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Research Article

Degree days and demography of *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) on maize at different temperatures

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Abstract
The temperature has a direct effect on the activity of insect pests and their developmental rate. The increasing temperature could profoundly influence the population dynamics, life cycle, length of reproduction, fecundity, and longevity. In the present study, the impact of different temperatures (32, 33, 34, 35 and 36°C) on the degree days and population fitness of *Spodoptera frugiperda* (J. E. Smith) was evaluated under artificial conditions. The results showed that for *S. frugiperda,* an average of 690.38 degree days was required to complete the total life span. The total larval developmental time, pupal duration and adult longevity required 237.38, 184.47 and 228.10 degree days, respectively. The life history data of *S. frugiperda* were analysed by using TWOSEX-MSChart. An increase in temperature reduced the developmental time of *S. frugiperda* at age *x* and stage *j*. The highest reproductive value (v_x) of *S. frugiperda* was obtained at 34°C (600 individuals per day) and was found to be reduced at a further increase in temperature of 35°C (260 individuals per day) and 36°C (120 individuals per day). These results signify the improved fitness of *S. frugiperda* with increasing temperature levels, and the degree days help to predict the development pattern of *S. frugiperda* based on heat accumulation.

Keywords: Degree days, Demography, Population fitness, *S. frugiperda,* Temperature

INTRODUCTION

Insects are found and flourish in all climates. Insect development, species distribution, abundance, changes in voltinism and survival rate are all highly influenced by climate change, particularly elevated temperatures (Ashok *et al*., 2021a). Several insect pests cause significant yield loss in maize from sowing until harvest. The recently introduced pest in maize, fall armyworm *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae), is of serious concern in India due to its gregarious feeding behaviour and polyphagous nature (Kalleshwaraswamy *et al.*, 2018; Montezano *et al.*, 2018; Ganiger *et al*., 2018).
The temperature has both direct and indirect effects on hosts and herbivory. Elevated temperature influences

the biochemistry of the host and in turn affects insect pests present in host plants (Shi *et al.*, 2014). The longevity, population dynamics and fecundity rate of insects are also influenced by elevated temperature levels (Kuo *et al.*, 2006). The temperature and mean generation time of insects are highly interrelated (Bale *et al.*, 2002). Heat units expressed as degree days, derived from average temperature, are an indirect means of quantifying a biological organism's thermal environment. Each insect requires a constant amount of heat accumulation to reach certain life stages, starting from egg hatching to reproduction by adult insects. Proper use of heat units can provide a reliable means of predicting the growth and development of many crop pests (Marchioro and Foerster, 2011). Herbert *et al.* (1988) stated that approximately 425 degree days are needed for the completion of one generation in most insects. An increase in daily average temperature over a threshold or base temperature is a well-known tool in developing insect, disease and plant models (Higley *et al.*, 1986)

Calculating the developmental time of an insect about temperature has been used as a vital tool for insect pest management (Roy *et al.*, 2002). Hence, by determining the degree days for each stage of the pest, a possible prediction of insect emergence could be given as a forewarning to farmers for planning control strategies. Considering these factors, the present investigation was programmed to determine the degree day requirements and to compare the demographics of *S. frugiperda* under different temperature levels.

MATERIALS AND METHODS

Test insects and plants

The nuclear culture of *S. frugiperda* was collected from the maize fields of Tamil Nadu Agricultural University, Coimbatore. The collected insects were mass produced on a semisynthetic diet (Ashok *et al*., 2021b) at the Department of Agricultural Entomology, Coimbatore (11° 0'45" N, 76°55'57" E), and uniform fourth-generation culture of the insect was used for the present study. Maize seeds were sown in pots containing a 1:1:1 ratio of pot mixture (red soil + vermicompost + sandy soil). Irrigation was done once in a couple of days. From sowing onwards, maize plants were separately maintained at different temperature levels using open top chambers (OTCs) available at the Department of Crop Physiology, TNAU, Coimbatore.

Open top chamber (OTC)

The OTC used in the present investigation was a cubical construction with open top sides manufactured with an iron frame (4 m x 4 m x 4 m) fitted with multilayered polycarbonate sheets (4-6 mm thickness). OTC was outfitted with SCADA (Supervisory Control and Data Acquisition) integration technology. Using the SCADA system, a final control element (FCE) was fixed with a control signal from the controller received by the heaters. Ceramic IR heaters were used inside the OTC to raise the temperature to approximately 10^0C above the control (ambient condition).

Experimental details

The demographics of *S. frugiperda* were studied by growing both maize plants and *S. frugiperda* larvae at five different temperatures (32°C, 33°C, 34°C, 35°C and 36°C) within OTCs. The observations of survival, fertility and mortality were recorded at 24-hour intervals. Dead and malformed individuals were removed every day. Readings on developmental time (duration from egg to eclosion), reproductive time (longevity of adult, first and last day of oviposition), life cycle and fertility (number of individuals produced per adult female) were observed to study the developmental time, longevity and fecundity of *S. frugiperda.*

Degree days

The difference between the temperatures at which the pest was reared and the minimum threshold temperature multiplied by the duration of development equals the heat accumulation for any one temperature and is referred to as 'degree-days' (Wilson and Barnett, 1983). The degree days were calculated by using the formula given below.

Degree days = $(T - T_b)$ × Days to develop

where T is the temperature at which the pest was reared and T_b is the minimum threshold or base temperature

The temperature below which insect growth and development cease is referred to as the base temperature or lower threshold temperature. The lower developmental threshold temperature of *S. frugiperda* (10.9°C) was used as the base temperature (Ramirez Garcia *et al.*, 1987).

Statistical analysis

Life history data on the developmental time, fecundity and survival of *S. frugiperda* were obtained using the computer program TWO SEX MSChart (Chi and Liu 1985, Chi 1988; Chi and Su, 2006). The age-stage-specific survival (S_{xj}), age-specific survival rate (l_x), age-specific fecundity (m_x), age-stage-specific fecundity (f_{xj}), age-specific life expectancy (e_x) and age-specific reproductive rate (v_x) were calculated using this software.

RESULTS AND DISCUSSION

Degree day accumulation

Global climate change envisages a greater frequency and magnitude of elevated temperature and this may have a biological effect on insects (Gao *et al.*, 2018). Present experiments were conducted to study the effect of elevated temperature on the demography and thermal requirement of *S. frugiperda* in maize. The average degree day required for eggs to emerge into adults was 40.58. The degree day requirements to complete the first-, second-, third-, fourth-, fifth- and sixth-instar larvae were 37.14, 36.08, 36.08, 36.50, 37.56 and 58.03, respectively, at 32°C. In total, the larvae of *S. frugiperda* required 247.08 degree days to complete their development at 32°C. At the same time, the requirement of degree days for first-, second-, third-, fourth-, fifth- and sixth-instar larvae was 28.11, 31.63, 30.37, 33.13, 28.61 and 40.41, respectively, at 36°C. In short, the larvae of *S. frugiperda* required only 229.92 degree days to complete their development at 36°C. On average, 237.38 degree days were required to complete the larval stage. The pupal stage of *S. frugiperda* required 214.38 degree days to emerge into an adult at 32°C and it emerged as an adult when it accumulated 141.31 degree days at 36°C. The average number of degree days required was 184.47 to complete the pupal stage at 36°C. The male adult ended their life after the average accumulation of 216.29 degree days, and the female moth completed its life when it accumulated 236.55 degree days. The total lifespan of *S. frugiperda* required 757.49 degree days at 32°C and 603.66 degree days at 36°C. The average number of days that accumulated to complete the total lifespan of male and female *S. frugiperda* was 685.36 and 693.63, respectively. On average, *S. frugiperda* required 690.38 degree days to complete the total lifespan (Table 1).

Insects cultured above upper threshold temperatures

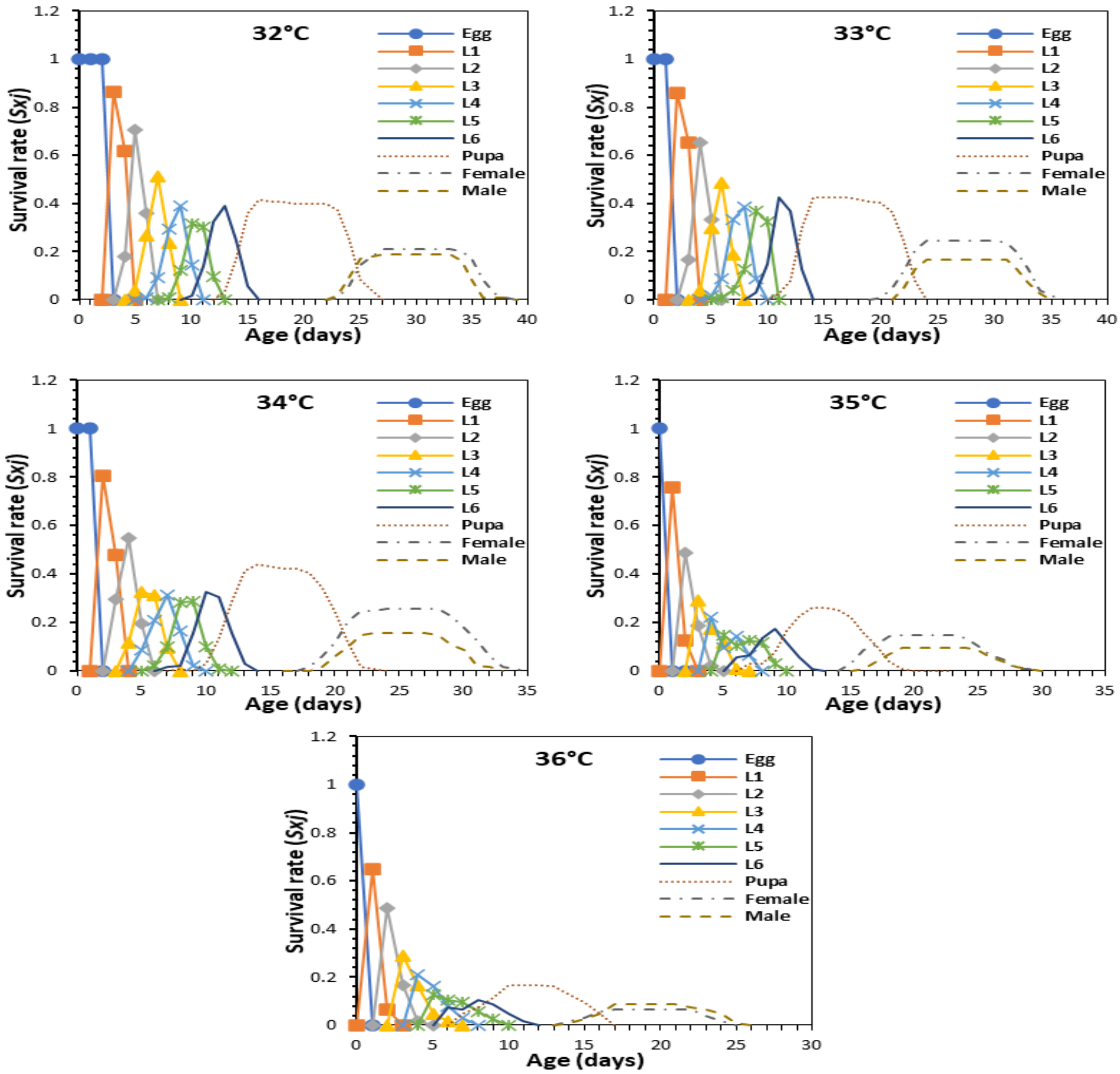


Fig. 1. *Age-stage-specific survival rate (S_{xj}) of S. frugiperda at different temperature levels*

Table 1. Accumulated degree days for *S. frugiperda* under different temperature regimes

Stage	Degree-days					
	32°C	33°C	34°C	35°C	36°C	Average
Egg	63.30	44.20	46.20	24.10	25.10	40.58
L1	37.14	38.90	36.04	27.96	28.11	33.63
L2	36.08	36.47	35.81	30.13	31.63	34.02
L3	36.08	37.13	33.03	30.37	30.37	33.40
L4	36.50	36.02	34.19	30.85	33.13	34.14
L5	37.56	39.34	38.12	37.11	28.61	36.15
L6	58.03	53.70	49.43	49.65	40.41	50.24
Larval total	247.08	245.75	234.47	229.67	229.92	237.38
Pupa	214.38	210.83	197.27	158.58	141.31	184.47
Pre adult	524.97	500.57	477.94	411.87	396.33	462.34
Male	229.36	229.40	210.21	209.43	203.04	216.29
Female	235.27	244.43	251.33	238.35	213.35	236.55
Adult longevity	232.52	238.46	235.39	226.78	207.33	228.10
Male lifespan	747.57	736.59	694.16	641.54	606.92	685.36
Female lifespan	766.14	740.79	725.11	636.72	599.39	693.63

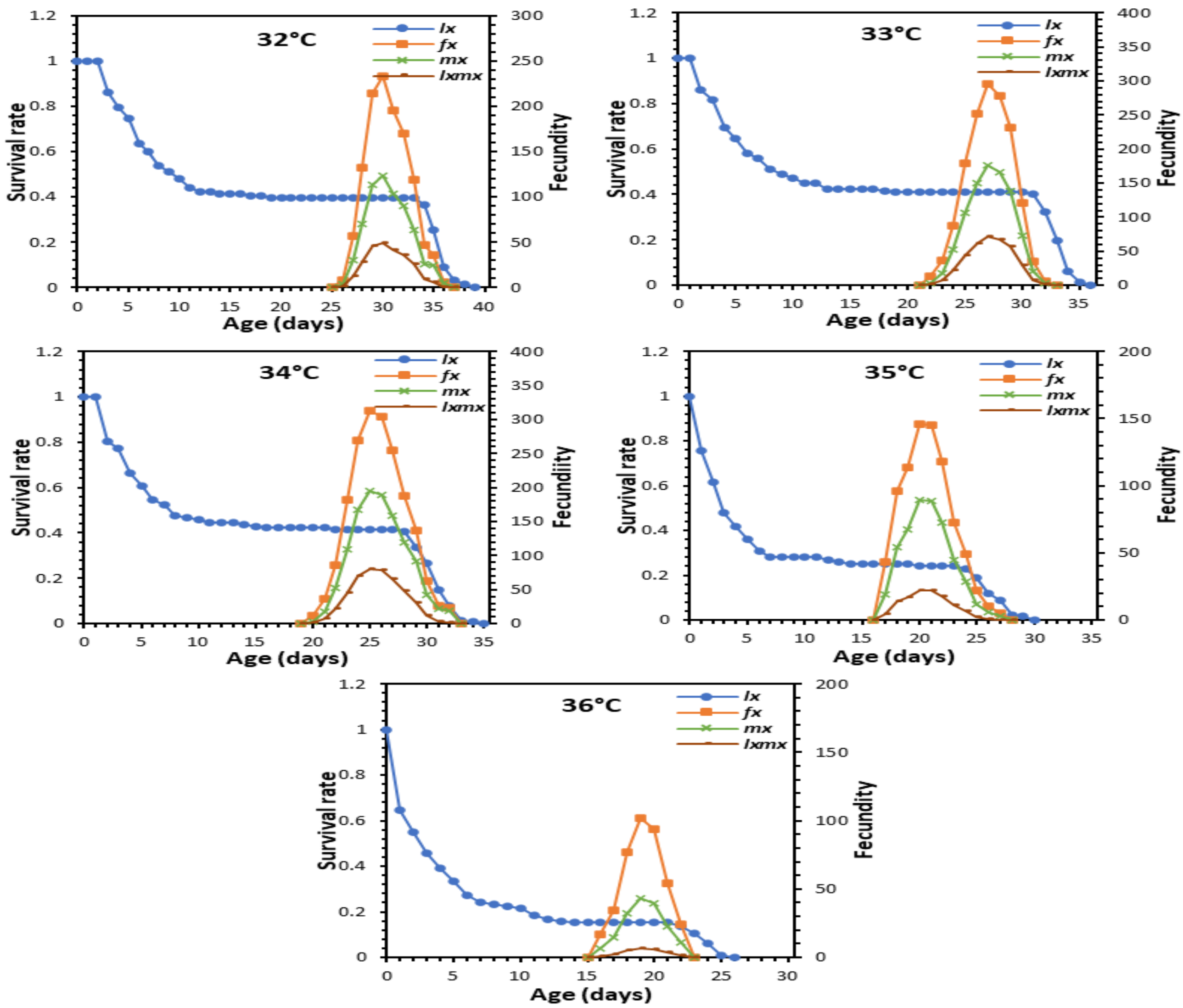
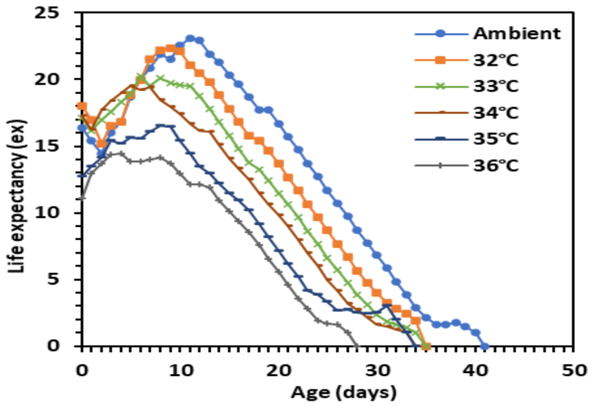


Fig. 2. *Age-specific survival rate (l_x), female age-specific fecundity (f_x), age-specific fecundity (m_x), and age-specific maternity (l_xm_x) of S. frugiperda at different temperature levels*



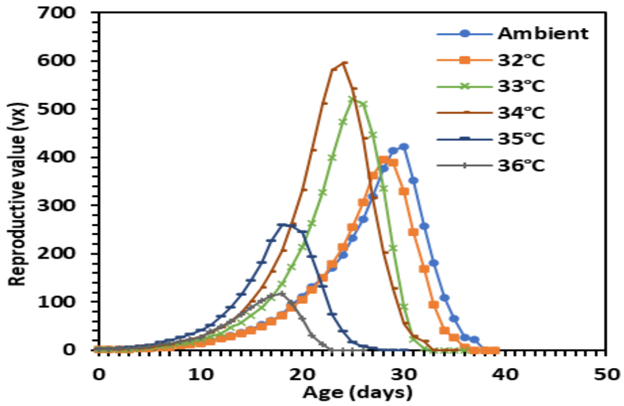


Fig. 3. *Age-specific life expectancy (e_x) and reproductive value (v_x) of S. frugiperda at different temperature levels*

show slower development than under most favourable conditions (Curry *et al.*, 1978). Degree days (DDs) are measurement units that combine time and temperature (Ascerno, 1991). Even at varying temperatures, the heat units needed to complete insect growth and development remain the same. Degree days provide a simple way to forecast the developmental time of an insect pest and hence are used in pest management decision making (Herms, 2004). A threshold temperature of 10.9°C and a requirement of 559.00 degree days to complete the life cycle of *S. frugiperda* were observed by Ramirez-Garcia *et al*. (1987). They also mentioned that *S. frugiperda* pupae require a threshold temperature of 14.6°C and 138.00 degree days.

The correlation of temperature and development of *Plutella xylostella* was studied by Golizadeh *et al.* (2007). The linear model demonstrated that *P. xylostella* required 312.5 degree-days above a lower threshold of 6.3°C to complete development. The degree day model showed that the number of diamondback moth generations in the tropical region of Brazil was near twice the number in the subtropical region of the country (Marchioro and Foerster, 2011). Khalil *et al.* (2010) recorded that the mean value of thermal units required for complete peach fruit fly generation was 491, 495 and 493 units in North Sinai, El Beheira and Asyout, respectively. Du Plessis *et al.* (2020) also recorded the number of degree days required for *S. frugiperda* egg to adult development was 391.01 degree days. Warmer temperature decreased the life span of *S. frugiperda*. Hence, a faster life cycle leads to increased population growth.

Demographic studies of *S. frugiperda*

The age-stage-specific survival rate (S_{xj}) indicates that the freshly oviposited egg of *S. frugiperda* will survive to age *x* and stage *j*. Fig. 1 depicts the survivorship curve and stage difference among individuals of *S. frugiperda* at five distinct temperature settings. The lowest S_{xj} of the adult stage was obtained at a higher temperature (36°C). When the temperature was raised from 32°C to 34°C, the m_x and $l_x m_x$ curves increased, but when the temperature was raised to 35°C and 36° C, they decreased (Fig. 2). With rising temperatures, the life expectancy of newly deposited eggs decreased. The age-specific reproductive value (v_x) indicates the fecundity level of *S. frugiperda* individuals at age *x* of the future population. The highest v_x peaks of *S. frugiperda* were observed at 34°C (Fig. 3).

The growth, development, survival and fertility of insects are influenced mainly by temperature (Koda and Nakamura, 2012; Park *et al*., 2014; Mironidis and Savopoulou-Soultani, 2014). In general, at lower temperatures, an insect's development pace slows down, resulting in a longer developmental time at all stages due to reduced metabolic rates (Benkova and Volf, 2007). The present results indicate that temperature affected the age-stage-specific survival rate (S_{xj}), age-specific survival rate (l_x), female age-specific fecundity (f_x), age-specific fecundity (m_x), age-specific maternity ($l_x m_x$), age-specific life expectancy (e_x) and reproductive value (v_x) of *S. frugiperda.* Increasing temperature resulted in the early maturity of insects observed at the highest temperature of 36°C. The results obtained might be attributed to the higher metabolic rate in *S. frugiperda* at higher temperatures.

Conclusion

The accumulated degree days are useful in scouting events such as when to place traps, when to look for damage, when to sample, etc. In the present study, *S. frugiperda* adults emerged from the pupa after accumulating 462.43 degree days from the egg stage. Therefore, effective scouting of the insects can be planned after accumulating 462.43 degree days. The biological development of insects over a period of time in correlation to accumulated degree days will provide information on key physiological events of insects, from egg hatching to adult emergence. Certain life stages of insects, such as neonates, are more susceptible to insecticide treatments. Degree days are useful in predicting these life stages. The spraying can be scheduled after the accumulation of 40.58 degree days to effectively control the larval stage of the insect. Although this information is only an approximation of a future event, it will be highly useful in planning pest management operations.

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Conflict of interest

The authors declare that they have no conflict of interest.

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