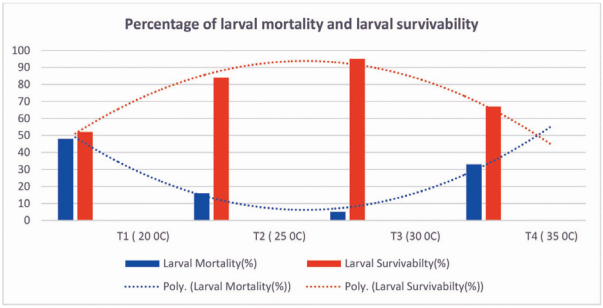

Fig. 4. Larval mortality and survivability of Fall Armyworm at different constant temperature under laboratory condition

observed at 25°C, followed by 9.06±0.04 days at 30°C (Table 1). Pupae developed at 35°C were slightly deformed, and the resulting adults emerged with crumpled wings.

Adult Longevity

Significant differences in male adult longevity were observed at four distinct temperatures: 20°C, 25°C, 30°C, and 35°C (Table 1). The highest longevity for males was noted at 20°C (10.28±0.08 days), followed by 25°C (9.38±0.06 days). The minimum longevity was recorded at 35°C, specifically 6.36±0.06 days. At 30°C, male longevity stood at 8.36±0.07 days.

For females, the maximum longevity was 11.02±0.08 days at 20°C, followed by 10.22±0.06 days at 25°C, and 9.2±0.07 days at 30°C. Female longevity was 7.58±0.06 days at 35°C. Additionally, it was observed across all four temperatures that female adults tend to live longer than their male counterparts.

Discussion

To achieve a better understanding of the phenological change that insect populations go through, it is important to have a clear understanding of how abiotic elements, such as temperature, affect their development rate (Karban and Valpine, 2010). The development rate of species rises linearly within their favourable temperature range, but becomes nonlinear at adverse temperatures (Wagner *et al.*, 1984). Hence, understanding the elements that determine FAW population demographics is crucial for integrated pest control. Numerous researchers have explored the biological aspects of the fall armyworm concerning different temperatures. In this context, our research has the potential to make a meaningful

Table 1. Mean development time for different life stages of *Spodoptera frugiperda* on maize

Temperature Regimes	Developmental stages of different stages in days (Mean ± SE)									
	Egg Period	I Instar	II Instar	III Instar	IV Instar	V Instar	VI Instar	Total Larval Period	Pupal Period	Male longevity	Female longevity
T1 (20 ^{0}C)	6.08±0.06^a	4.52±0.08^a	4.20±0.03^a	3.16±0.05^a	3.34±0.06^a	3.94±0.07^a	5.98±0.06^a	25.14±0.06^a	17.2±0.07^a	10.28±0.08^a	11.02±0.08^a
T2 (25 ^{0}C)	3.40±0.07^b	3.36±0.05^b	2.60±0.05^b	2.36±0.05^b	2.42±0.05^b	2.68±0.03^b	3.64±0.05^b	17.06±0.07^b	11.52±0.03^b	9.38±0.06^b	10.22±0.06^b
T3 (30 ^{0}C)	2.36±0.05^c	2.74±0.05^c	1.96±0.06^c	1.70±0.04^c	1.72±0.05^c	2.22±0.03^c	2.26±0.07^c	12.60±0.06^c	9.06±0.04^c	8.36±0.07^c	9.20±0.07^c
T4 (35 ^{0}C)	2.76±0.05^d	2.02±0.08^d	1.40±0.03^d	1.28±0.03^d	1.30±0.05^d	1.46±0.06^d	2.08±0.03^d	9.54±0.06^d	6.50±0.07^d	6.36±0.06^d	7.58±0.06^d
SEm (±)	0.06	0.07	0.05	0.05	0.06	0.05	0.06	0.08	0.06	0.10	0.07
CD(1%)	0.18	0.21	0.15	0.14	0.17	0.16	0.18	0.23	0.17	0.31	0.21
CV(%)	3.70	4.88	4.31	4.88	5.90	4.76	3.79	1.05	1.15	2.73	1.67
F value	769.28	236.18	610.44	313.3	237.64	360.39	926.06	8065.84	6431.22	257.75	435.98

SE = Standard Error, SEm = Standard error of mean, CD = Critical difference, CV= Coefficient of variation, F= F value of Turkey's test, Mean ± SE within the same column followed with different letters are significantly different ($p < 0.05$)

contribution to comprehending how temperature influences the development of the fall armyworm (FAW).

Our results indicated that the duration of development and the survival rate of the fall armyworm (FAW) were notably impacted by temperature. The developmental rate of *S. frugiperda* eggs, larvae, pupae, and adults correlated positively as temperatures increase from 20°C to 35°C, which is consistent with the findings of Du Plessis *et al.* (2020), who reported that the rate of growth of FAW eggs, larvae, and pupae increased consistently as temperatures rose from 18°C to 30°C.

Sarkar *et al* (2021) reported that incubation period of eggs of FAW decreased with an increase in temperature from 18 ±2°C (7.08 ± 1.3 days) to 30±2°C (3.54 ± 0.76 days), but increased to 3.58±0.71 days at 32 ±2°C and Huag *et al.*, 2021 also reported that the time it takes for eggs to incubate reduced significantly from 7.5 days at 19°C to 2.0 days at 31°C, which is in line with the present finding. The hatching percentage of egg increased linearly with increase in temperature from 30% (at 18°C) to 96 % (at 26°C) and thereby decreased with further increase in temperature up to 32°C (44%) was reported by Savadatti *et al.,* 2023 which was similar to this current study where hatching was maximum at 25°C and further decreased with increase in temperature to 35°C.

A significant difference of 15.6 days in the average duration of the larval period was observed between individuals raised at 20°C and those reared at 35°C. This finding aligns with the observations of Malekara *et al.* (2022), who noted a 12.3-day difference in development duration between individuals raised at 20°C and 34°C. Our study's conclusion, indicating the highest larval survivability at 30°C, mirrors the findings of Sarkar *et al.* (2021), where larval survivability peaked at 30°C (100%) and dropped to a minimum at 18°C (64%). The current results are consistent with Du Plessis *et al.* (2020), who identified the optimal range for larval development between 26°C and 30°C. Additionally, our study supports Barfield *et al.'s* (1978) findings, reporting higher *S. frugiperda* larval mortality at 18°C and 37°C than at 26.7°C. Similar results were obtained by Prasad *et al.* (2021), indicating reduced larval survival rates at elevated temperatures.

The pupal period demonstrated a reverse correlation with rising temperatures from 20°C to 35°C, aligning with the findings of Du Plessis *et al.* (2020). In their research, the pupal period of the fall armyworm ranged from 7.82 to 30.70 days at temperatures spanning from 32°C to 18°C. This discovery is also consistent with the outcomes of Chen *et al.* (2022), who observed a decrease in the pupal period from 18.36 days to 7.69 days as temperatures ranged from 20°C to 30°C, respectively.

Table 2. Egg Hatchability and Larval Survivability of Fall Armyworm at constant temperature under laboratory conditions (Mean±SE)

Temperature Regimes	Egg Hatchability	Larval Survivability
T1 (20 ^{0}C)	52.20±0.48^a	10.40±0.24^a
T2 (25 ^{0}C)	94.20±0.58^b	16.80±0.37^b
T3 (30 ^{0}C)	89.20±0.73^c	19.00±0.31^c
T4 (35 ^{0}C)	48.40±0.67^d	13.40±0.50^d
SEm (±)	0.63	0.43
CD(1%)	1.88	1.12
CV(%)	1.98	5.62
F value	1463.02	102.19

*Number of eggs taken=100; number of larvae taken=20. SE = Standard Error, SEm = Standard error of mean; CD = Critical difference; CV= Coefficient of variation; F= F value of Tukey's test; Mean ± SE within the same column followed by different letters is significantly different ($p < 0.05$)

Table 3. Larval mortality and larval survivability percentage of Fall armyworm at constant temperature under laboratory conditions

Temperature Regimes	Larval Mortality (%)	Larval Survivability (%)
T1 (20 ^{0}C)	48	52
T2 (25 ^{0}C)	16	84
T3 (30 ^{0}C)	5	95
T4 (35 ^{0}C)	33	67

Our findings on the longevity of adult insects are comparable to those published by Ashok et al (2021). They discovered a substantial drop in adult longevity from 32°C to 36°C. At 32°C, the adult lifetime was 11.02 days, with male and female longevity measured at 10.87 and 11.15 days, respectively.

Conclusion

Spodoptera frugiperda exhibits growth capability across all four temperatures studied: 20°C, 25°C, 30°C, and 35°C. However, the most favourable temperature range for growth falls between 25°C and

30°C. The highest rate of egg hatching was recorded at 25°C (94.2±0.58), while maximum larval survivorship occurred at 30°C (19.00 ±0.31). Optimal temperature conditions led to faster and shorter growth and development, suggesting the potential for a greater number of generations. The temperature thresholds identified in this study can serve as parameters for modelling locations conducive to assessing the prospective dispersion and long-term establishment of *S. frugiperda.*

Conflict of Interest: The authors have no financial or non-financial interests to declare that are directly or indirectly relevant to the content of this article.

References

Aguilon, D.J.D. and Velasco, L.R.I. 2015. Effects of larval rearing temperature and host plant condition on the development, survival, and coloration of African armyworm, *Spodoptera exempta* Walker (Lepidoptera: Noctuidae). *Journal of Environmental Science and Management.* 18: 54-60

Ashok, K., Balasubramani, V., Kennedy, J.S., Geethalakshmi, V., Jeyakumar, P. and Sathiah, N. 2021. Effect of elevated temperature on the population dynamics of fall armyworm, *Spodoptera frugiperda*. *Journal of Environmental Biology*. 42: 1098-1105.

Barfield, C.S., Mitchell, E.R. and Poe, S.L. 1978. A temperature dependent model for Fall Armyworm development. *Annals of Entomological Society America.* 71: 70-74.

Busato, G.R., Grutzmacher, A.D., Garcia, M.S., Giolo, F.P., Zotti, M.J. and Bandeira, J.M. 2005. Thermal requirements and estimation of the number of generations of biotypes 'corn' and 'rice' of *Spodoptera frrugiperda*. *Pesqui Agropec Bras.* 40: 329-335.

Chen, Y.C., Chen, D.F., Yang, M.F. and Liu, J.F. 2022. The Effect of Temperatures and Hosts on the Life Cycle of *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *Insects.13:*211. https://doi.org/10.3390/insects13020211

Denlinger, D.L. and Yocum, G.D. 1998. Physiology of Heat Sensitivity. In *Temperature Sensitivity in Insects and Application in Integrated Pest Management*; West_View Press: Boulder, CO, USA; Oxford, UK, 1998; pp. 7–53. ISBN 0 8133 8990 9(HB)

Du Plessis, H., Schlemmer, M.L., Van and Berg, J. 2020. The effect of temperature on the development of *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *Insects.* 11(4): 228-232.

Huang, L.L., Xue, F.S., Chen, C., Guo, X., Tang, J.J., Zhong, L. and He, H.M. 2021. Effects of temperature on life-history traits of the newly invasive fall armyworm, *Spodoptera frugiperda* in Southeast China. *Ecological Evolution.* 11(10): 5255-5264. doi: 10.1002/ece3.7413.

Ju, R.T., Wang, F. and Li, B. 2011. Effects of temperature on the development and population growth of the sycamore lace bug, *Corythuchaciliata*. *Journal of Insect Science.* 11(1): 16.

Karban, R. and Valpine, P.D. 2010. Population dynamics of an Arctiid caterpillar - tachinid parasitoid system using state-space models. *Journal of Animal. Ecology.* 650-661.

Malekera, M.J., Acharya, R., Mostafiz, M.M., Hwang, H.S., Bhusal, N. and Lee, K.Y. 2022. Temperature-Dependent Development Models Describing the Effects of temperature on the Development of the Fall Armyworm *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae). *Insects. 13:* 1084.https://doi.org/10.3390/insects1312108

Prasad, T.V., Srinivasa, R.M., Rao, K., Bal, S.K., Muttapa, Y., Choudhary, J.S. and Singh, V.K. 2021. Temperature-based phenology model for predicting the present and future establishment and distribution of recently invasive *Spodoptera frugiperda* (J. E. Smith) in India. *Bulletin of Entomological Research.* 112: 1–15. https://doi.org/10.1017/s0007485321000882

Sarkar, S., More, S.A., Tamboli, N.D., Kulkarni, S.R. and Nimbalkar, C.A. 2021. Effect of temperature on the reproductive ability of Fall Armyworm-*Spodoptera frugiperda* (J E Smith) under laboratory condition. *Journal of Pharmacognosy and Phytochemistry.* 10(6): 154-158. https://www.thepharmajournal.com/archives/2021/vol10issue11S/PartK/S-10-10-292-678.pdf

Savadatti, E., Ginnu, S.A., Mariyanna, L., Hosamani, A., Desai, B.R.K.R., Subbanna, A.D. and Jalamangala, A. 2023. Temperature Effects on the Development of Life Stages of Fall Armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) on Maize. *International Journal of Environment and Climate Change.* 13 (9): 1884-1892. https://doi.org/10.9734/ijecc/2023/v13i92419

Sharanabasappa, S.D., Kalleshwaraswamy, C.M., Asokan, R., Mahadeva Swamy, H.M., Maruthi, M.S. and Pavithra, H.B. 2018. First report of the fall Armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera, Noctuidae), an alien invasive pest on maize in India. *Pest Management in Horticultural Ecosystems.* 24(1): 23-29.

Wagner, T.L., Wu, H., Sharpe, P.J.H., Schoolfield, R.M. and Coulson, R.M. 1984. Modelling distributions of insect development time: A literature review and application of the Weibull function. *Annals of Èntomological. Society America*. 77: 475–487.