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Effect of elevated temperature on the population dynamics of fall armyworm, *Spodoptera frugiperda*

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Abstract

Aim: The present study was conducted to determine the growth, survival, fecundity and mortality rate of *Spodoptera frugiperda* in maize at elevated temperature.

Methodology: Biology and life table experiments were carried out in custom made Open Top Chambers (4m x 4m x 4m size) fitted with SCADA under increasing temperature regimes viz., 32°C, 33°C, 34°C, 35°C and 36°C. Each stage of the insects was examined daily and the fertility and life-table parameters were calculated by using TWOSEX-MS chart.

Results: The overall developmental time for egg, larva, pupa and adult stages (total lifespan) at different elevated temperatures were in the order of 32°C > 33°C > 34°C > 35°C > 36°C. The fecundity rate of *S. frugiperda* at different elevated temperatures were in the order of 34°C > 33°C > 32°C > 35°C > 36°C.

Interpretation: The current study confirms that the elevated temperature regimes had a positive correlation with fecundity rate upto 34°C and negative correlation with the survival rate of *S. frugiperda*.

Key words: Life table, Population dynamics, *S. frugiperda*, Temperature

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Introduction

Insects flourish in all climates. Climate change, especially elevated CO₂ and elevated temperature, the effects insect physiological, behavioral, developmental process, species distribution and abundance. It was evidenced by changes in the number of generations per year, survival rate and earlier occurrence within the cropping season (Huang *et al.*, 2010). Invasive alien species (IAS) causes a serious threat to agriculture and cost billions of dollars in terms of reduced the productivity. About 1300 species of invasive insect pests and pathogens have been introduced into 124 countries due to increased trans-boundary movement of agricultural commodities, anthropogenic activities, climate change etc. (Paini *et al.*, 2016).

Maize (*Zea mays*) the “Queen of cereals” is cultivated for human consumption, cattle and poultry feed. In India, maize is cultivated in an area of 93.80 million hectares with a production of 280.80 million tonnes and productivity of 3.07 tonnes per hectare. In Tamil Nadu, maize is cultivated over an area of 32.45 million hectares with a production of 259.17 million tonnes and 7.99 tonnes per hectare (Directorate of Economics and Statistics, 2018). Several insect pest causes damage to maize crop right from sowing to harvest, resulting in significant yield loss. Among them, the recently introduced pest, fall armyworm (*Spodoptera frugiperda*) is one of the serious concern due to its notorious and polyphagous behavior. *S. frugiperda*, is a native pest of America (Luginbill, 1928) and has recently been reported in Africa (Goergen *et al.*, 2016) and India. First observations of *S. frugiperda* was made during 2018 in Shivamogga, Karnataka (Sharanabasappa *et al.*, 2018), consequently, reported in different parts of the country (Ganiger, 2018; Srikanth *et al.*, 2018; Sisodiya *et al.*, 2018; Bajracharya *et al.*, 2019; Chormule *et al.*, 2019). Larvae can survive on 353 different plant species belonging to 76 botanical families (Montezano *et al.*, 2018). It is reported to cause major damage to the crops including rice, maize, sorghum, sugarcane, cabbage, beet, tomato, potato, cotton, peanut, soybean and alfalfa (Pogue, 2002; Chapman *et al.*, 2000; CABI, 2016).

In ecological studies, life table is an important and necessary tool for analyzing and understanding the growth, survival, reproduction and mortality. Life table parameters help to identify the changes in the insect pests population during each developmental stage throughout their life cycle (Kakde *et al.*, 2014). Different methods of analyzing life tables have been developed and widely adopted in ecological studies (Deevey, 1947; Birch, 1948; Southwood, 1978; Carey, 1993). The reproductive potential, fecundity and fertility of *S. frugiperda* have been studied under natural and controlled environmental conditions. This indicates a wide variation in those parameters, which may be influenced by temperature, larval diet and the strain of *S. frugiperda* (Simmons and Lynch, 1990; Rogers and Marti, 1994).

It is essential to understand the population dynamics of a pest before an effective IPM can be implemented (Maia *et al.*,

2000). The traditional life table, which is based only on the female population (Birch, 1948). Age-stage, two-sex life table can eliminate many of the inherent errors characteristic of female-based life tables (Chi, 1988; Huang and Chi, 2011). Keeping in view the above, this study was conducted to determine the growth, survival, fecundity and mortality rate of *S. frugiperda* in maize at different elevated temperature levels using age-stage, two-sex life table.

Materials and Methods

Open Top Chamber: Open Top Chamber used in this study is a custom made cubical structure with a partially opened top side built with galvanized iron (GI) frames of 4 m x 4 m x 4 m and high-quality multilayer polycarbonate sheets (4-6 mm thickness). The chamber is provided with humidity and temperature supervising control and wireless signal transmission amenities along with Supervisory Control and Data Acquisition (SCADA) integration technology.

Host plants: The potted plants of maize (Variety: CO 6) were maintained using soil mixture of red soil + vermicompost + sandy soil in 1:1:1 ratio. Irrigation was done once in two days. From the day of sowing, the plants were maintained at different temperature inside open top chamber. These plants were used in the experiment as insect feed.

Insect source and rearing: Egg masses and larvae of *S. frugiperda* were collected from maize fields at Department of Millets in Tamil Nadu Agricultural University, Coimbatore. The collected insects were mass cultured in artificial diet (Patel *et al.*, 1968) in laboratory of Department of Agricultural Entomology, Coimbatore for the availability of continuous and uniform culture of insects throughout the research period. Larvae were provided with artificial diet until larvae reached the pre-pupal stage. Following pupation, each pupa was kept in a separate plastic cup containing soil until eclosion. After eclosion, the adults were released into the rearing cages, covered with mesh net on three sides and glass on top, and a clean cotton wick containing 10% honey solution. The insects were bred for six complete generations under laboratory conditions (27±2°C, 75±10% RH and 12L: 12D) before subjecting to life table studies at elevated temperature regimes.

Experiment design: Demography of *S. frugiperda* were studied at five different temperature regimes (32°C, 33°C, 34°C, 35°C and 36°C) in separate Open Top Chambers (OTC). Single egg mass of almost equal size was taken per treatment. After hatching, the individual larvae were kept in separate plastic containers (3 cm diameter x 4 cm height). The larvae were fed with fresh maize leaves, it was changed every 24 hours, until pupation. Each individual was considered as separate replication. The number of replications depend on the number of eggs in individual egg mass taken at the beginning of the experiment and, hence, varied among five treatments. Data were collected daily, to monitor hatched eggs and the duration of each developmental stage of *S. frugiperda* on different elevated temperature levels. Dead larvae and malformed pupae were recorded and discarded every day.

After emergence, one female with one male were paired and kept in a mating cage. The fecundity rate was recorded daily from the period of oviposition until mortality of adults.

Life table study: For understanding the change in performance and population dynamics of insect pests on elevated temperature regimes, life table parameters are important indicators that explain the impact of growth, survival and fecundity of insect populations (Andrewartha and Birch, 1954; Chi and Su, 2006). Based on the procedures developed by Birch (1948) and Carey (1993), the following life table parameters viz., net reproductive rate (R_0), intrinsic rate of increase (r_m), finite rate of increase (λ), and mean generation time (T_0), gross reproductive rate (GRR) and population doubling time (DT) were calculated. The possibility of survival in function of age period of an insect pest followed Type III curve (logistic pattern) and displayed in semi-logarithmic scale (Gotelli, 2001). Therefore, fixation of survivorship curve was done using Doesn't Use Derivative (DUD) method (Raltson and Jenrich, 1978).

Statistical analysis: The age-stage, two-sex life table was used to analyse the raw life history and life table data of *S. frugiperda* using the computer program, TWOSEX-MS Chart (version 2019.11.17) (Chi 1988; Chi and Liu 1985). Data from the development time of *S. frugiperda* met the requirements of the analysis of variance (ANOVA) at $P < 0.05$, and their means were compared by Tukey's Honest Significant Difference (HSD) test using STAR (Statistical tool for agriculture research, IRRI, 2013). The population survival curve from the given sample can be estimated over different lengths of time period using Kaplan-Meier analysis in SPSS (Kaplan and Meier, 1958).

Results and Discussion

Insects are poikilothermic in nature, where their distribution range, growth, development, food consumption, number of generations and life cycle depends on atmospheric temperature conditions (Arora and Dhawan, 2013). In the present study, all the eggs hatched on 3rd day at 32°C, 2nd day at 33 and 34°C and 1st day at 35 and 36°C. This result was on par with the findings of Du Plessis *et al.* (2020) on *S. frugiperda* in maize at different temperatures from 18 to 32°C. Duration of all the larval stages were significantly different, for except L5 (fifth instar larva), when temperature increased from 32 to 36°C. The total larval development was 11.71 days at 32°C, whereas it was 9.16 days under 36°C and the difference was statistically significant among the different temperatures. According to Ali *et al.* (1990), most of the *S. frugiperda* larvae completed their development in more than 6 stadia at 17°C, and all larvae died by fourth stadium at 38°C. Earlier, Mironidis and Savopoulou-Soultani (2014) found that the total larval developmental period of *H. armigera* in cotton was significantly longer with 68 days at 15°C and it decreased to 14.52 days at 37.5°C. The pupal stage also exhibited significant differences at different temperature regimes, with the shortest developmental time of 5.63 days at 36°C and the longest of 10.16 days at 32°C. Pupal eclosion was recorded at all the temperature regimes. Simmons (1993) recorded failure of eclosion in *S.*

frugiperda at 10°C and 40°C, however, the eclosion was not affected between 15°C and 35°C. The duration of the pre-adult stage (egg to eclosion) also exhibited significant differences at different temperature regimes, with the shortest developmental time for the pre-adult stage occurring at 36°C with 15.79 days and the longest at 32°C with 24.88 days. The overall developmental time for egg, larva, pupa and pre-adult stages at different temperatures were in the order of 32°C > 33°C > 34°C > 35°C > 36°C (Table 1). According to Du Plessis *et al.* (2020), the developmental time of *S. frugiperda* in maize was also decreased with increasing temperature regimes varying from 18°C (34.39 days) to 32°C (10.45 days) at larval stage and from 18°C (30.68 days) to 32°C (7.82 days) at pupal stage.

Adult longevity significantly decreased from 32°C to 36°C. The adult longevity at 32°C was 11.02 days with male longevity and female longevity of 10.87 and 11.15 days, respectively. However, at 36°C the male longevity and female longevity was 8.09 and 8.50 days, with adult longevity of 8.26 days. The order was 32°C > 33°C > 34°C > 35°C > 36°C. Similarly, Mironidis (2014) reported that adult longevity of both sexes were significantly affected with fluctuating temperatures. The average life span of *H. armigera* male ranged from 9.88 to 20.39 days, whereas females from 11.09 to 18.56 days, at 32 and 25°C, respectively. The total lifespan significantly reduced increasing the temperature 32 to 36°C. The mean total lifespan at from 32°C was 35.90 days with 35.43 and 36.61 days for male and female entire lifespan, respectively. However, at 36°C male and female entire lifespan was 24.18 and 23.88 days, respectively, with mean total lifespan of 24.05 days. The order of lifespan was 32°C > 33°C > 34°C > 35°C > 36°C (Table 2). This result is in line with the susceptibility to elevated temperature studies. Tamiru *et al.* (2012) reported that at 22°C the mean duration of *Chilo partellus* was 70.20 days while it needed only 26.50 days at 30°C to complete its life duration.

The Adult Pre Oviposition Period (APOP) proved to be longest at 32°C, with similar results found between 34°C and 35°C, following the order of 32°C > 36°C > 34°C = 35°C > 33°C, while total pre oviposition period (TPOP) was longest at 32°C, in the order of 32°C > 33°C > 34°C > 35°C > 36°C. Females reared at 34°C had the highest fecundity, while the lowest fecundity occurred at 36°C, in the order of 34°C > 33°C > 32°C > 35°C > 36°C and the difference was statistically significant. The number of oviposition days for females decreased from 34°C to 36°C, in the order of 34°C > 32°C > 33°C > 35°C > 36°C and the difference was statistically significant (Table 3). Chen *et al.* (2014) reported that fecundity (eggs per female) increased with increasing temperatures in *Paraponyx crisonalis*. The number of eggs laid per female increased from 7.00 at 27°C to 164.86 at 30°C. Soh *et al.* (2018) revealed that the fertility per female of *Brevicoryne brassicae* was 39.84 nymphs per female at 15°C but increased to 46.36 nymphs per female at 20°C. Similar trend was also observed in this present study where the eggs per female was 1203.96 under 32°C and steadily increased to 1805.58 at 34°C.

Table 1: Developmental time (days) of *S. frugiperda* under different temperature regimes

Life stages	Temperature regimes											
	32°C			33°C			34°C			35°C		
	n(N)	X ± SE	n(N)	X ± SE	n(N)	X ± SE	X ± SE	n(N)	X ± SE	n(N)	X ± SE	F
Egg	106(123)	3.06±0.00 ^a	109(127)	2.08±0.00 ^b	103(128)	2.00±0.00 ^b	1.25±0.00 ^c	96(127)	1.25±0.00 ^c	81(125)	1.21±0.00 ^c	194.66
L1	92(106)	1.76±0.05 ^a	89(109)	1.76±0.05 ^{ab}	87(103)	1.56±0.05 ^{bc}	1.16±0.04 ^c	74(96)	1.16±0.04 ^c	69(81)	1.12±0.04 ^d	13.98
L2	78(92)	1.71±0.05 ^a	78(89)	1.65±0.05 ^{ab}	76(87)	1.55±0.06 ^{abc}	1.25±0.05 ^c	61(74)	1.25±0.05 ^c	54(69)	1.26±0.06 ^{bc}	2.97
L3	66(78)	1.71±0.06 ^a	71(78)	1.68±0.06 ^{ab}	69(76)	1.43±0.06 ^{bc}	1.26±0.06 ^c	53(61)	1.26±0.06 ^c	47(54)	1.21±0.06 ^c	3.55
L4	60(66)	1.73±0.06 ^a	63(71)	1.63±0.06 ^a	63(69)	1.48±0.06 ^{ab}	1.28±0.07 ^b	46(53)	1.28±0.07 ^b	38(47)	1.32±0.08 ^{ab}	2.57
L5	54(60)	1.78±0.06	59(63)	1.78±0.05	62(63)	1.65±0.06	1.54±0.08	39(46)	1.54±0.08	32(38)	1.14±0.09	0.92
L6	51(54)	2.75±0.07 ^a	54(59)	2.43±0.07 ^b	58(62)	2.14±0.07 ^c	2.06±0.09 ^c	36(39)	2.06±0.09 ^c	28(32)	1.61±0.09 ^d	22.51
Total larva	51(106)	11.71±0.11 ^a	54(109)	11.12±0.11 ^b	58(103)	10.15±0.13 ^c	9.53±0.20 ^d	36(96)	9.53±0.20 ^d	28(81)	9.16±0.18 ^d	49.95
Pupa	49(51)	10.16±0.09 ^a	52(54)	9.54±0.07 ^b	54(58)	8.54±0.09 ^c	6.58±0.11 ^d	32(36)	6.58±0.11 ^d	19(28)	5.63±0.14 ^e	310.83
Pre-adult	49(123)	24.88±0.15 ^a	52(127)	22.65±0.13 ^b	54(128)	20.69±0.17 ^c	17.09±0.24 ^d	32(127)	17.09±0.24 ^d	19(125)	15.79±0.25 ^e	363.05

N = total replicate number; n = effective replicate number; X = mean value; SE = standard error; F = F value of Tukey's Test; P = statistical significance. Means ± SE followed by different letters in the same row are significantly different at P < 0.05 (ANOVA followed by Tukey's Honest Significant Difference test)

Table 2: Adult longevity and lifespan of *S. frugiperda* under different temperature regimes

Parameters (days)	Temperature regimes											
	32°C			33°C			34°C			35°C		
	n	X ± SE	n	X ± SE	n	X ± SE	X ± SE	n	X ± SE	n	X ± SE	F
Male longevity	23	10.87±0.07 ^a	21	10.38±0.07 ^a	28	9.10±0.27 ^b	8.69±0.42 ^{bc}	13	8.69±0.42 ^{bc}	11	8.09±0.11 ^c	12.26
Female longevity	26	11.15±0.10 ^a	31	11.06±0.09 ^a	33	10.88±0.12 ^a	9.89±0.14 ^b	19	9.89±0.14 ^b	8	8.50±0.13 ^c	27.50
Adults longevity	49	11.02±0.09 ^a	52	10.79±0.09 ^a	54	10.19±0.22 ^b	9.41±0.30 ^c	32	9.41±0.30 ^c	19	8.26±0.15 ^d	25.77
Male lifespan	23	35.43±0.15 ^a	21	33.33±0.14 ^b	28	30.05±0.31 ^c	26.62±0.43 ^d	13	26.62±0.43 ^d	11	24.18±0.25 ^e	119.87
Female lifespan	26	36.31±0.16 ^a	31	33.52±0.16 ^b	33	31.39±0.21 ^c	26.42±0.29 ^d	19	26.42±0.29 ^d	8	23.88±0.16 ^e	238.70
Total lifespan	49	35.90±0.16 ^a	25	33.44±0.15 ^b	54	30.87±0.26 ^c	26.50±0.34 ^d	52	26.50±0.34 ^d	19	24.05±0.21 ^e	325.12

n = effective replicate number; X = mean value; SE = standard error; F = F value of Tukey's Test; P = statistical significance. Means ± SE followed by different letters in the same row are significantly different at P < 0.05 (ANOVA followed by Tukey's Honest Significant Difference test)

Table 3: APOP, TPOP, oviposition period and fecundity of *S. frugiperda* under different temperature regimes

Parameter	Temperature regimes										FP	
	32°C		33°C		34°C		35°C		36°C			
	n	X ± SE	n	X ± SE	n	X ± SE	n	X ± SE	n	X ± SE		
APOP (days)	26	3.00±0.00 ^a	31	1.94±0.05 ^c	33	2.00±0.00 ^c	19	2.00±0.00 ^c	8	2.12±0.13 ^b	636.62	<0.000
TPOP (days)	26	28.15±0.21 ^a	31	24.39±0.19 ^b	33	22.52±0.23 ^c	19	18.53±0.28 ^d	8	17.50±0.39 ^d	249.83	<0.000
Oviposition period (days)	26	6.27±0.09 ^b	31	6.23±0.11 ^b	33	7.39±0.14 ^a	19	6.00±0.11 ^b	8	4.75±0.16 ^c	39.23	<0.000
Fecundity (Eggs/female)	26	1203.96±30.09 ^c	31	1519.87±25.87 ^b	33	1805.58±24.17 ^a	19	784.21±17.73 ^d	8	401±18.19 ^e	308.90	<0.000

APOP = adult pre-ovipositional period; TPOP = total pre-ovipositional period (from egg to first oviposition); n = effective replicate number; X = mean value; SE = standard error; F = F value of Tukey's Test; P = statistical significance. Means ± SE followed by different letters in the same row are significantly different at P < 0.05 (ANOVA followed by Tukey's Honest Significant Difference test).

Fig. 1 : Survivorship curves of *S. frugiperda* under different temperature regimes.

The survival of *S. frugiperda* showed that it belongs to Type III survivorship curve (Fig. 1). The rate of mortality was found to be higher during early stage of the insect at higher temperature regimes (35 and 36°C) as depicted by steep fall in the survival curve. The probability of survival of *S. frugiperda* is function of age trailed logistic pattern under increasing temperatures. The parameter 'a' (50 % mortality of the insect) symbolized the point of inflexion and the parameter 'b' symbolized the shape of the curve. The results showed that the survival per cent decreased with the function of age under increasing temperatures. At lower temperature (32°C), 50 per cent mortality of *S. frugiperda* was observed after 11.90 days of development. However, at higher temperature regimes (35 and 36 °C), 50 per cent mortality occurred earlier on 5.30 and 4.90 days, respectively (Table 4). Similarly, the results of Golizadeh *et al.* (2007) revealed that increased temperature of 35°C caused 100 per cent mortality in

Fig. 2 : Radar representation of life characters of *S. frugiperda* under different temperature regimes.

second instar larvae of *Plutella xylostella* in cauliflower. Kuo *et al.* (2006) studied the survivorship of *Rhopalosiphum maidis* in corn at seven different temperatures and found that 50 per cent mortality at 6°C was observed on 38th day, while at 35°C, 50 per cent and 100 per cent mortality was observed on 7th day and 14th day, respectively.

The life characters of *S. frugiperda* under elevated temperature are presented in Fig. 2. At 34°C, the *S. frugiperda* started to oviposit at 20th day of pivotal age and it continued for the next 13 days and the maximum oviposition was recorded at 25th day of pivotal age. However, at higher temperatures (35°C and 36°C), the fertility started within 17th and 16th days by shortening its developmental period. At 35°C and 36°C, the length of oviposition observed was 11 and 7 days, respectively. The length of oviposition period decreased with increasing temperatures. This

Fig. 3 : Kaplan-Meier estimate of survival of *S. frugiperda* under different temperature regimes.

signifies early maturity and the intense fertility of *S. frugiperda* under increasing temperatures.

The cumulative survival probability of *S. frugiperda* with respect to number of days in maize plants under elevated temperature levels are represented using Kaplan-Meier estimate in Fig. 3. Each survival curve indicated different treatments at elevated temperature levels. Each step down in each curve denotes the death of insects on each day. It was observed that the survival period of *S. frugiperda* ranged from 26 to 38 days at different treatments. The survival period of insect in different treatments were compared using log rank test. The mean survival distributions over 38 days was statistically non-significant

between different treatments. The probability of insect mortality increased with increased temperature. Favored climatic conditions hastened the rate of growth and development, leading to more number of generations per year and hence probable expansion of geographical range (Parmesan *et al.*, 1999; Bale *et al.*, 2002).

The gross reproductive rate (GRR) of *S. frugiperda* observed was 645.61 number per female per lifetime at 32°C and increased to 1212.66 number per female per lifetime at 34°C whereas it was 163.16 number per female per lifetime at 36°C. Similarly, the net reproductive rate (R_0) also increased from 254.62 number per female per lifetime (32°C) to 473.82 numbers per female per lifetime (34°C) and decreased at higher temperatures (112.67 and 24.82 numbers per female per lifetime at 35 and 36°C, respectively). Soh *et al.* (2018) also observed similar trend in which the gross reproductive rate of *B. brassicae* was 27.31 at 10°C and increased to 33.42 at 20°C. The net reproductive rate increased from 10.23 nymphs per female at 10°C to 24.04 nymphs per female at 20°C. However, above 20°C the net reproductive rate tend to decrease (11.06 and 0.15 nymphs per female at 25 and 30°C, respectively). Ramalho *et al.* (2015) studied the life table parameters of *Hyadaphis foeniculi* in fennel at increasing temperatures of 20, 25, 28 and 30°C. The results showed that the mean generation time decreased with increasing temperatures (23.51 days at 20°C to 9.46 days at

Table 4: Response of survival of *S. frugiperda* under different temperature regimes

Temperature	Day at 50% mortality	Regression model	r^2 value
32°C	11.90	$y = -0.0185x + 0.5533$	0.735
33°C	10.80	$y = -0.017x + 0.7656$	0.727
34°C	9.70	$y = -0.0188x + 0.7683$	0.766
35°C	5.30	$y = -0.018x + 0.5615$	0.661
36°C	4.90	$y = -0.0218x + 0.5279$	0.664

Table 5: Kinetics of life history of *S. frugiperda* under different temperature regimes

Parameters	Temperature regimes				
X ± SE	32°C	33°C	34°C	35°C	36°C
R_0	254.62 ± 46.77 ^c	374.39 ± 51.02 ^b	473.82 ± 68.43 ^a	112.67 ± 21.67 ^d	24.82 ± 7.84 ^e
r_m	0.18 ± 0.01 ^d	0.21 ± 0.01 ^c	0.24 ± 0.01 ^a	0.22 ± 0.01 ^b	0.16 ± 0.02 ^e
λ	1.19 ± 0.01 ^d	1.24 ± 0.01 ^c	1.27 ± 0.01 ^a	1.25 ± 0.01 ^b	1.17 ± 0.02 ^e
T_c	31.12 ± 0.22 ^a	27.77 ± 0.21 ^b	26.09 ± 0.22 ^c	21.25 ± 0.29 ^d	20.10 ± 0.32 ^e
GRR	645.61 ± 85.53 ^c	924.89 ± 102.86 ^b	1212.66 ± 130.17 ^a	484.13 ± 70.48 ^d	163.13 ± 43.30 ^e
DT	3.90 ± 0.07 ^a	3.25 ± 0.12 ^b	2.95 ± 0.06 ^b	3.09 ± 0.11 ^b	4.28 ± 0.12 ^a

R_0 = net reproductive rate (no./female/lifetime); r_m = intrinsic rate of increase (no./female/day); λ = finite rate of increase (no./female/day); T_c = mean generation time (days); GRR = gross reproductive rate (no./female/lifetime); DT = population doubling time (days); X = mean value; SE = standard error. Means ± SE followed by different letters in the same row are significantly different at $P < 0.05$ (ANOVA followed by Tukey's Honest Significant Difference

30°C). The population doubling time also decreased with higher temperature regimes (11.09 days at 20°C to 3.94 at 30°C). Similar results were noted in the present study where mean generation time (T) at 32°C was 31.12 days and it declined to 20.10 days at 36°C. The population doubling time (DT) also reduced from 3.90 days (32°C) to 2.95 days (34°C). The intrinsic rate of natural increase (r_m) positively responded to elevated temperature conditions. At 32°C, the r_m was 0.18 number per day and increased to 0.24 number per day at 34°C. The same trend was also observed in finite rate of increase (λ) where it was 1.19 number per day at 32°C and increased to 1.27 numbers per day at 34°C (Table 5). Mironidis (2014) studied the effect of fluctuating temperature on *H. armigera* and found that r_m showed increasing trend from 0.077 individuals per day (17.5°C) to 0.170 individuals per day (27.5°C). At 17.5°C, the finite rate of increase was 1.080 individuals per day and increased to 1.185 individuals per day at 27.5°C.

In conclusion, the results of this indicate study that the elevated temperature levels showed positive correlation with fecundity rate and negative correlation with the survival rate of *S. frugiperda*. In this study, two-sex, age-stage life table of *S. frugiperda* 32, 33, 34, 35 and 36°C, and measured population parameters, including developmental duration, survival rate, fecundity, APOP, TPOP, r_m , λ , R_0 , GRR, DT and mean generation time were established. The results indicated that *S. frugiperda* has strong reproductive potential at 34°C, and that this temperature range could result in rapid population growth. The present study demonstrated that it is vital to collect life table data at elevated temperature regimes for a comprehensive understanding of the effects of elevated temperature on pest populations and for predictive pest management.

Add-on Information

Authors' contribution: K. Ashok: Conducted the study, analysed, interpreted the data and wrote the first draft of the manuscript; V. Balasubramani: Designed the study, arranged funding, helped in interpreting the data, edited and proofread the manuscript; J. S. Kennedy: Designed the study, helped in statistical analysis and revised the manuscript; V. Geethalakshmi: Designed the study and arranged funding; P. Jeyakumar: Provided facilities for conducting experiments; N. Sathiah: Provided facilities for conducting experiments.

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