Impact of eCO2 and Temperature on Aphis craccivora koch. on Groundnut and Future Pest Status During Climate Change Scenarios

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Impact of eCO$_2$ and Temperature on *Aphis craccivora* koch. on Groundnut and Future Pest Status During Climate Change Scenarios

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Abstract

Studies were conducted to quantify the direct effects of temperature and indirect effect of elevated CO_2 (eCO_2), on *Aphis craccivora* Koch. on groundnut (*Arachis hypogaea* L.). The mean development time (DT) of nymph was significantly reduced by 1-2 days from 20 to 35°C temperature at eCO_2 over ambient CO_2 (aCO_2) conditions. Increased production of offspring was noticed at eCO_2. The thermal requirement of nymph varied from 74-102 DD on eCO_2 with temperature in the range of 20-30°C as against 90-130 DD on aCO_2. Non-linear mostly quadriatic relationship of lifetable parameters r_m, R_o, T and λ varied with temperature and CO_2 and found to have non-linear relationship. Prediction of pest scenarios based on PRECIS A1B emission scenario data at eleven groundnut cultivating locations of India during near (NF) and distant future (DF) periods showed that increase of 'r_m' and 'λ' with varied 'R_o' and reduced 'T'. Similar trends were reflected in three decadal periods of NF also. The present results indicate that incidence of *A. craccivora* is likely to be higher in the future climate change periods.

Keywords

Aphids; Development time; Thermal constant; Life table parameters; Climate change; Pest status

Introduction

Global Mean Surface Temperature (GMST) and Global atmospheric CO_2 concentrations have been increasing at a significant rate since last 19th century. It is well known that 0.78°C increase in temperature was noted between average of the 1850–1990 period and the 2003-2012 period. The increase in the amount of CO_2 in the atmosphere will be by about 40% when compared with pre-industrial levels [1]. Increase in temperature and elevated CO_2 (eCO_2) influence crop growth significantly and in turn affect the insect herbivores both directly and indirectly. Though it is known that the increase in temperature will have a greater effect on insects than the rising CO_2 concentration, the interactive and combinational effect of both parameters is more evident.

Among various insect pests, *Aphis craccivora* Koch. is one of the threats to groundnut (*Arachis hypogaea* L.) growers in all over the country. The area, production and productivity of crop is stagnant since several decades due to the various biotic and abiotic stresses and the productivity of groundnut crop is found to be low. The growth and development of phloem-feeding insect species vary with increase in temperature [2] and elevated CO_2 [3]. Under eCO_2 conditions the variation of biochemical constituents *viz.,* reduction of nitrogen, increased carbon and C:N ratio was reported [4] which can be the major causative factor in influencing the aphids. In addition to the abiotic factors the role of host plant [5] and quality of the diet are vital in influencing the survival, reproduction and life table parameters of insect herbivore. Understanding of population dynamics of insect pests is possible with the construction of life tables. These life table parameters are dynamic and function of various factors and differ with temperature [6], larval host and diet and was reported with lepidopteran insects [7]. Significant variation of life table parameters of aphids with respect to temperature in case of *Aphis glycines* in soybean [8] and with eCO_2 on other species of aphids [9] was reported.

No studies are available on construction of life table of *A. craccivora* on groundnut considering the temperature and CO_2 concurrently. Hence, the studies were conducted **i.** to measure the effects of constant temperatures and eCO_2 on life table parameters of *Aphis craccivora* on groundnut **ii.** to estimate the threshold temperatures and thermal constants and, **iii.** to predict the aphid pest scenarios during near and distant future climate change periods at different locations of India.

Materials and Methods

Plant growing conditions-CO_2 enrichment

Elevated atmospheric CO_2 concentration of 550 ± 25 ppm CO_2 and ambient CO_2, aCO_2 (380 ± 25 ppm CO_2) were maintained in open top chambers (OTC) of 4 × 4 × 4 m dimensions, constructed at Central Research Institute for Dryland Agriculture (CRIDA), (17.38°N; 78.47°E) India. Elevated CO_2 concentration was maintained in two OTC chambers and experiments were conducted and compared over ambient CO_2 of two OTC chambers [10]. Groundnut (JL-24) seeds were sown in the month of June 2015 in OTCs and crop plants were raised during the entire crop season. The adults of *A. craccivora* were collected from infested plants of groundnut from field and maintained in the entomology laboratory of CRIDA at optimum conditions of temperature (25 ± 2°C), humidity (80 ± 5%) and with 14 L/10D cycle.

Growth and development

Feeding trials were carried out at constant temperatures (20, 25, 27, 30, 33 & 35 ± 0.5°C) and CO_2 levels (550 ± 25 ppm and 380 ± 25 ppm) to study the growth and development of *A. craccivora* using 'cut leaf' method. The stock cultures were maintained in the CO_2 growth chambers and reared on leaves of potted plants of groundnut. The aphids were reared individually in the petridish of 110 mm diameter 10 mm height. A group of adults of *A. craccivora* were placed in a closed petridishes and were maintained at six constant temperatures at 75 ± 5% relative humidity (RH) and 14L/10D hour photoperiod in CO_2 growth chambers. Different sets containing thirty replications were kept for each CO_2 level (380 ppm and 550 ppm). The freshly moulted adults of *A. craccivora* were kept individually in the petridish

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each consisting of a groundnut leaves and allowed for laying. The total number of aphids at each temperature was observed and various parameters *viz.*, development time (DT) of nymph including early and late nymphs, Reproductive time (RT) of adult, total life cycle (TLC) and fecundity were recorded as per the standard procedure [11].

Degree days requirement

The data obtained from above feeding trials were analyzed to estimate the degree days/thermal constant of each stage of the aphid. Degree days requirement was calculated after considering the average development time for six temperatures tried in the experiment. Linear regression co-efficient (b) and constant (a) were estimated after plotting the reciprocal of development time (development rate) over temperature. The standard formula of Y=a + bx was used to estimate the threshold development (T_0) and further degree day calculation based on developmental rate [12] will enable to estimate the physiological time and same was adopted here.

The life table parameters and future pest status

The life table parameters of *Aphis craccivora* was estimated by adopting the TWOSEX–MS Chart software [13] by using primary parameters data of aphids on groundnut foliage from *e*CO_2 and *a*CO_2 independently. Non-linear equations were arrived after plotting this data against tested temperatures to estimate the thermal requirements.

The future climate data (maximum and minimum temperature-Tmax and Tmin) projections of AIB PRECIS emission scenario was considered for the period of 1961-2098 to estimate the level of pest incidence. The future period was designated as near and distant future periods (NF and DF) with 2021-2050 and 2071-2098 years respectively. The level of pest incidence during these periods were compared over base line (BL) period of 1961-1990. The future daily temperature (maximum and minimum) for 11 groundnut cultivating regions of the country was obtained using PRECIS model. Future pest status in terms of predicted life table parameters of *A. craccivora* at these 11 locations was estimated for the crop duration of 133 days coinciding with the rainy season of 26-44 Standard Weeks.

Statistical analysis

The data on development rate of each stage of insect pests at six constant temperatures at two CO_2 conditions were analyzed by adopting two factorial design considering the temperatures and CO_2 levels as main and sub-factors. The mean values of life table parameters of *A. craccivora* across 11 groundnut cultivating regions for the three periods *viz.,* baseline, NF and DF were compared using two-sample *t-test*. SPSS version 16.0 was used for statistical analyses.

Results

Variation in growth and development

The results on variation in primary parameters of *A. craccivora* on groundnut at two CO_2 conditions and at six constant temperatures are presented in the Table 1. Development Time (DT) was significantly influenced by first factor, CO_2 ($F_{1,29}$=236.50; P<0.01) and second factor, temperature ($F_{5,29}$=342.57; P<0.01)

The findings of the present study indicated that DT of aphid decreased by 1–2 days as temperature increased from 20 to 35°C and more evident at *e*CO_2. A similar trend of shortened DT of *A. gossypii* in cotton [14] and *Rhopalosiphum maidis* in barley [15] at *e*CO_2 than ambient was reported. Sun and Ge [16] mentioned that species specific responses to *e*CO_2 with Phloem-sucking insects (aphids) and are able to alleviate the disadvantages of *e*CO_2 by reducing DT. The developmental rate of insect pests is highly responsive to fluctuations in temperature because of their physiological sensitivity [17]. After nymphal development, aphids exhibited increased reproductive time and were able to produce offspring for a longer period and were more evident with elevated CO_2.

Increase in Reproductive Time (RT) was noticed with CO_2 ($F_{1,29}$=269.53; P<0.01) and a gradual reduction with temperature ($F_{5,29}$=8573.25; P<0.01) whereas it was observed that reduction of Total Life Cycle (TLC) with CO_2 ($F_{1,29}$=31.24; P<0.01) and temperature ($F_{5,29}$=5677.91; P<0.01). The interaction of both the factors was also significant on RT ($F_{5,290}$=16.45; P<0.01) and TLC ($F_{5,290=}$1.90; P<0.01) of *A. craccivora*. The offspring production per female was also impacted by CO_2 ($F_{1,29=}$485.46; P<0.01) and temperature ($F_{5,29=}$1765.60; P< 0.01) considerably. A substantial increase in the production of offspring was noticed at *e*CO_2 (84.23) over *a*CO_2 (61.56). The higher offspring production was noticed between 20-27°C and started declining with increase in temperature (30-35°C). Significant interaction ($F_{5,290=}$32.10; P<0.01) of CO_2 and temperature on fecundity was evident.

In our studies the offspring production of *A. craccivora* (fecundity per female) was also impacted by CO_2 and temperature significantly and substantial increase in the production of offspring was noticed with *e*CO_2 (84) over *a*CO_2 (62). Aphids are able to overcome the indirect effects of *e*CO_2 by increasing fecundity at *e*CO_2 [16]. Several workers reported the increased fecundity of various species of aphids *viz., Myzus persicae* on *Triticum aestivum, Brassica napus* [9] and *A. craccivora* on cow pea at *e*CO_2 [11]. Increase in temperature from 20–27°C resulted in increase in production of progeny but further increased in temperature led to a reduction of fecundity and similar trend was reported by Xie et al. [15].

In the present study we tried to quantify the impact of host mediated effect of *e*CO_2 and direct effect of temperature on *A. craccivora* and the corroborative evidences for it's change in the growth and development were identified. We previously reported decreased N (3%) and increased C:N ratio (13%) and polyphenols (2%) in foliage of groundnut *e*CO_2 and significant influence on growth and development of chewing insect herbivore (*Spodoptera litura*) [10]. The variation of primary parameters of aphids is attributed to change in the biochemical composition of the peanut foliage at *e*CO_2 conditions. The documented information reveals significant impact of elevated CO_2 levels on photosynthesis, growth, yield and change in biochemical constituents in crop plants including groundnut [18]. The changes in biochemical constituents in plants grown under *e*CO_2 affect the nutritional quality of the plants, which in turn influences the consumption pattern of lepidopteran and homopteran insect herbivores [19].

Estimation of thermal constants

In the present experiment, linear regression was used to calculate the temperature threshold (X intercept), and thermal requirement (inverse of the slope) of nymph and adult stage of aphid seperately. The development rate of nymph and adult was regressed on temperature and linear regression equations were depicted in Figure 1. The thermal requirement of nymph varied from 74-102 DD on *e*CO_2 with temperature in the range of 20-30°C as against 90-130 DD on *a*CO_2 indicating the lower degree days requirement for completion

Table 1: Influence of CO_2 and temperature on growth and development of A. *craccivora* on groundnut.

Temperature (± 0.5)	Primary parameters of *A.craccivora*	CO_2 Concentrations	
		Elevated	Ambient
20	Development Time (days)	7.40 ± 0.855^{Ba}	9.00 ± 0.182^{Aa}
	Reproductive Time (days)	20.00 ± 0.946^{Aa}	19.03 ± 0.182^{Ba}
	Total Life Cycle (days)	27.40 ± 0.932^{Ba}	28.06 ± 0.253^{Aa}
	Fecundity (female^{-1})	57.60 ± 5.541^{Ac}	46.70 ± 4.771^{Bc}
25	Development Time (days)	6.43 ± 0.727^{Bb}	7.86 ± 0.571^{Ab}
	Reproductive Time (days)	15.40 ± 0.674^{Ab}	14.03 ± 0.182^{Bb}
	Total Life Cycle (days)	21.83 ± 1.053^{Bb}	21.90 ± 0.607^{Ab}
	Fecundity (female^{-1})	67.83 ± 8.200^{Ab}	52.83 ± 4.676^{Bb}
27	Development Time (days)	5.20 ± 0.714^{Bc}	7.66 ± 0.479^{Ab}
	Reproductive Time (days)	12.03 ± 0.718^{Ac}	10.33 ± 0.546^{Bc}
	Total Life Cycle (days)	17.23 ± 1.135^{Bc}	18.00 ± 0.870^{Ac}
	Fecundity (female^{-1})	84.23 ± 7.314^{Aa}	61.56 ± 9.088^{Ba}
30	Development Time (days)	5.10 ± 0.844^{Bc}	6.10 ± 0.784^{Ac}
	Reproductive Time (days)	5.10 ± 0.711^{Ad}	4.96 ± 0.587^{Ad}
	Total Life Cycle (days)	10.20 ± 1.063^{Bd}	11.06 ± 0.944^{Ad}
	Fecundity (female^{-1})	22.03 ± 4.563^{Ad}	18.23 ± 2.534^{Bd}
33	Development Time (days)	4.06 ± 0.639^{Bd}	5.00 ± 0.668^{Ad}
	Reproductive Time (days)	3.60 ± 0.498^{Ae}	2.96 ± 0.454^{Be}
	Total Life Cycle (days)	7.66 ± 0.844^{Be}	7.96 ± 0.718^{Ae}
	Fecundity (female^{-1})	14.86 ± 2.991^{Ae}	6.30 ± 1.028^{Be}
35	Development Time (days)	3.73 ± 0.784^{Bd}	4.50 ± 0.568^{Ae}
	Reproductive Time (days)	2.96 ± 0.182^{Af}	2.60 ± 0.571^{Bef}
	Total Life Cycle (days)	6.70 ± 0.836^{Bf}	7.10 ± 0.844^{Af}
	Fecundity (female^{-1})	7.16 ± 1.577^{Af}	5.23 ± 1.095^{Be}
LSDp ≤ 0.01	CO_2	Temperature	CO_2 × Temp
Development Time (days)	0.246^{**}	0.311^{**}	0.44^{**}
Reproductive Time (days)	0.145^{**}	0.272^{**}	0.384^{**}
Total Life Cycle (days)	0.252^{**}	0.409^{**}	0.578^{**}
Fecundity (female^{-1})	1.312^{**}	2.473^{**}	3.498^{**}

**Significant at P ≤ 0.01; Same upper case alphabets across CO2 levels and lower case alphabets across temperatures indicate that means are not statistically significant, at P<0.01

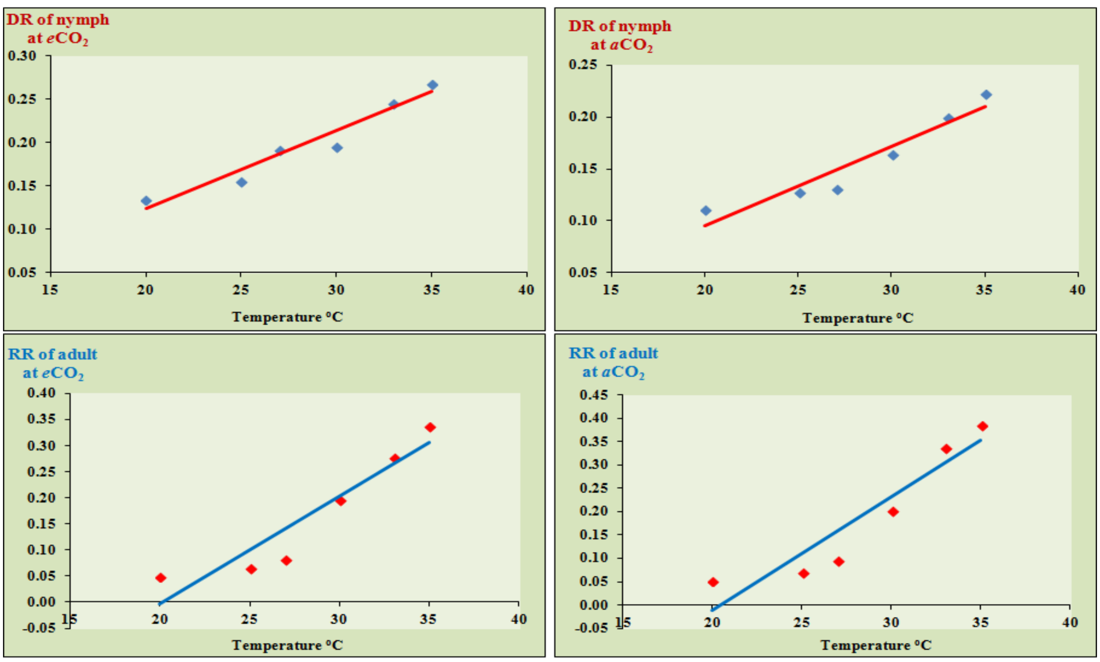

Figure 1: Relation between developement rate (DR), Reproduction rate (RR) with temperature for nymphs and adults of *A. craccivora* at eCO_2 and aCO_2.

of nymphal stage at eCO_2. In contrast Adult required higher degree days of 74-231 at eCO_2 with the corresponding temperatures of 20-27°C as against 64-210 on aCO_2. The mean degree day requirement of nymph (91.294 ± 9.574) and adult (149.089 ± 70.149) at eCO_2 varied over aCO_2 and similar trend is reflected after the summation of degree days requirement of both nymph and adult stages also at eCO_2 (240.3 ± 66.6) and aCO_2 (249.5 ± 64.2).

Development rate and temperature were plotted to determine the lower development thresholds of *A. craccivora* at two CO_2 conditions separately. The best fit linear regression equation for nymph (Y=0.009x– 0.0557, R^2=0.9415) and adult (Y=0.0207x–0.4171, R^2=0.8826) and thus the mean lower development thresholds for both the stages were 6.1 and 20.1°C on eCO_2 foliage. In contrast on aCO_2 foliage, similar and significant trends with nymph (Y=0.0077x–0.0596, R^2= 0.91) and adult (Y=0.0242x–0.4962, R^2=0.88) stages were noted. The mean lower development thresholds for nymph were slightly higher (7.7°C) at aCO_2.

Our findings showed the lower thermal requirement for nymph and higher with adult stage at eCO_2 foliage at set temperatures over aCO_2 indicating the significant variation due to CO_2 and temperatures of 20–35°C though the mean thermal constants of both the stages were closer to values of (150-250 DD). Present findings recorded the lower degree days requirement for completion of nymphal stage at eCO_2 and might be due to shortening of DT. The lower thermal constants of *A. craccivora* at eCO_2 conditions might be due to reduction of DT as reported earlier [20]. Kuo et al. [21] reported lower thermal constants for *R. maidis* from 33.15 DD for first instars to 25.96 DD for fourth instars. Similar kind of variation of 513-290 DD for soybean aphid was reported by McCornack et al. [22] in the 20-35°C temperature range.

Construction of life tables

The results on variation of lifetable parameters at two CO_2 conditions are given int he Table 2 which indicated that 'r_m' increased with increase in temperature from 20°C and later started declining from 30°C. The 'R_o' of *A. craccivora* was higher at 27°C temperature by recording 84.23 offspring at eCO_2. The 'r_m' and 'R_o' increased gradually with temperature and reached maximum values at 27°C. The reduction of '*T*' was evident from 13.41 days at 20°C to minimum of 5.91 days at 35°C and followed the non-linear trend at eCO_2. The 'λ' which is the indicator of reproductive value of aphid was found to be highest 1.61 at 27°C and followed the decreasing trend with an increase in temperature.

The results on non-linear models developed at eCO_2 condition for four life table parameters *viz.*, 'r_m', 'R_o', '*T*' and 'λ' were depicted in Figure 2. The best fit quadratic form of equation wirh higher R^2 (0.89) at eCO_2 was noticed between'r_m' and temperature. Other parameters *viz.*, 'R_o', '*T*' and 'λ' followed the similar trend. When the first order derivative of the equation is taken as 'Zero', the temperature at which higher 'R_o' was estimated to be 25.15°C on eCO_2 foliage as against 23.62 (aCO_2) and later started declining. The r_m and λ showed declining trend at about 26 at eCO_2 and similar non-linear trends were observed at aCO_2 which are as follows($r_{m=}$–0.002x² + 0.132x–1.418, R^2=0.82), ($R_{o=}$–0.428x² + 20.221x–188.57, $R^2$0.80), (*T*=0.007x²–0.238x + 23.04, $R^2$0.94) and (λ=–0.003x² + 0.166x–0.813, R^2=0.85). When the first order derivative is equated to 'Zero' and to solve the 'x' (variable) the r_m and λ started declining at 33.05°C and 27.66°C on aCO_2 foliage and found to be higher than eCO_2.

The findings of the present study indicated the increased 'r_m' and 'R_o' with reduced and were proportional to temperature from 20°C-30°C and later started declining and was more evident with eCO_2. Similar non-linear trend was noticed by Kuo et al. [21] at eCO_2 over aCO_2. Similar observations of Increased 'R_o' and reduction of '*T*' were reported in case of *Myzus persicae* [9] and *Rhopalosiphum maidis* [15]. In our study eCO_2 influenced the 'r_m' of *A. craccivora* which was contradictory to Flynn et al. [23] who reported that 'r_m' of *R. padi* and *M. persicae* did not increase significantly due to eCO_2.

Future pest status

Across 11 groundnut cultivating regions of the country, it is predicted that substantial increase of Tmax and Tmin by 1.8-4.4°C would occur during NF and DF climate change scenarios which inturn would result in rising of mean temperatures by about 2-4°C higher than BL. The quantified associations of life table parameters with temperature at two CO_2 conditions were additionally adopted for predicting the future pest status during NF and DF scenarios. The 'r_m' values increased during NF (1.289) and DF (1.307) climate change periods when compared to baseline period (0.746) at Vridhachalam location and similar increase was predicted at at majority of locations compared to the baseline. Results on per cent change in predicted 'r_m' and '*T*' of *A. craccivora* at eleven groundnut cultivating locations during climate change scenarios were depicted in Figure 3. The per cent change in 'r_m' was predicted to be significantly higher at all locations during both NF (up to 79.75 %) and DF (up to 98.75 %) periods.

It was predicted that generation time (*T*) of aphids would decrease at Vridhachalam (6.77 days), Kadri (8.37 days) and Bhubaneswar

Table 2: Mean ± standard error of life table parameters of *A. craccivora* on groundnut at six constant temperatures and two CO_2 conditions.

Temp (± °C)	r_m		*Ro*		*T*		*λ*	
	eCO_2	aCO_2	eCO_2	aCO_2	eCO_2	aCO_2	eCO_2	aCO_2
20	0.281 ± 0.010 (0.000104)	0.249 ± 0.007 (0.000062)	43.730 ± 4.486 (20.12461)	41.870 ± 2.807 (7.88291)	13.410 ± 0.214 (0.046)	14.950 ± 0.354 (0.125)	1.3254 ± 0.013 (0.000182)	1.283 ± 0.010 (0.000103)
25	0.361 ± 0.006 (0.000047)	0.285 ± 0.006 (0.000042)	63.830 ± 3.516 (12.36653)	48.700 ± 3.126 (9.7729)	11.500 ± 0.145 (0.021)	13.600 ± 0.178 (0.032)	1.435 ± 0.009 (0.000097)	1.330 ± 0.008 (0.000073)
27	0.478 ± 0.008 (0.000073)	0.351 ± 0.005 (0.00003)	84.230 ± 1.324 (1.75387)	61.570 ± 2.339 (5.47298)	9.260 ± 0.169 (0.029)	11.710 ± 0.174 (0.03)	1.613 ± 0.013 (0.000191)	1.432 ± 0.007 (0.000061)
30	0.396 ± 0.0126 (0.000161)	0.359 ± 0.012 (0.000153)	31.270 ± 1.709 (2.92128)	18.830 ± 1.318 (1.73888)	7.710 ± 0.181 (0.033)	8.160 ± 0.2 (0.04)	1.486 ± 0.018 (0.000354)	1.400 ± 0.017 (0.000314)
33	0.219 ± 0.026 (0.000683)	0.239 ± 0.020 (0.000421)	13.000 ± 1.832 (3.35625)	5.070 ± 0.662 (0.43843)	6.120 ± 0.186 (0.035)	6.790 ± 0.17 (0.029)	1.32 ± 0.039 (0.001561)	1.270 ± 0.025 (0.000671)
35	0.138 ± 0.041 (0.001706)	0.157 ± 0.038 (0.001511)	2.270 ± 0.512 (0.26307)	2.800 ± 0.232 (0.45168)	5.910 ± 0.236 (0.056)	6.540 ± 0.232 (0.054)	1.148 ± 0.046 (0.002181)	1.170 ± 0.044 (0.002003)

Note: Figures in parentheses are variance values

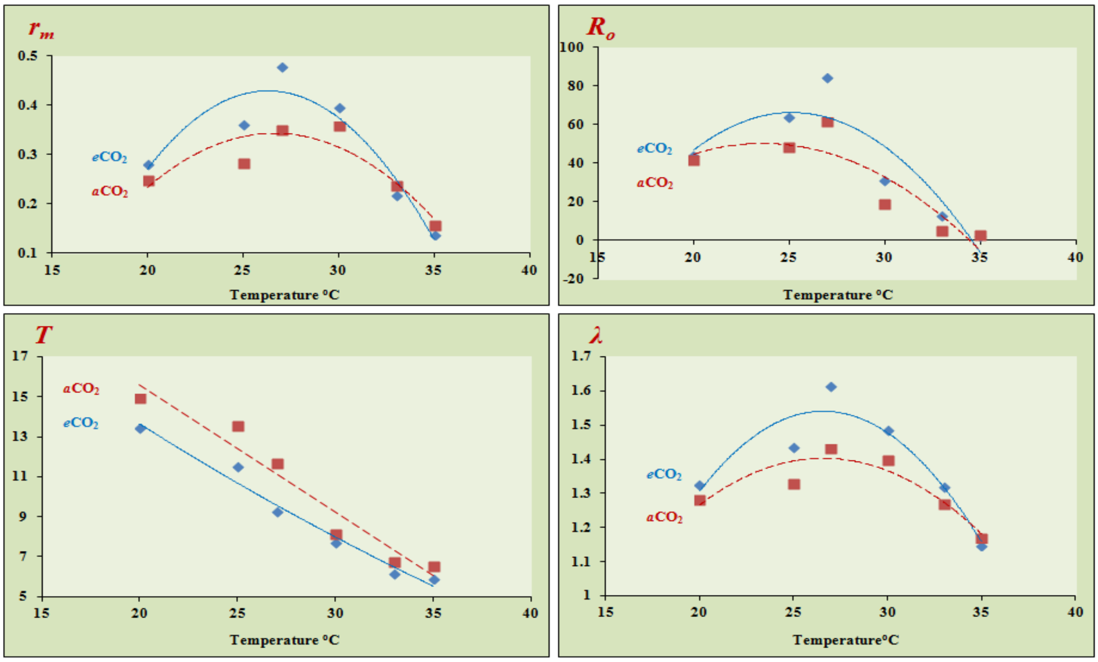

Figure 2: Relationship between temperature and life table parameters of *A. craccivora* on groundnut at eCO_2 and aCO_2.

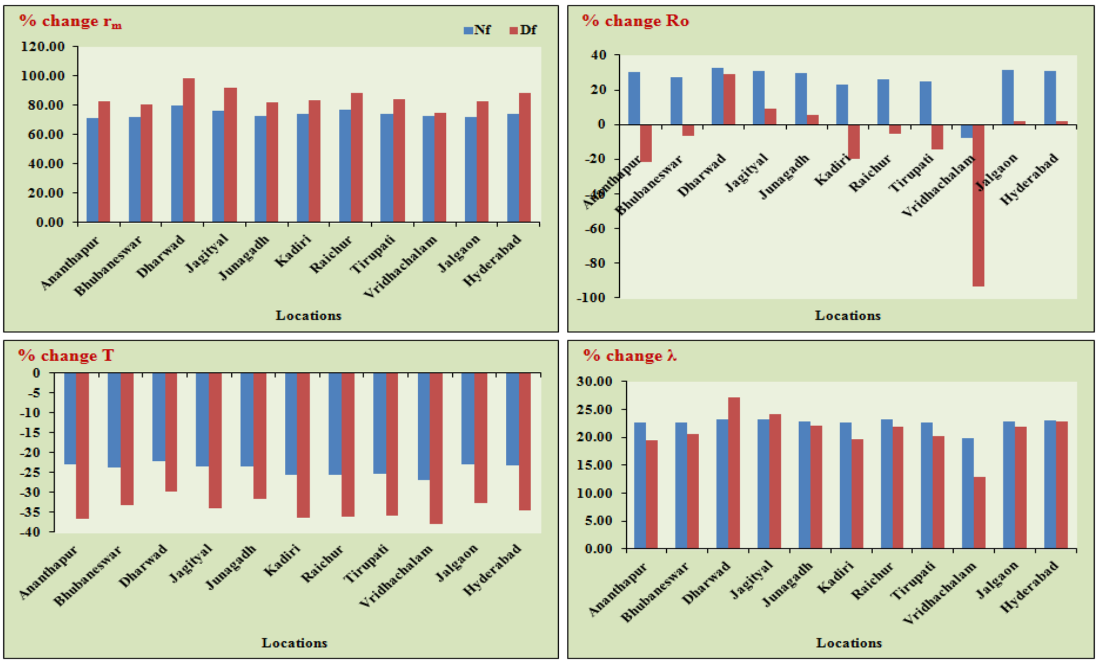

Figure 3: Percent change in pest scenarios (R_0 and T) during NF & DF climate change periods over baseline.

(8.46 days) during NF while an increased generation time was predicted at rest of locations over BL. The reduction of '*T*' by 5.76-9.74 days was observed at all eleven locations studied during DF period over BL. The highest percent reduction of generation time '*T*' is expected to be in DF (up to 37.86 %) than NF period (up to 26.95 %) and shift was also noticed. At majority of locations, λ and R_o was expected to increase in both NF (23.29 %) and DF (27.12 %) periods.

The other life table parameter (R_o) would be higher during both NF (66.21) and DF (64.58) periods over baseline (49.96) and the 'λ' recorded increasing trend in NF (1.74-1.81) and DF (1.64-1.81) periods over baseline (1.41-1.48) at eleven locations studied implying more number of females per female of *A. craccivora* per day. The 'λ' recorded increasing trend in NF and DF periods over baseline at all eleven locations studied and 'R_o' would be varied during future climate change periods and similar kinf of prediction was done for leaf miner [24]. The '*T*' of insect pests is expected to decrease significantly during NF and DF periods leading to occurrence of more number of generations of *Cydia pomonella* [25], *S. litura* and *H. armigera* [7,26] during climate change periods.

Conclusions

The growth and development of *A. craccivora* was significantly influenced by temperature and the CO_2 condition under which host plants were grown. Both lower and upper threshold temperatures were identified and the higher level for the growth of the pest is at 27°C temperature. It was noted that variation of thermal requirement of *A. craccivora* on groundnut during future climate change period. Our findings on future pest status based on PRECIS A1B showed increased 'r_m' and '*λ*' with varied 'R_o' and reduced '*T*' of A. craccivora at 11 groundnut cultivating regions of India. These findings suggest that pest incidence would be higher during future climate periods. Mostly the impacts of climate change on insect pests are complex and confounding in nature and elaborative studies are required to comprehend further.

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