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Temperature- and CO_2-Dependent Life Table Parameters of *Spodoptera litura* (Noctuidae: Lepidoptera) on Sunflower and Prediction of Pest Scenarios

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ABSTRACT. Predicted increase in temperature and atmospheric CO_2 concentration will influence the growth of crop plants and phytophagous insects. The present study, conducted at the Central Research Institute for Dryland Agriculture, Hyderabad, India, aimed at 1) construction of life tables at six constant temperatures *viz*., 20, 25, 27, 30, 33, and 35 ± 0.5°C for *Spodoptera litura* (Fabricius) (Noctuidae: Lepidoptera) reared on sunflower (*Helianthus annus* L.) grown under ambient and elevated CO_2 (eCO_2) (550 ppm) concentration in open top chambers and 2) prediction of the pest status in near future (NF) and distant future (DF) climate change scenarios at major sunflower growing locations of India. Significantly lower leaf nitrogen, higher carbon and higher relative proportion of carbon to nitrogen (C:N) were observed in sunflower foliage grown under eCO_2 over ambient. Feeding trials conducted on sunflower foliage obtained from two CO_2 conditions showed that the developmental time of *S. litura* (Egg to adult) declined with increase in temperature and was more evident at eCO_2. Finite (λ) and intrinsic rates of increase (r_m), net reproductive rate (R_o), mean generation time, (T) and doubling time (DT) of *S. litura* increased significantly with temperature up to 27–30°C and declined with further increase in temperature. Reduction of '*T*' was observed from maximum value of 58 d at 20°C to minimum of 24.9 d at 35°C. The DT of population was higher (5.88 d) at 20°C and lower (3.05 d) at 30°C temperature of eCO_2. The data on these life table parameters were plotted against temperature and two nonlinear models were developed separately for each of the CO_2 conditions for predicting the pest scenarios. The NF and DF scenarios temperature data of four sunflower growing locations in India is based on PRECIS A1B emission scenario. It was predicted that increased 'r_m', 'λ', and 'R_o' and reduced '*T*' would occur during NF and DF scenario over present period at all locations. The present results indicate that temperature and CO_2 are vital in influencing the population growth of *S. litura* and pest incidence may possibly be higher in the future.

Key Words: phytophagous insect, developmental time, insect pest, climate change, PRECIS

Global mean surface temperature has increased since the 19th century, each of the past three decades has been warmer than all previous decades, with the decade of the 2000's being the warmest so far. The increase in temperature between the average of the 1850–1990 period and the 2003–2012 period is 0.78 (0.72–0.85) °C and the amount CO_2 in the atmosphere has grown by about 40% over preindustrial levels (IPCC Climate Change 2013). The impacts of predicted increases in global average surface temperatures and atmospheric CO_2 concentrations on insect-plant interactions have been studied separately, only a few studies have considered them together (Murray et al. 2013). Temperature influences the developmental rate of insects significantly and has direct effects, whereas the effect of elevated CO_2 (eCO_2) is host-mediated and indirect (Hunter 2001). It is well known that developmental rates increase with temperature up to certain levels beyond which they usually decrease (Tshiala et al. 2012). The most predicted effects of climate change, i.e., increase in atmospheric temperature and CO_2 concentration, will have a significant effect on agriculture in general and on herbivore insect populations in particular. Quantification of the relationship between insect development and temperature is vital to predict population dynamics of the insect pests.

Sunflower (*Helianthus annuus* L.), is one of the most important edible vegetable oil crops in the world. Sunflower oil is a frying oil, light in taste, appearance, and contains typical vegetable tri-glycerides with vit E (http://en.wikipedia.org/wiki/sunflower).The Russian federation, Ukraine, Argentina, China, and France are the major sunflower growing countries (http://faostat.fao.org). India stands in the 14th position in the world production with an average annual production of 5.17 million tons (http://agricoop.nic.in) from 7.32 m ha area with an average yield of 706 kg per ha. It is an introduced crop in India and the pest complex is different from temperate regions. The tobacco caterpillar, *Spodoptera litura* Fab. (Lepidoptera: Noctuidae) is a major pest of sunflower (Basappa and Santhalakshmi 2005) and causes significant yield losses. Larvae cause severe defoliation during flower initiation stage leading to reduced supply of assimilates to the capitulum thereby affecting floret and seed production (Sujatha and Lakshminarayana 2007). Temperature (Ranga Rao et al. 1989) and CO_2 (Srinivasa Rao et al. 2012) are known to alter the growth and development of *S. litura.*

Life tables are important tools for understanding the population dynamics of insect pests and explain the impact of various factors on the growth, survival, and reproduction of insect populations. Variation of life table parameters of lepidopterans (intrinsic rate of increase 'r_m' and finite rate of increase 'λ') with temperature (Hardev et al. 2013), larval host and diet (Sheng 1994) and eCO_2 (Dyer et al. 2013) have been reported. Life table parameters of *S. litura* were altered substantially in peanut (Tuan et al. 2013) and in non-*Bt* cotton (Prasad and Sreedhar 2011) with temperature. Studies analyzing variation of life table parameters with both temperae and CO_2 have not been attempted. The objectives of our study were 1) to measure the effect of constant temperatures and eCO_2 on life table parameters of *S. litura* on sunflower and 2) to predict the pest status during near future (NF) and distant future (DF) climate change scenarios.

Materials and Methods

Open Top Chambers. Two square open top chambers (OTC) of 4 × 4 × 4 m, were constructed at the Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad (17.38° N; 78.47°E), one

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for maintaining eCO_2 at concentrations of 550 ± 25 ppm and another one for ambient CO_2 (aCO_2) concentrations (380 ± 25 ppm CO_2). Chambers were replicated twice making a total of four OTCs for experimentation. Carbon dioxide gas was supplied to chambers and maintained at set levels using manifold gas regulators, pressure pipelines, solenoid valves, rotameters, a sampler, a pump, a CO_2 analyzer, a PC-linked Program Logic Control (PLC) and Supervisory Control and Data Acquisition (SCADA). The fully automated control and monitoring system includes a CO_2 analyzer PLC and SCADA programme with PC that enabled the maintenance of desired levels of CO_2 within the OTCs. The system monitored continuously the concentration of CO_2, temperature, and relative humidity (RH) within the OTCs. The air was sampled from the centre point of the chamber through a coiled copper tube, which can be adjusted to different heights as the crop grows.

Sunflower (Var. KBSH-1) seeds were sown in the month of June in the four OTCs at two different CO_2 concentrations and crop plants were maintained during entire crop season till December.

Biochemical Constituents of Sunflower Foliage. Leaf tissue used in the feeding experiments was analyzed for carbon, nitrogen, and C: N ratio. To determine carbon and nitrogen concentrations, samples were dried at 80°C and subsequently ground to powder. Leaf carbon and nitrogen were measured using a CHN analyzer (Model NA 1500 N, Carlo Erba Strumentazione, Italy) using standard procedures (Jackson 1973).

Insects. Egg masses of *S. litura* were collected from the field and maintained at the entomology laboratory of CRIDA. The cultures were maintained in a growth chamber (PERCIVAL I-36LL, Perry, Iowa, USA). Stock cultures were maintained on leaves of sunflower plants grown under open field condition. RH was maintained at 60% during the day and at 70% during the night. Temperatures were maintained at 27 ± 1°C and a photoperiod of 14:10 (L:D) h.

Developmental Rate. Groups of newly laid eggs of *S. litura* (N ≥ 100) were placed in closed Petri dishes of 110 mm diameter and 10 mm height with a piece of wet filter paper to maintain humidity. Petri dishes were maintained at six constant temperatures (20, 25, 27, 30, 33, and 35 ± 0.5°C) at 75 ± 5% RH and a photoperiod of 14:10 (L:D) h in CO_2 growth chambers. The eggs were observed daily and the wet filter paper was replaced as required. The total number of eggs hatching at each temperature and the duration of egg development were recorded. After hatching of eggs, neonates were collected and feeding trials were initiated. At 10:00 am on the day of initiating the feeding trial, freshly hatched neonates were placed in petri dishes of 110 mm diameter and 10 mm height. Ten neonates were kept in each petri dish, forming one replication later larvae were transferred in each petri dish and tracked as a single replication till adult stage (egg laying). In total, 10 replications were used. Moistened filter papers were kept at the bottom of the petri dishes to maintain leaf turgidity. Neonate larvae were fed with tender sunflower leaves picked from plants grown under the two CO_2 concentrations in the OTCs. Fresh leaves were provided daily in the morning. Daily data were recorded corresponding temperature condition. Every day, larvae were provided with sunflower foliage obtained from eCO_2 and aCO_2 conditions separately and this was repeated throughout the experiment up to larval period. Mean larval period was recorded and after cessation of feeding, pre-pupae were collected and transferred to glass jars. Later pupae were collected from the respective treatments and pupal periods were noted according to the treatments. After the emergence of adults from pupae, moths were paired and each pair was kept in a separate plastic container and fed with 10% honey solution. Egg masses laid were collected separately and counted.

A visible exuvia was used as an evidence of molting when observed along with frass of developing larvae. Observations were recorded daily in order to measure survival and developmental time of each larval instar and pupa until adults emerged. After the emergence of adults, their sex ratio was also recorded. The number of eggs laid per female, longevity of adults, and total life span (TLS) at each temperature were recorded. All growing conditions (RH, photoperiod and fresh leaves as food source) were maintained as described above.

Life Table Parameters. Life table parameters were estimated by using TWOSEX–MS Chart software which groups the raw data and calculates a number of life-table parameters. The r_m as a composite index of growth, development, and fecundity of the whole population was estimated by using the iterative bisection method from the Duler-Lotka formula $\sum_{x=0}^{\infty} e^{-r(x+1)} l_x m_x = 1$ (Chi 2005). The raw life history data of *S. litura* were analyzed based on the theory of age-stage, two-sex life table. The means and SEs of the life table parameters were estimated by using the Jackknife method. To facilitate life table analysis, a user-friendly computer program, TWOSEX-MS-Chart was adopted (Chi 2005).

The life table parameters were estimated using sunflower foliage from eCO_2 and aCO_2 separately six temperatures and were plotted against temperature to compare the thermal sensitivities of parameters. Among different forms of distribution, a nonlinear (polynomial) relationship was observed against temperatures and was found to be the best fit equation. Two nonlinear models were developed separately for each of the CO_2 conditions and used for predicting the pest scenarios at four locations of the country.

Pest Scenarios. Data of historical daily temperatures (maximum and minimum) for four study locations *viz*., Akola (20° 42′ N, 77° 2′ E); Bangalore (12° 58′ N, 77° 35′ E); Hyderabad (17° 18′ N, 78° 60′ E); and Raichur (16° 12′ N, 77° 25′ E) were collected from a 1 × 1 degree grid database provided by the India Meteorological Department (http://www.imd.gov.in/doc/nccraindata.pdf) for the period 1991–2005 referred to as present (PR) period in this research. The future data was obtained using PRECIS model. A number of global circulation models with their corresponding versions of downscaled projections at a relatively smaller spatial resolution are available and the projections vary from the parent GCM (Krishna Kumar et al. 2011). In this article, we chose to use the projections obtained at a resolution of 50 × 50 km grid using the PRECIS where the daily data on maximum temperature, minimum temperature, and rainfall are available. The output for the A1B emission scenario showing 'reasonable skill in simulating the monsoon climate over India' (Krishna Kumar et al. 2011) was considered. A1B is 'the most appropriate scenario as it represents high technological development, with the infusion of renewable energy technologies following a sustainable growth trajectory' (MoEF 2012).The future temperature data thus obtained were classified into two categories *viz*., 'NF consisting of 2,021–2,050 and DF consisting of 2,071–2,098. The daily data during the crop duration of 133 days commencing from 26 to 44 Standard Weeks was considered for predicting the life table parameters of *S. litura* in future as pest scenarios.

Statistical Analysis. The data on developmental rate of each stage of insect pest at six constant temperatures and two CO_2 conditions were analysed by using one-way analysis of variance (ANOVA). Results presented are mean value of each determination (treatment) ± standard deviation (SD). The differences between mean values of treatments were determined by Tukey's test and the significance was defined at $P < 0.05$. The mean values of life table parameters of *S. litura* across four locations for the three periods *viz.,* present, near and future periods were compared using two-sample *t*-test assuming equal variances. The significance of mean values was defined at $P < 0.01$. All statistical analyses were done using SPSS version 16.0.

Results

Biochemical Analysis of Sunflower Foliage. In this study, the nutritional quality of sunflower leaves differed significantly at eCO_2 and aCO_2 concentrations. Leaf nitrogen content was distinctly lower (2.67 %) in elevated compared with ambient (2.81%). However, with increased CO_2 concentrations, the carbon content of leaf tissue increased significantly (41.63 %) over aCO_2 which recorded 38.63 %. This resulted in a significant increase in C: N ratio under eCO_2 conditions (15.60) compared with ambient (13.76) (Table 1).

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Table 1. Change in bio chemical constituents of sunflower foliage grown under eCO_2 and aCO_2

Biochemical constituents	CO_2 Concentrations		F(P)	LSD
	eCO_2	aCO_2		$P \leq (0.05)$
Nitrogen %	2.67 ± 0.10	2.81 ± 0.12	16.19 ($P \leq 0.01$)	0.091
Carbon %	41.63 ± 0.95	38.63 ± 0.83	46.71 ($P \leq 0.01$)	1.129
C:N ratio	15.60 ± 0.42	13.76 ± 0.59	61.17 ($P \leq 0.01$)	0.606

Mean values ± SD.

Table 2. Developmental time (days) of different stages of *Spodoptera litura* on sunflower at six constant temperatures and two CO_2 conditions

Temperature °C	Developmental time at eCO_2					
	Egg	Larva	Pupa	Adult	Fecundity	Total life span
20	7.61 ± 0.51a	29.80 ± 2.21a	16.47 ± 1.73a	5.34 ± 1.00a	1,769 ± 549b	59.20 ± 2.69a
25	6.19 ± 0.68b	15.07 ± 2.12b	10 ± 0.88b	3.70 ± 5.3b	2,880.8 ± 569a	35.13 ± 2.91b
27	4.15 ± 4.00c	14.07 ± 0.78c	9.92 ± 1.14b	5.36 ± 1.72a	2,172.37 ± 1,039b	33.27 ± 6.51bc
30	3.48 ± 0.60d	12.27 ± 0.59d	6.71 ± 1.07c	5.00 ± 2.64a	2,092.7 ± 324b	28.00 ± 6.96d
33	4.21 ± 0.56c	12.87 ± 1.19d	10.43 ± 2.22b	2.94 ± 0.97b	585.8 ± 97c	30.33 ± 3.28cd
35	3.32 ± 0.49d	12.87 ± 1.3d	7.96 ± 0.98c	3.56 ± 1.57b	518 ± 48c	27.80 ± 2.90d
Temperature °C	**Developmental time at aCO_2**					
	Egg	Larva	Pupa	Adult	Fecundity	Total life span
20	7.53 ± 0.74a	27.60 ± 1.55a	16.80 ± 4.04a	7.0 ± 1.93a	1,952 ± 355b	58.93 ± 2.84a
25	7.26 ± 0.96b	15.20 ± 1.82c	12.40 ± 1.14b	4.13 ± 1.16b	1,896.8 ± 447b	39.00 ± 2.68b
27	4.08 ± 0.56cd	17.73 ± 2.64b	9.73 ± 2.13c	3.60 ± 2.13bc	2,834 ± 1939a	35.13 ± 8.43c
30	3.98 ± 0.56cd	14.53 ± 1.74c	9.53 ± 1.05c	3.80 ± 0.7bc	477.8 ± 256c	30.86 ± 4.41d
33	4.14 ± 0.52c	13.20 ± 1.08d	7.86 ± 0.45d	3.87 ± 0.67bc	779.40 ± 569c	29.06 ± 1.85d
35	3.68 ± 0.49 e	13.13 ± 1.77 d	6.66 ± 0.79 d	2.60 ± 0.40 d	273.4 ± 64 c	26.06 ± 1.78 e

Means in the same column followed by different letter (a,b,c and d) are significantly different at $P < 0.05$ (ANOVA) by Tukey's test.

Table 3. Variation of table parameters of *Spodoptera litura* on sunflower at six constant temperatures and two CO_2 conditions

Temperature °C	r_m		Net reproductive rate (R_o)		T		Finite rate of increase (λ)		DT	
	eCO_2	aCO_2	eCO_2	aCO_2	eCO_2	aCO_2	eCO_2	aCO_2	eCO_2	aCO_2
20	0.1179	0.125	933	625.33	58	52.65	1.125	1.133	5.88	5.55
25	0.189	0.1721	933.73	601.4	36.19	37.18	1.208	1.187	3.67	4.03
27	0.207	0.202	1,056.1	612.75	33.63	31.73	1.23	1.224	3.35	3.43
30	0.227	0.22	539.55	275.55	27.64	29.92	1.255	1.206	3.05	3.15
33	0.1868	0.193	188.73	181.13	28.06	26.89	1.205	1.213	3.71	3.59
35	0.205	0.194	165.86	123.2	24.9	24.77	1.227	1.214	3.38	3.57

Effect of Temperature and CO_2 on Developmental Rate. The variation in developmental time for egg, larva, pupa, and adult stages of *S. litura* on sunflower at six constant temperatures at two CO_2 conditions is presented in Table 2. Reduction in average developmental time for the egg stage ($F_{5,495}$=880.89; $P < 0.01$), larva ($F_{5,295}$=1,288.50; $P < 0.01$), pupa ($F_{5,270}$=93.72; $P < 0.01$), adult ($F_{5,245}$=9.79; $P < 0.01$), and TLS ($F_{5,295}$=26.04; $P < 0.01$) was observed with increase in temperature under both eCO_2 and aCO_2. The duration of all stages was shorter under eCO_2 than aCO_2 (Table 2). Decreased mean developmental time (days) of each stage, egg (from 7.61 to 3.32), larva (from 29.8 to 12.87), pupa (from 16.46 to 7.93), adult (from 5.33 to 3.67), and TLS (from 59.2 to 27.8) from 20 to 35°C temperature on eCO_2 foliage. Survivorship of four stages of *S. litura* was akin to developmental rate and significant variation was observed with temperature increase at eCO_2. The highest (1.051) and lowest (1.013) survival rates from egg to adult were observed at 30 and 20°C temperature (Table 2).

Life Table Parameters. The data on life table parameters *viz.*, 'r_m', net reproductive rate ('R_o'), 'T', and 'λ' at six constant temperatures with two CO_2 levels are shown in Table 3. The 'r_m' increased with increase in temperature from 20 to 30°C and declined with further increase in temperature. The 'R_o' of *S. litura* was higher at 27°C temperature according to records obtained from observation of 1,056 offspring. Comparison of values of 'r_m' and 'R_o' with temperature indicated a gradual increase to a maximum values. The reduction of 'T' was observed from a maximum value of 58 days at 20°C to minimum of 24.9 days at 35°C and followed polynomial trend under eCO_2. The 'λ' which is the indicator of reproductive value of new eggs was found to be highest at 30°C and followed a decreasing trend with increase in

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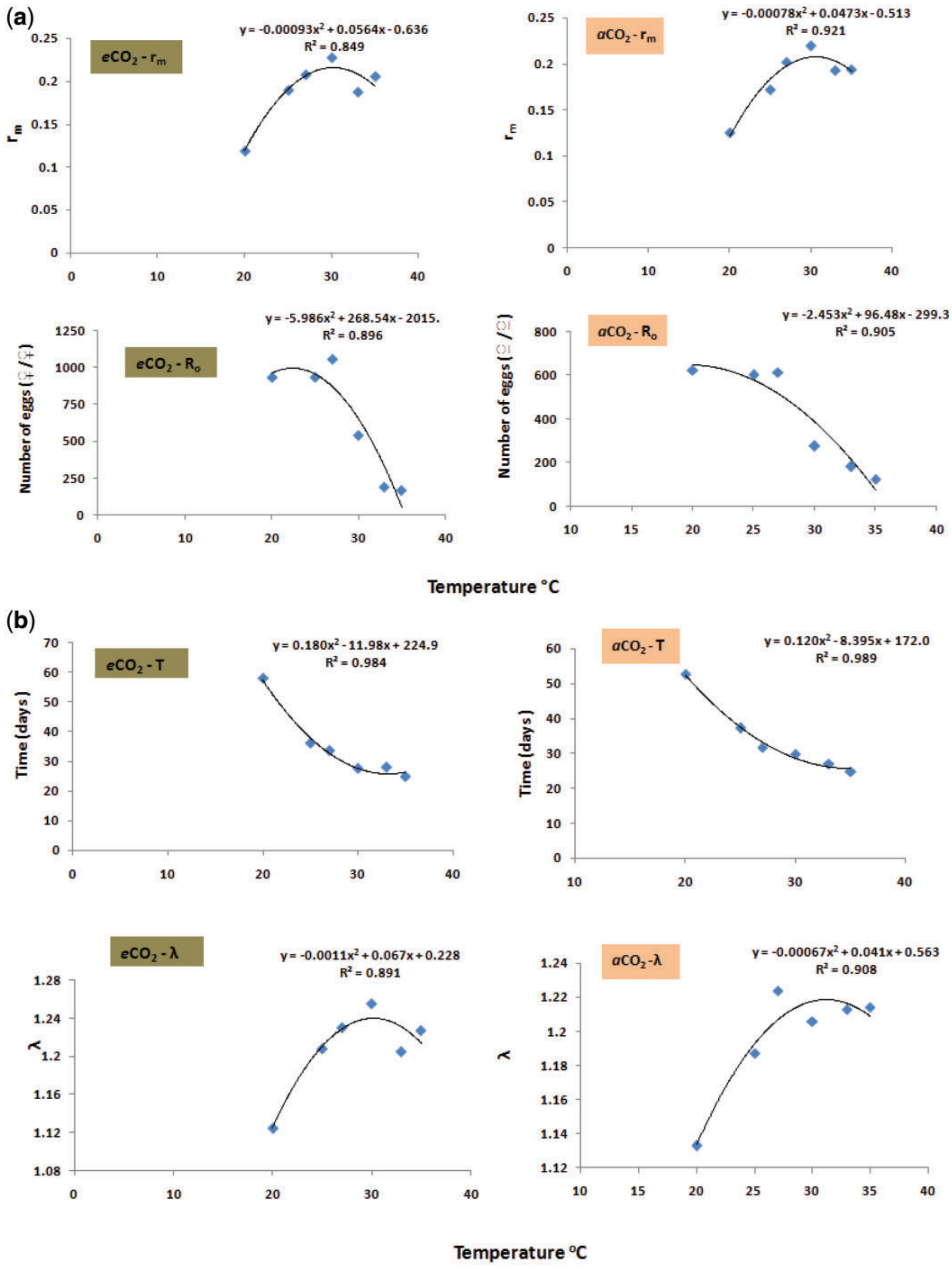

Fig. 1. (a) Relationship between temperature and life-table parameters ('r_m' and 'R_o') of *Spodoptera litura* on sunflower at eCO_2 and aCO_2. (b) Relationship between temperature and life-table parameters ('*T*' and 'λ') of *Spodoptera litura* on sunflower at eCO_2 and aCO_2.

temperature. The doubling time (DT) of population was highest (5.88 days) at 20°C and lowest (3.05 days) at 30°C temperature under eCO_2 (Table 3). The results on two nonlinear models developed for eCO_2 and aCO_2 conditions separately are depicted in Figure 1a and b. The relationship between 'r_m' and temperature followed the polynomial/quadratic form and was found to be the best fit with R^2 in the range of (R^2=0.899). A polynomial pattern was observed when the 'R_o' values were plotted against temperature ($R^2 = 0.896$) and the highest value was recorded at 21.48°C under eCO_2. The highest values of 'r_m' were observed at 28.0°C for eCO_2 (0.227) and 23.5°C for aCO_2 (0.220).The reduction of '*T*' and increase in 'λ' were observed at 33.28 and at 33.50°C, temperature respectively.

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Prediction of Pest Scenarios Using Life Table Parameters Under Climate Change Scenario. Predicted life table parameters of *S. litura* at four sunflower growing locations during climate change scenarios are presented in Table 4. The 'r_m' (0.15) values increased significantly during the NF climate change scenario compared with current climatic conditions (0.02–0.07) making it possible to produce greater numbers of females per female per day. At Bangalore location the negative value of 'r_m' increased to 0.14 in NF scenario. It was predicted that similar increases of 'r_m' would occur during DF scenario. The 'λ' recorded an increasing trend in NF (2.66–2.90) and DF (2.94–3.13) scenario in comparison within present period (0.96 - 0.99) at four locations. Results showed that 'R_o' would be higher (602–911offspring) during future climate change scenarios than during present period (486–525).

Table 4. Prediction of pest scenarios using life table parameters during NF and DF CCS at four sunflower growing locations

Locations	Present	NF	DF
r_m			
Akola	0.02 ± 0.02	0.15 ± 0.00**	0.15 ± 0.00**
Bangalore	(−0.05) ± 0.01	0.14 ± 0.00**	0.15 ± 0.00**
Hayathnagar	0.07 ± 0.01	0.15 ± 0.00**	0.14 ± 0.00**
Raichur	0.03 ± 0.01	0.15 ± 0.00**	0.14 ± 0.01**
Ro			
Akola	525.44 ± 13.73	871.41 ± 31.14**	704.51 ± 89.01**
Bangalore	571.71 ± 8.25	911.38 ± 36.95**	775.44 ± 56.68**
Hayathnagar	486.11 ± 11.56	849.25 ± 47.15**	653.78 ± 88.48**
Raichur	519.63 ± 10.45	799.01 ± 58.39**	602.20 ± 105.78**
T			
Akola	33.29 ± 0.79	32.82 ± 1.28**	28.57 ± 1.46**
Bangalore	36.46 ± 0.69	35.01 ± 2.31**	29.86 ± 1.24**
Hayathnagar	31.34 ± 0.49	32.06 ± 1.61**	27.75 ± 1.11**
Raichur	32.95 ± 0.56	30.53 ± 1.66**	27.18 ± 0.98**
λ			
Akola	0.97 ± 0.00	2.76 ± 0.07**	3.05 ± 0.13**
Bangalore	0.99 ± 0.00	2.66 ± 0.10**	2.94 ± 0.09**
Hayathnagar	0.96 ± 0.00	2.81 ± 0.09**	3.13 ± 0.12**
Raichur	0.97 ± 0.00	2.90 ± 0.11**	3.20 ± 0.14**

**The difference relative to the present period is significant at $P < 0.01$.

The '*T*' of insect pest was found to decrease significantly during NF (1–2 d at three locations) and DF (5–6 d at all locations) climate scenarios.

The results of per cent change in predicted life table parameters during NF and DF scenarios over present climate period were calculated and are depicted in Figure 2. The per cent change in 'r_m' was higher at three locations under both NF and DF scenarios excepting Bangalore where negative 'r_m' values were predicted to occur indicating that the number of females per female would be reduced. The increase in 'R_o' was found to be higher in NF (50–70%) than DF (15–35%) at all four locations. The reduction of '*T*' is expected to be higher in DF (11–18%) at four locations than NF scenario (1–7%). A minimal increase (2 %) of '*T*' would occur at Hyderabad during NF scenario. At all four locations λ was found to increase in both NF and DF by 69–230%.

Discussion

Plant growth and biochemical constitution varied with CO_2 concentration causing a reduction in foliar nitrogen, which is the single most important limiting resource for phytophagous insects (Hunter 2001, Srinivasa Rao et al. 2012). Our results on biochemical analysis of sunflower foliage revealed a significant reduction (5%) of leaf nitrogen under eCO_2 compared with aCO_2 condition. In addition to this, most herbivorous insects appear to be negatively affected by eCO_2 because of the reduction in foliar N and increase in C: N ratio. In our study, an 8% increase of 'C' and 13% increase in C: N ratio was observed under eCO_2. Similar increase of C: N ratio was reported by De La Mata et al. (2013) for sunflower. The reduction in protein content and increase of C/N ratio in leaves under eCO_2 (Bezemer and Jones 1998, Hunter 2001) imply changes in food quality which can influence insect growth and development.

Temperature is the most significant factor influencing growth and development of insects (Bale et al. 2002). The effects of temperature on insects are species specific. Generally lower temperatures result in a decrease in the rate of development and an increase in the duration of the time of each developmental stage. It is well known that the relationship between temperature and development in insects is linear over most of the normal operating, middle range of temperature, but

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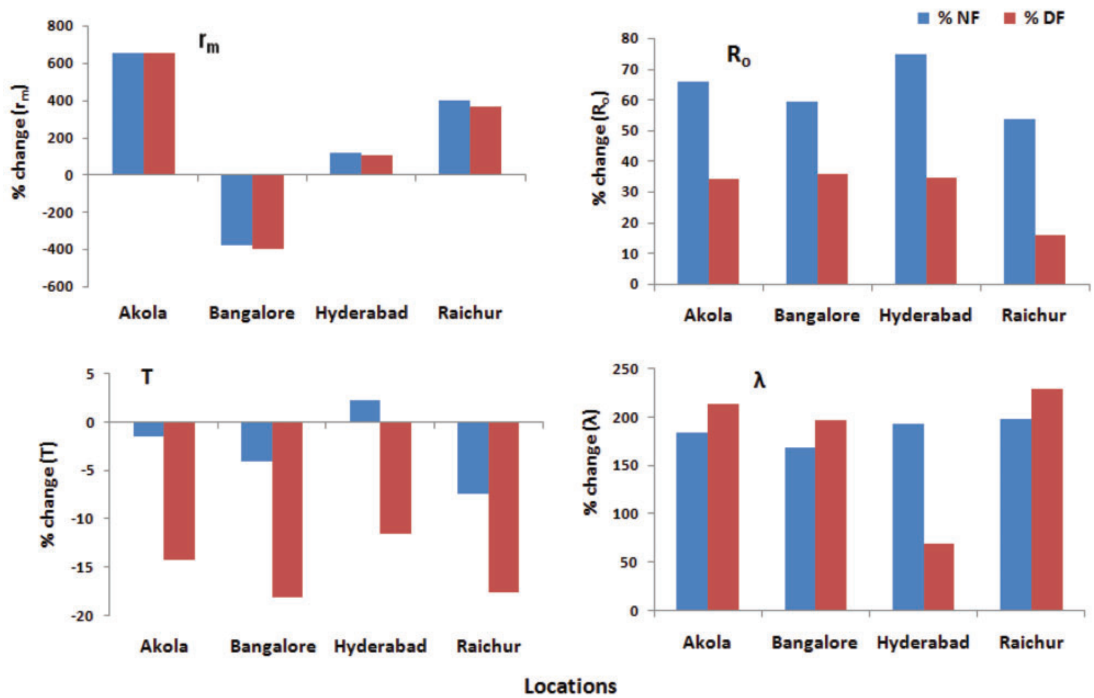

Fig. 2. Per cent change in pest scenarios during NF and DF Climate change over persent period.

becomes sigmoid over the whole temperature range that permits development (Arbab et al. 2006). Earlier studies have revealed that the growth and development of *S. litura* are significantly influenced by temperature (Ranga Rao et al. 1989) and CO_2 (Srinivasa Rao et al. 2012) on various hosts. The results of the present study showed that the developmental time of four stages of *S. litura* (Egg-adult) declined with increase in temperature on sunflower and was more evident at eCO_2. The rate of development was lower at both lower (20°C) and higher temperatures (35°C) studied, signifying that the two extreme temperatures had adverse effects on growth of *S. litura*.

It is well known that insects do not live in stable environments with constant temperature; however the results of the present study under constant temperature are relevant in comprehending the dynamics of insect pests (Tshiala et al. 2012). Life table parameters showed that the 'r_m' values of *S. litura* on eCO_2 foliage are higher than those previously reported in the literature highlighting the significant influence of eCO_2 in altering biochemical constituents, though Yin et al. (2010) observed a non-significant effect of eCO_2 on 'r_m' for cotton boll worms. In case of aphids, eCO_2 influenced performance by producing an increase of 'r_m', 'λ', '*T*' and 'DT' (Amirijami et al. 2012). Significant variation of 'r_m' of *S. litura* with host plants and temperature was reported by Zhu et al. (2000) and Gedia et al. (2008).

Decrease of developmental time and increase in 'r_m' of Sunn pest, *Eurygaster integriceps* (Iranipour et al. 2010) and sugar cane pest *Elasmopalpus linosellus* (Hardev et al. 2013) with increase in temperature has been reported.

Our studies recorded higher 'r_m', 'λ', with lower '*T*' and 'DT' at 30°C temperature and higher 'R_o' at 27°C under eCO_2. These findings are in agreement with Tuan et al. (2013) who reported 'r_m' values for *S. litura* in the range of 0.13 - 0.18 on peanut. The present results revealed that the association between temperature and life table parameters was a non-linear polynomial relationship. Many empirical models incorporating 'r_m' as a key parameter have been used for prediction of insect pest population dynamics. Temperature-driven phenology models developed using laboratory information and projections of future populations can be made (Vincent et al. 1997). The approach of using laboratory measurements of temperature was adopted by Tshiala et al. (2012) to model the empirical relationship between LT parameters and temperature and assess the impact of climate change on leaf miner population dynamics. The quantified relationship between life table parameters and temperature for eCO_2 foliage was used for predicting pest incidence in NF and DF climate change scenarios at four major sunflower growing locations of India. The 'r_m' (0.15 ± 0.004) and 'λ' (2.94 ± 0.10) values for *S. litura* increased significantly during NF and DF over present period. At one location, the negative value (−0.05) of 'r_m' during the present period predicted a reduction of population. It was predicted that the 'R_o' would be higher during future climate change scenarios than during the present period. The decrease in '*T*' of insect pest during NF and DF scenarios would lead to more generations of insect pests. The reduction of '*T*' and the possibility of occurrence of more generations under climate change scenario was reported earlier in *Phthorimaea operculella* (Abolmaaty et al. 2011), and *Cydia pomonella* (Hirschi et al. 2012).

For the majority of insect pest populations the r_m gradually increases with temperature up to a certain level and later it decreases sharply. The increasing phase is often related to decrease in development time and increase in reproductive rate. The present results indicated that the mean generation time needs to increase to R_o-fold of its size was reduced, defined as the time length that a population as the stable age distribution and the stable increase rate are reached. The reduction of development time can lead to more number of generations in a year. Current investigations showed that increased 'r_m', 'R'_o', and 'λ' with a reduction in '*T*' due to increase in temperature and eCO_2 condition which will be more evident in future climate change scenarios.

In conclusion, the growth and development of *S. litura* were significantly influenced by temperature and CO_2. Results from this study showed that both low and high temperatures limited the survival and development of this insect pest and the ideal condition for the growth was at 27°C temperature, while the developmental rate increases with temperature up to 30°C However the life table parameters are sensitive to temperature and CO_2 which are the major factors of climate change. Our prediction of pest scenarios based on PRECIS A1B emission scenario data at four sunflower growing locations of India during NF and DF future climate change scenarios shows increase of 'r_m' and 'λ' with higher 'R_o' and reduced '*T*' meaning that pest incidence would be higher in the future. These findings indicate that *S. litura* has potential to become even more damaging insect pest on sunflower as a result of climate change. Further investigations are required to quantify the role of biotic and other abiotic factors on possible predicted pest scenarios.

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