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Developmental response of *spodoptera exigua* (Noctuidae: lepidoptera) on chickpea under elevated co_2 and constant temperatures based on two - sex life table

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Abstract

The objective of this study was to examine the direct effects of two different CO_2 concentrations (380 ppm and 550 ppm) on the life table parameters of *Spodoptera exigua* at six temperatures (20, 25, 27, 30, 33 and 35 °C) fed on chickpea foliage. The life history and fitness of *S. exigua* was analyzed using two-sex life table. Our results showed significantly the development time (days) of *S. exigua* (egg to adult) declined with increase in temperature and was more evident under elevated CO_2 conditions. Additionally, the fecundity of *S. exigua* was lower under elevated CO_2 than ambient CO_2 conditions across the temperatures. Finite (l) and intrinsic rates of increase (rm), net reproductive rate (Ro), gross reproductive rate (GRR), mean generation time (T) and doubling time (DT) of *S. exigua* varied significantly with temperature and CO_2 and were found to have quadratic relationships with temperature. The reduction of 'T' was noticed from a maximum of 49.52 days at 20 °C to minimum of 20.20 days at 35 °C under elevated CO_2 conditions. According to population projections, a much smaller total population size would be expected in an elevated CO_2 atmosphere due to lower fecundity and higher mortality compared with ambient CO_2 conditions.

Keywords: *Spodoptera exigua*, development time, life table parameters, mortality, fecundity and population projection

Introduction

Climate change is the most important, complex and global environmental issue to date. Atmospheric CO_2 had reached to a concentration of 380 ppm during 2005 and has been predicted to reach up to550 ppm by 2050 and to be doubled by the end of the 21st century due to continuous high levels of fossil fuel consumption. The increase in the amount of atmospheric CO_2 would be about 40 per cent compared with pre-industrial levels of 280 ppm (IPCC, 2007 and 2013) [10, 11]. Due increasing concentrations of greenhouse gases, there is much concern about future changes in climate and its effect on the biology of living organisms including insects and agricultural crop plants (Aggarwal, 2003; IPCC, 2007) [1, 10]. The average increase in temperature between 1850 to 1990 and 2003 to 2012 was reported as 0.78 ºC (IPCC, 2013) [11]. Temperature influences the developmental rate of insects significantly and has direct effects, whereas the effect of elevated CO_2 is host-mediated and indirect (Hunter, 2001) [9]. It is well known that development rate of insects increases with temperature up to certain levels beyond which they usually decrease (Tshiala *et al.*, 2012) [22]. Quantification of the relationship between insect development and temperature is vital to predict population dynamics of the insect pests. Understanding of population dynamics of insect pests is possible with the construction of life tables which explain the impact of various factors on growth, survival and reproduction of insect populations. The life table parameters are function of various factors and differ with temperature (Hardev *et al.*, 2013) [7], larval host and diet (Sheng, 1994) [19] and CO_2 conditions (Dyer *et al.*, 2013) [5] and are more evident in case of lepidopteran insects.

The changes in temperature and CO_2 concentration can influence the growth and development of insect pests and in turn influence population dynamics and their status. Chickpea (*Cicer arietinum* L.) is a highly nutritious pulse crop and its cultivation is mainly confined to Asia, which accounts for 90 per cent of the global area. Chickpea being a C_3 crop, its response to enriched CO_2 conditions is more evident and significant. Among the biotic stresses that influence chickpea production, beet armyworm (*Spodoptera exigua* Hubner.) (Noctuidae: Lepidoptera) is an extremely destructive and economically important pest of diverse agricultural commodities throughout the world. Recently the infestation of *S. exigua* is noticed at significant levels in different states of south India and is gaining major insect pest status on chickpea.

Life table is an important research method for theoretical population dynamics and population parameters of insects. At present, life tables have been widely used to forecast pest population, evaluate various control measures, and to develop population dynamic models (Ding, 1994) [4]. Life table parameters of *S. exigua* were altered substantially in peanut (Tuan *et al.,* 2013) [23] and in non-*Bt* cotton (Prasad and Sreedhar, 2011) [18] with temperature. Studies analyzing variation of life table parameters of *S. exigua* with both temperature and CO_2 have not been attempted. This study is useful to accurately estimate and develop insect models which are central to population dynamics.

Material and Methods

Open top chambers (OTCs) for plant growing conditions

The experiments were carried out by using open top chambers (OTCs; 4 m x 4 m x 4 m) of CRIDA, Hyderabad (17 º 38' N; 78 º 47' E). Out of six open top chambers, three were maintained with elevated CO_2 (*e*CO_2; 550 ± 25 ppm) and remaining three were set with ambient CO_2 (*a*CO_2; 380 ± 25 ppm). Carbon dioxide gas was maintained at set levels in OTCs using manifold gas regulators, pressure pipelines, solenoid valves, rotameters, sampler pump, CO_2 analyzer, PC linked program Logic Control (PLC) and Supervisory Control and Data Acquisition (SCADA). CO_2 analyzer, PLC and SCADA programme with PC enable to maintain the desired level of CO_2 within the OTCs along with temperature and relative humidity sensors. The CO_2 is released into the OTCs through a perforated GI pipe fitted at the base of each chamber. The air is sampled from the canter point of the chamber through a coiled copper tube, which can be adjusted to different heights as the crop grows.

Maintenance of *Spodoptera exigua* Culture

The stock culture (neonate larvae) of *S. exigua* was obtained from the nearby chickpea crop fields, Rajendranagar, Hyderabad. The culture of *S. exigua* was maintained at optimum temperature of 27 ± 1 ºC and 75 ± 5% RH in the insectory of Entomology section, CRIDA, Hyderabad. The larvae were reared on chickpea leaves for one generation (from egg to egg) to obtain bulk population for further experimentation. Light intensity of 30, 000 Lx being provided by 26 W florescent bulb was maintained inside the chamber during the 14 hours light period with relative humidity of 60% (day) and 70% (night). Insects were reared in growth chambers (I 36LL; Percival Scientific, Inc. Perry, USA) under set conditions of 27±1 ºC, 60-70% relative humidity with a photoperiod ratio of 14: 10 (14 hours of light: 10 hours of dark). The light and illumination is provided through fluorescent lamps horizontally mounted in pairs above each shelf. Programming and control of the lighting were done *via* the Intellus Ultra real time controller.

Methodology for life table studies

Experiments on life tables were conducted at six temperatures of 20, 25, 27, 30, 33 and 35 °C both in ambient CO_2 (*a*CO_2; 380 ± 25 ppm) and elevated CO_2 (*e*CO_2; 550 ± 25 ppm) conditions. In order to construct life tables, a group of newly laid eggs of *S. exigua* were placed on a piece of wet filter paper in petridish (75 x 10 mm). These petridishes were maintained at six different temperatures at 75 ± 5% relative humidity (RH) and 14L: 10D hour's photoperiod in CO_2 growth chambers. After egg hatching, the egg period was recorded at different temperatures under both CO_2 conditions. Freshly hatched neonates (thirty) were collected and experimental trials were initiated. Freshly hatched thirty neonates were reared individually in petridishes (75 x 10 mm) till the adult stage. Larvae were fed with fresh chickpea foliage collected from the plants grown in OTCs at two CO_2 levels *i.e., e*CO_2 and *a*CO_2 conditions. The data on durations of egg, larval, pupal and adult and total development periods (TDP) at each temperature under *e*CO_2 and *a*CO_2 conditions were recorded. The relationship between developmental period (by stage) and temperature was analysed by using one-way ANOVA.

Calculation of life table parameters

TWO-SEX MS Chart software (Chi, 2005) was adopted for calculating various life table parameters using the raw data of insect stages. The theory of age-stage, two-sex life table was implied while analyzing the raw life history data of *S. exigua*. For life table analysis, Bootstrap method, a user-friendly computer program was developed using the age-stage specific survival rate (sxj, where x = age and j = stage), the age-stage specific fecundity (fxj: number of eggs produced at each age), the age-specific survival rate (lx), the age specific fecundity (mx: eggs produced per surviving individual at each age o fecundity).

Observations on Intrinsic rate of increase (r_m: the rate of progeny production per female per day), Finite rate of increase (λ: the number of individuals added to the population per head per unit time or number of births per female per day), Net reproductive rate (Ro: the number of times that the population would multiply by the end of each generation), Gross reproductive rate (GRR) and Mean generation time (T: the time required to complete a generation) were estimated at six temperatures under *e*CO_2 and *a*CO_2 conditions.

Results and Discussion

Durations of different growth stages of *S. exigua*

The durations of different growth stages *S. exigua* were significantly affected by temperatures and CO_2 concentrations. The results pertaining to the variation in durations of egg, larva, pupa and adult stages of *S. exigua* on chickpea at six temperatures of 20, 25, 27, 30, 33 and 35°C and the two test CO_2 conditions *viz*., ambient CO_2 (*a*CO_2; 380 ± 25 ppm) and elevated CO_2 (*e*CO_2; 550 ± 25 ppm) were presented in Table 1.

Spodoptera exigua successfully developed to the adult stage at temperatures 20 °C to 35 °C under both *e*CO_2 and *a*CO_2 conditions. The incubation period did not vary significantly among the varying temperatures and CO_2 concentrations. Development time of *S. exigua* (Egg to adult) declined with increase in temperature and was more evident under *e*CO_2 conditions. The durations of egg (5.20 to 2.00 days), larva (24.60 to 9.45 days), pupa (15.45 to 5.60 days), adult (11.50 to 5.40 days) and total developmental periods (56.75 to 22.45 days) decreased from 20 to 35 °C temperature under *e*CO_2 conditions. Similar trend of reduction of development period with increasing temperature was noticed under *a*CO_2 conditions. Moreover, temperature had a significant influence on larval durations of *S. exigua.* The larval period was decreasing with increasing temperature from 15 to 35 °C under both *e*CO_2 and *a*CO_2 conditions. Thus, the larval period increased one (or) two days under *e*CO_2 compared to that of *a*CO_2 conditions at the tested temperatures. Similarly, total development period (TDP) was inversely related to temperature. It means the development period of *S. exigua* decreased with increasing temperature from 15 to 35°C under both eCO_2 and aCO_2 conditions.

In nature, many biotic and abiotic factors affect the life tables of insect populations. Temperature is the most important and critical abiotic factor exerting profound influence on growth and development of insects. The effects of temperature on insects are species specific. The effects of climate change on insect pests can be both direct (temperature) and indirect (CO_2) on different life history parameters *viz.*, durations of different growth stages and fecundity. Increase in temperature will have a greater effect on insects than the rising CO_2 concentrations (Harrington *et al*., 2001) [8]. The reduction of duration of an insect occurs with increasing temperature (Tomaso *et al*., 2007) [21].

The present results are in conformity with the findings of Manimanjari *et al*. (2014), who reported that the reduction in durations of egg, larva, pupa, adult and total development period of *S. litura* was observed with increase in temperature under both eCO_2 and aCO_2 conditions. Mean developmental time of egg (7.61 to 3.32 days), larva (29.8 to 12.87 days), pupa (16.46 to 7.93 days), adult (5.33 to 3.67 days) and total development period (59.2 to 27.8 days) decreased from 20 to 35 °C temperature under eCO_2 conditions. Similarly under aCO_2 conditions, the development period for egg (7.53 to 3.68 days), larva (27.60 to 13.13 days), pupa (16.80 to 6.66 days), adult (7.0 to 2.6 days) and total development period (58.93 to 26.06 days) from 20 to 35 °C. Similar results have been reported by Srinivasa Rao *et al*. (2014), who reported that the reduction in durations of egg, larva, pupa, adult and total development period of *S. litura* with increase in temperature under both eCO_2 and aCO_2 conditions. Karimi-Malati *et al.* (2014a) [13] reported that the egg period decreased with increasing temperature and varied from 5 days at 20 °C to 2 days at 30 and 33 °C and the development time of the immature stages ranged from 41.63 to 14.5 days at 20 °C and 33 °C, respectively. The present results are in conformity with Dai *et al*. (2017) [3] who showed that at 20~35 ℃, the development duration of *S. exigua* reduces with the temperature. At 20 °C, the egg, the different larval stages, the pupa and the entire generation have the longest development duration, followed by 25, 27 and 30 °C, whereas at 35 °C it has the shortest development duration. The total developmental time for *S. exigua* at 25 - 26 °C has been reported to be 20.2–26.4 days (Greenberg *et al.*, 2001), 24.71–33.2 days (Saeed *et al*., 2010) and 21.63–27.22 days (Farahani *et al.*, 2011) [6] on different host plants. Similar decrease in development period with an increase in temperatures was reported in case of other lepidopteran insect pests like *Cnaphalocrocis medinalis* Guenee. (Padmavathi *et al*., 2013) and *Elasmopalpus lignosellus* Zeller. (Hardev *et al*., 2013) [7].

Results indicated that the growth and development of *S. exigua* were significantly influenced by temperature and CO_2 concentrations. Both lower and higher temperatures inhibited the development of insect pest and the ideal conditions for the growth of the pest are at 25 and 27 °C temperature. This study provides the biological response of *S. exigua* to a wide range of temperatures to predict its population dynamics under filed conditions.

The fecundity of *S. exigua* did not vary significantly among the test temperatures and CO_2 concentrations ($F_{3,\ 29}$ = 1.28, P =>0.05) are showed in Table 2. Fecundity of 390.50, 428.20, 456.60, 355.30, 291.20 and 207.80 eggs/ female were recorded under eCO_2 conditions as against 428.10, 476.50, 505.60, 406.20, 352.10 and 253.40 eggs/female under aCO_2 conditions at 20, 25, 27, 30, 33 and 35°C, respectively. The highest fecundity was noticed under aCO_2 (505.60 eggs) than eCO_2 (456.60 eggs) conditions at 27 °C.

The results showed that the highest fecundity occurred at 27 °C, which was not significantly different from that observed at other temperatures. Present results are in agreement with the results of Karimi-Malati *et al*. (2014b) [14], who reported that the fecundity of *S. exigua* on sugar beet was 796.42, 899.10, 613.16 and 494.32 eggs at 20, 25, 30 and 33 °C, respectively. Fye and McAda (1972) reported that the highest fecundity of the beet armyworm was 1,521.9 eggs at 20 °C and followed by 874.8 eggs at 25 °C. Similarly, Liu *et al*. (2017) [15] noticed the mean number of hatched eggs was highest under aCO_2 conditions than that under eCO_2 conditions.

Life table parameters of *S. exigua*

The results pertaining to the life table parameters of *S. exigua viz*., intrinsic rate of increase (r_m), finite rate of increase (λ), net reproductive rate (Ro), gross reproductive rate (GRR) and mean generation time (T) were varying among the tested temperatures and CO_2 concentrations were presented in Table 3.

The r_m and λ increased with increase in temperatures from 20 - 33 °C and declined with further increase in temperature which is a polynomial trend under eCO_2 and aCO_2 conditions. Higher r_m and λ were recorded under eCO_2 conditions (0.20 and 1.22 day^{-1}) as against aCO_2 conditions (0.22 and 1.25 day^{-1}) at 33 °C, respectively, whereas lower r_m and λ were recorded under eCO_2 conditions (0.09 and 1.09 day^{-1}) as against aCO_2 conditions (0.10 and 1.10 day^{-1}) at 20 °C, respectively. R_O and GRR increased with increase in temperatures from 20 to 27 °C and declined with further increase in temperature from 30 to 35 °C which is a polynomial trend under eCO_2 and aCO_2 conditions. Higher R_O and GRR were recorded under eCO_2 conditions (114.23 and 122.26 off-springs/female) as against aCO_2 conditions (123.40 and 134.21 off-springs/female) at 27 °C, respectively, whereas lower R_O and GRR were recorded under eCO_2 conditions (51.92 and 68.94 off-springs/female) as against aCO_2 conditions (63.35 and 84.95 off-springs/female) at 35 °C, respectively. The T was decreased with increasing temperatures from 20 to 35°C. Reduction of 'T' was observed from maximum of 49.52 days at 20 °C to minimum 20.20 days at 35°C under eCO_2 as against aCO_2 conditions (Figure 1a & 1b).

From the present findings it was understood that the 'r_m' and 'λ' increased with increase in temperature from 20 to 33 °C and later declined at 35 °C. The 'r_m' gradually increases with temperature till some threshold; thereafter it decreases (Hardev *et al.*, 2013) [7]. Decrease in development time with increase in temperature causes increase in 'r_m' (Iranipour *et al.*, 2010) [12]. The 'Ro' of *S. exigua* was higher at 27 °C by recording maximum offspring and 'Ro' decreased with increase in temperature due to less fecundity at higher temperatures. The higher fecundity is the reason for higher R_o at 27 °C compared with 20 °C and 25 °C. The reduction of 'T' was noticed from maximum value of 49.52 days at 20 °C to minimum of 20.20 days at 35 °C and followed the trend of non-linearity at eCO_2 conditions. The findings of the present study are in agreement with Tuan *et al*. (2013) [23] who reported 'r_m' values of *S. litura* in the range of 0.13 to 0.18 day^{-1} on peanut.

The present life history parameters of *S. exigua* were in conformity with the findings of Srinivasa Rao *et al.* (2014) [20] who reported that the finite (λ), intrinsic rates of increase (r_m), net reproductive rate (Ro) and mean generation time (T) of *S. litura* varied with temperature and CO_2 as estimated by the bootstrap technique. Under *e*CO_2 conditions, the range of r_m (0.13 - 0.27), λ (1.14 - 1.264) and T (50.59 - 22.23 days) were noticed from 20 to 35 °C. The 'Ro' of *S. litura* was higher at 27 °C by recording 944.12 off-springs as compared to *a*CO_2 (753 off-springs). Similarly, Manimanjari *et al.* (2014) [16, 20] reported the finite, intrinsic rates of increase, net reproductive rate and mean generation time of *S. litura* increased significantly with temperature up to 27 to 30 °C and decline with further increase in temperature.

Table 1: Effect of elevated temperatures and CO_2 concentrations on the duration of different growth stages of *S. exigua* on chickpea

Temp (°C)	Egg period (days)		Larval period (days)		Pupal period (days)		Adult period (days)		Total development period (days)	
	***a*CO₂ (380 ppm)**	***e*CO₂ (550 ppm)**	***a*CO₂ (380 ppm)**	***e*CO₂ (550 ppm)**	***a*CO₂ (380 ppm)**	***e*CO₂ (550 ppm)**	***a*CO₂ (380 ppm)**	***e*CO₂ (550 ppm)**	***a*CO₂ (380 ppm)**	***e*CO₂ (550 ppm)**
25	3.35 ± 0.49	3.40 ± 0.50	14.05 ± 0.69	15.95 ± 0.67	9.00 ± 0.73	8.55 ± 0.61	9.70 ± 0.77	9.50 ± 0.92	36.10 ± 1.29	37.40 ± 1.23
27	3.00 ± 0.00	3.00 ± 0.00	12.80 ± 0.41	14.80 ± 0.50	7.85 ± 0.88	8.10 ± 0.79	9.10 ± 0.75	8.80 ± 0.79	32.75 ± 1.16	34.85 ± 1.23
30	2.55 ± 0.51	2.65 ± 0.49	9.45 ± 0.51	11.50 ± 0.94	7.05 ± 1.28	7.45 ± 0.69	8.75 ± 0.75	7.85 ± 0.64	27.80 ± 1.70	29.35 ± 1.09
33	2.00 ± 0.00	2.00 ± 0.00	8.70 ± 0.80	10.30 ± 0.66	6.20 ± 0.95	6.85 ± 0.88	7.10 ± 0.83	6.80 ± 0.79	24.00 ± 1.70	25.95 ± 1.10
35	2.00 ± 0.00	2.00 ± 0.00	9.05 ± 0.69	9.45 ± 0.51	5.40 ± 0.68	5.60 ± 0.68	5.70 ± 0.75	5.40 ±0.66	22.15 ± 1.27	22.45± 0.95
F test	0.72^{NS}		8.67**		2.43**		1.18^{NS}		2.56**	
S.Em ±	0.10		0.23		0.27		0.24		0.43	
CD (p=0.05)	NS		0.46		0.53		NS		0.86	
CV (%)	11.41		6.61		11.65		9.43		5.06	

aCO_2 = Ambient CO_2; *e*CO_2 = Elevated CO_2
All values are mean ± standard deviation
**Significant @ 5% level of significance
NS = Non-significant

Table 2: Effect of elevated temperatures and CO_2 concentrations on the duration of different growth stages of *S. exigua* on chickpea

Temperature (°C)	Fecundity	
	*a*CO₂ **(380 ppm)**	*e*CO₂ **(550 ppm)**
20	428.10 ±35.17	390.50 ± 9.02
25	476.50 ±15.33	428.20 ± 7.07
27	505.60 ± 4.15	456.60 ± 5.60
30	406.20± 10.88	355.30 ± 7.63
33	352.10 ± 8.17	291.20 ± 7.28
35	253.40 ± 3.89	207.80 ± 5.43
F test	1.28^{NS}	
S.Em ±	6.21	
CD (P = 0.05)	NS	
CV (%)	3.97	

aCO_2 = Ambient CO_2; *e*CO_2 = Elevated CO_2
All values are mean ± standard deviation
**Significant @ 5% level of significance
NS = Non-significant

Table 3: Effect of elevated temperatures and CO_2 on life table parameters of *S. exigua* on chickpea

Temp. (⁰C)	Intrinsic rate of increase (r_m, day^{-1})		Finite rate of increase (λ, day^{-1})		Net reproduction rate (Ro, offsprings/ female)		Gross reproductive rate (GRR, offsprings/ female)		Mean generation time (T, days)	
	*a*CO₂ **(380 ppm)**	*e*CO₂ **(550 ppm)**	*a*CO₂ **(380 ppm)**	*e*CO₂ **(550 ppm)**	*a*CO₂ **(380 ppm)**	*e*CO₂ **(550 ppm)**	*a*CO₂ **(380 ppm)**	*e*CO₂ **(550 ppm)**	*a*CO₂ **(380 ppm)**	*e*CO₂ **(550 ppm)**
20	0.10 ± 0.01 (0.000022)	0.09 ± 0.004 (0.000025)	1.10 ± 0.01 (0.000031)	1.09 ± 0.01 (0.000030)	109.28 ± 24.27 (589.05)	98.32 ± 22.16 (491.14)	135.99 ± 28.51 (812.73)	109.42 ± 23.60 (556.87)	48.61 ± 0.53 (0.29)	49.52 ± 0.38 (0.15)
25	0.16 ± 0.01 (0.000061)	0.15 ± 0.01 (0.000063)	1.17 ±0.01 (0.000082)	1.16 ± 0.01 (0.000084)	119.77 ± 23.82 (567.29)	107.05 ± 23.96 (574.56)	123.51 ± 26.12 (684.60)	118.97 ± 26.34 (693.89)	29.81 ± 0.31 (0.09)	31.38 ± 0.31 (0.10)
27	0.18 ± 0.01 (0.000080)	0.16 ± 0.01 (0.000074)	1.19 ± 0.01 (0.00011)	1.18 ± 0.01 (0.00010)	123.80 ± 27.51	114.23 ± 25.60	134.21 ± 29.12 (847.93)	122.26 ± 27.25	27.61 ± 0.29	29.11 ± 0.32

					(757.02)	(655.17)		(742.77)	(0.08)	(0.14)
30	0.20 ± 0.11 (0.00013)	0.18 ± 0.01 (0.00011)	1.23 ± 0.01 (0.00019)	1.20 ± 0.01 (0.00016)	101.55 ± 22.65 (512.84)	88.83 ± 19.72 (388.98)	120.04 ± 26.51 (702.57)	103.04 ± 22.93 (525.65)	22.59 ± 0.38 (0.14)	24.61 ± 0.47 (0.22)
33	0.22 ± 0.01 (0.00016)	0.20 ± 0.01 (0.00013)	1.25 ± 0.02 (0.00024)	1.22 ± 0.01 (0.00020)	88.02 ± 19.76 (390.41)	72.12 ± 15.99 (255.69)	104.37 ± 23.82 (567.47)	107.27 ± 24.17 (584.29)	20.07 ± 0.24 (0.06)	21.87 ± 0.37 (0.13)
35	0.21 ± 0.01 (0.00018)	0.19 ± 0.01 (0.00015)	1.24 ± 0.02 (0.00027)	1.21 ± 0.02 (0.00023)	63.35 ± 14.21 (202.00)	51.92 ± 11.58 (134.05)	84.95 ± 18.99 (360.44)	68.94 ± 12.85 (165.00)	18.95 ± 0.31 (0.10)	20.20 ± 0.28 (0.08)

All values are mean ± standard deviation
Figures in parentheses are variance values

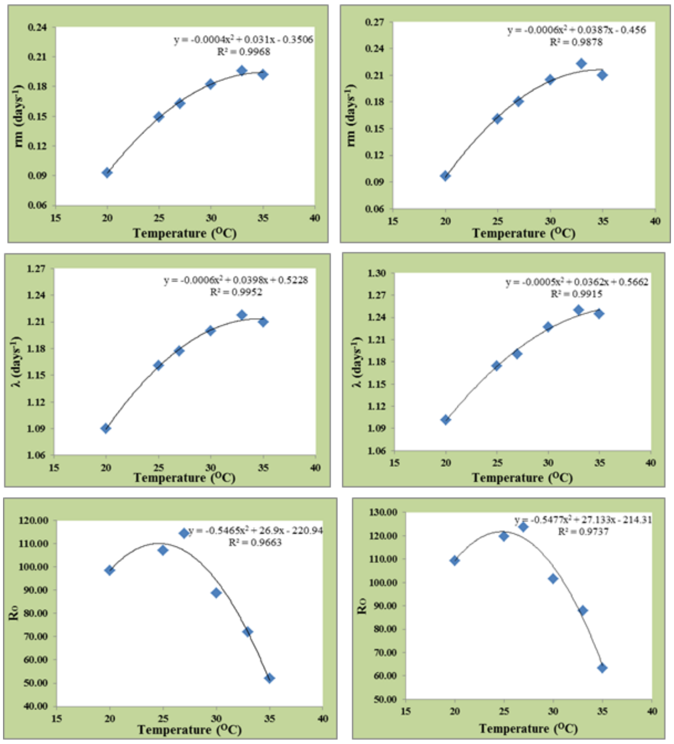

Fig 1a: Effect of elevated temperatures and CO_2 concentrations on intrinsic rates of increase (r_m), intrinsic rates of increase (λ) and net reproductive rate (R_O) of *S. exigua* on chickpea

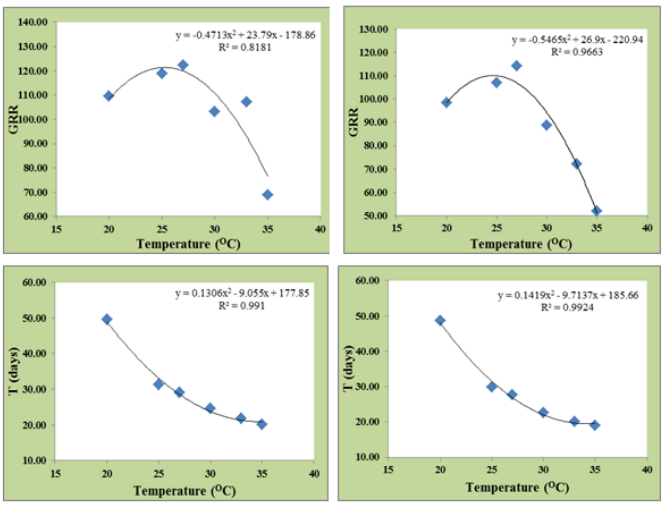

Fig 1b: Effect of elevated temperatures and CO_2 concentrations on gross reproductive rate (GRR) and mean generation time (T) of *S. exigua* on chickpea

Conclusions

It concluded that the association between temperature and life table parameters was non-linear and were best fit. Many empirical models by incorporating 'r_m' as a key parameter were used for prediction of population dynamics of insect pests. Temperature-driven phenology models developed using laboratory information can be used for projection of status of future insect population. This approach offers a promising tool for pest management.

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