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Full Length Research Paper

Estimation of number of generations of *Spodoptera litura* Fab. on peanut in India during near and distant future climate change scenarios

M. Srinivasa Rao[1]*, C. A. Rama Rao[1], S. Vennila[2], D. Manimanjari[1], M. Maheswari[1] and B. Venkateswarlu[1]

[1]Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad, 500 059 India.
[2]National Centre for Integrated Pest Management (NCIPM), LBS Building, IARI campus, Pusa, New Delhi 110012, India.

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Studies were conducted to estimate the impact of increase in temperature on number of generations of tobacco caterpillar, *Spodoptera litura* on peanut for seven different locations of various agro ecological zones of the country for baseline (1961 to 1990), present (1991 to 2005), near future (2021 to 2050) and distant future (2071 to 2098) climate change (A1B) scenarios. The daily minimum and maximum temperature (MinT and MaxT) records were used to obtain cumulative degree days (DD) for each generation of insect using a temperature threshold of 10°C. Faster accumulation of degree days will making it possible for one or two additional generations with shortened life cycle (completion of generation would be 5 to 6 days earlier) of *S. litura* was inferred for both near and distant-future climate change scenarios (CCS) compared to baseline and present periods, at all locations. The additional number of generations and variation in the generation time of *S. litura* across seven growing locations of India imply the definitive and differential impacts, respectively of the projected increasing temperature in the future CCS.

Key words: *Arachis hypogaea*, climate change scenario, degree days, generation time, number of generation, *Spodoptera litura.*

INTRODUCTION

During this century, global mean temperature has been predicted to rise by 2 to 5°C. Climate model projections were summarized in the 2007 Fourth Assessment Report (AR4) by the Intergovernmental Panel on Climate Change (IPCC). They indicated that during the 21st century the global surface temperature is likely to rise a further 1.1 to 2.9°C (2 to 5.2°F) for their lowest emissions scenario and 2.4 to 6.4°C (4.3 to 11.5°F) for their highest (IPCC, 2007). Though climate change is global in its occurrence and consequences, it is the developing countries like India that face more adverse impacts as majority of the population depends on agriculture with excessive pressure on natural resources and because of poor coping mechanisms. Increasing temperatures and

*Corresponding author. E-mail: msrao909@gmail.com or msrao@crida.in. Tel: 09849547302. Fax: 91-40-24531802.

atmospheric CO_2 have been very significant during the last three decades (Stern, 2007) influencing all sectors of agriculture. Within agriculture, how the climate change impacts insect pests and diseases is an important area that is engaging biological scientists. Climate change projections made up to 2100 for India indicate an overall increase in temperature by 2 to 4°C with no substantial change in precipitation quantity (Krishna Kumar, 2011). Last three decades witnessed a sharp rise in mean annual temperature in India (Venkateswarlu, 2009).

Analysis of data for the period 1901 to 2005 by Indian Meteorological Department (IMD) suggested that annual mean temperature for the country as a whole increased by 0.51°C over the period. It may be mentioned that annual mean temperature has been consistently above normal (base period: 1961 to 1990) since 1993. This warming is primarily due to rise in maximum temperature over a larger part across the country.

Peanut (*Arachis hypogaea* L.) also known as groundnut, earthnut and ground bean, is the world's fourth most important source of edible vegetable oil and third most important source of vegetable protein. Production is concentrated in Asia (50% of global area and 64% of global production) and Africa (46% of global area and 28% of global production), where the crop is grown mostly by smallholder farmers under rainfed conditions with limited inputs. China, India, Nigeria, USA and Myanmar are the major peanut growing countries. India is the second largest producer of peanut in the world with an average annual production of 5.51 million tons (http://faostat.fao.org) from an area of 5.47 million ha. Productivity levels of peanut in India is1007 kg/ha as against 1522 kg/ha of the globe and 3356 kg/ha of China. Elevated CO_2 was reported to cause significant increase in total biomass at final harvest of peanut crop but decreased final seed yield in selected cultivars (Bannayan et al., 2009). The tobacco caterpillar, *Spodoptera litura* (Fab.) is a major pest which can cause yield losses of 35 to 55% and larvae feed gregariously on leaves causing severe defoliation, leaving only midrib veins. Insects are physiologically sensitive to temperature, have short life cycle and great mobility, and their developmental rate and geographical distribution are therefore highly responsive to changes in temperature (Lange et al., 2006). Insect developmental rate, geographical distribution and the intensity of their feeding increased historically with increasing temperature (Bale et al., 2002) and resulting in increased herbivory and insect diversity. The increase in surface temperatures would permit multivoltine species to increase the number of generations per year or during crop season. It is well known that the relationship between climate change and voltinism could be more complex. The number of generations is used as a parameter to assess the role of temperature on population dynamics of the insect pest.

The present study is aimed to estimate and quantify the impact of increase in temperature on number of generations of *S. litura* on peanut crop considering four different climatic periods *viz*; baseline, BL (1961 to 1990), present, PR (1991 to 2005), near future, NF (2021 to 2050) and distant future, DF (2071 to 2098) for seven major peanut growing locations of the country.

MATERIALS AND METHODS

The work comprises of three components *viz;* (i) obtaining historical data and climate projections on daily temperature from respective grid points, (ii) computation of growing degree days (GDD) for completion of life cycle of *S. litura* based on the threshold temperature and (iii) estimation of the possible number of generations during crop season in the future projected climate by substituting the projections on the temperature using SRES A1B scenario.

Collection of historical temperature data

Historical daily temperature (maximum and minimum) for seven study locations *viz*; Jalgaon (21° 5' N, 75° 40' E); Raichur (16° 12' N, 77° 25' E); Bhubaneswar (20° 16' N, 85° 50' E); Hayathnagar (17° 18' N, 78° 60' E); Tirupathi (13° N, 79° E); Jagityal (18° 8' N, 78° 9' E); and Kadiri (14° 12' N, 78° 10' E) were collected from a 1x1 degree grid database provided by IMD (Srivastava et al., 2008) for the period 1991 to 2005 being referred as a present (PR) period in this research.

Estimation of number of generations of *S. litura* on peanut

The standard GDD approach was followed to estimate the number of generations of *S. litura* occurring on peanut during a crop season. The maximum and minimum temperatures were transformed to heat units using the lower threshold temperature of (t_0) 10°C for *S. litura* on peanut and the standard method for estimation of the degree days (Thermal requirements) for each day was calculated by using the formula (Elsaadany et al., 2000).

$H = \Sigma$ D-D

Where:

H=Number of heat unit to emergence.

D-D = (Max. t. + Min. t.)/2 – t_0, if Max. t.>t_0<Mint

t_0= threshold temperature = 10°C.

The minimum and maximum daily temperatures of different periods (BL, NF and DF) were used for estimating the accumulated thermal heat units. The degree days required for completing life cycle of *S. litura* (egg to adult) on peanut was taken as 522.7 DD (Ranga Rao and Wightman, 1989) and GT generation time (average development time) needed for completion of one cycle was estimated. The number of generations of *S. litura* was calculated using cumulative degree days (Degree Day Units) for each generation of insect. Web introduction for the Insect Development Database (IDD) was consulted for obtaining the degree day units of these insect pests (www.nappfast.org/databases/). The website has database on thermal requirements of several insect pests, which is maintained by The North Carolina State University-APHIS Plant insects' life cycle esp. number of generations during the season by

Pest Forecast (NAPPFAST) System and Global Pest and Disease Database (GPDD). GDD approach can be used to predict the measuring the growth in terms of temperature over time and considers average daily temperatures which influence insect development.

Expected number of generations were estimated using INGEN (β – version) software developed at CRIDA, wherein accumulated thermal degree days was calculated by horizontal cut-off (degree-day accumulations above the upper threshold do not count) method. The software provides data on GT (Generation Time) in days as given above, Mean GDD (Mean Growing Degree Days - accumulated degree days to complete one generation after reaching cut-off GDD) and Total Degree Days (TDD - total summation of the degree days in a calendar year or crop season).

Future climate data

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 paper, we utilize 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 for the period between 1961 and 2098. 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*; 'near future' (NF) consisting of 2021 to 2050 and distant future (DF) consisting of 2071 to 2098. The period between 1961 and 1990 was referred as the base line (BL) period.

Accumulation of degree days was calculated considering the specific biological event called as "biofix". In this case the pheromone trap 'first catch' was considered as a Biofix and the cumulative degree days for *S. litura* was estimated for the crop season covering 133 days of crop duration across seven locations. The analysis of historical data on pheromone trap catch across various locations was reported by following the first order Markov chain probability model (Victor et al., 2003). A first order Markov chain probability model was adopted to estimate the probabilities of occurrence of pheromone trap catch which was > 30 adult moths / week. The results indicated that the probability of occurrence of pheromone trap catch was significant during the entire crop season ranging from 26 to 44 standard week (swk) comprising 133 days of crop duration mostly (Srinivasa Rao et al., 2012).

Statistical analysis

The data on variation in number of generations of *S. litura* across seven locations for the four periods *viz;* base, present, near and future periods were analyzed using the Kendall Family of Trends test (Helsel et al., 2006). The mean number of generations in BL, PR, NF and DF scenarios was compared using two-sample t-test assuming equal variances. The significance of mean values was defined at $p < 0.01$ and all statistical analysis were done using SPSS version 16.0.

RESULTS AND DISCUSSION

The findings on the possible number of generations during peanut crop season, time taken to complete a generation and the inter-generation variations therein are presented hereunder.

Variation in total accumulated degree days (TDD) and number of generations

Results on the variation in accumulated degree days of *S. litura* at seven peanut growing locations are presented in Table 1. The insect *S. litura* accumulated lower thermal degree days of 2193 and higher of 2493 DD at Jalgaon and Tirupathi during the present period accommodating about 4.20 and 4.77 generations respectively (Table 2). The mean growing degree days of the insect was in the range of 522.7 DD as the units are universal and will not vary with the locations. The number of degree days increased to 2393 DD during near-future and 2689 DD during the distant-future making it possible to complete one more generation compared to the current climatic conditions at Jalgaon. At Kadiri, the number of generations possible increased to between five and six (4.89 to 5.50) during near and distant future climate scenarios resulting in two generations higher than current climatic periods. In other locations also, it is predicted that the higher accumulation of degree days would be possible during both the near and distant-future climate change scenarios (CCS) and expected to accommodate one or two additional generation during the crop season compared to four generations during the base line and present periods.

The mean number of generations among four climate scenarios analyzed using t-test indicated that the variation was significant at majority of locations. Increased number of generations are expected during NF ($p=< 0.01$; $t= 5.05$) and DF ($p=< 0.01$; $t= 11.78$) scenarios at Raichur and NF ($p=< 0.01$; $t= 8.06$) and DF ($p=< 0.01$; $t= 12.74$) Jalgaon, during NF ($p=< 0.01$; $t= 8.96$) and DF ($p=< 0.01$; $t= 19.90$) Bhubaneswar locations. The expected number of generations would be higher by one and the increased number of generations were predicted to be significant in NF scenario at Kadiri ($p=< 0.01$; $t= 7.48$). The predicted number of generations would vary significantly in NF scenario at Tirupathi ($p=< 0.01$; $t= 0.71$) and at Jagityal NF ($p=< 0.01$; $t= 0.84$). In rest of locations the increase in number of generations was found to be highly significant during NF over present climatic conditions (Table 2). It was expected that there would be significant increase in number of generations at all peanut growing locations during DF scenario.

The percent change in the variation of number of generations of *S. litura* under present and future climate change-NF and DF scenarios over BL period at four locations indicated that the percent increase was found to be minimum (0 to 5%) during the present period however, the increase was higher (19 to 27%) DF and (8 to 13%) NF scenarios over BL period.

Table 1. Mean generation time (GT) and total accumulated degree days (TDD) of *S. litura* on peanut under climate change scenario (CCS).

Name of the location	Current climate period					
	Base Line			Present		
	Mean GT	Mean GDD	TDD	Mean GT	Mean GDD	TDD
Jalgaon	31.71± 0.42	526.04 ±3.23	2223.35 ± 119.07	31.73 ±1.23	525.66 ±7.30	2193.58 ± 56.86
Raichur	32.41 ± 1.85	524.62 ± 2.61	2138.00 ± 128.12	30.76 ± 0.73	524.61 ± 4.09	2251.71 ± 38.81
Kadiri	29.94 ± 0.47	524.98 ± 4.37	2315.67 ± 94.79	29.10 ± 0.89	524.84 ± 6.38	2366.84 ± 49.04
Bhubaneswar	29.18 ± 0.54	524.77 ± 5.11	2351.20 ± 41.17	29.35 ± 0.27	524.84 ± 4.80	2347.63 ± 52.32
Tirupathi	30.08 ± 1.36	524.36 ± 5.73	2280.39 ± 86.46	27.36 ± 0.83	525.08 ± 5.80	2493.59 ± 47.56
Hayathnagar	32.62 ± 0.99	524.66 ± 4.38	2101.05 ± 121.60	29.06 ± 0.84	524.42 ± 5.63	2371.72 ± 37.28
Jagityal	33.80 ± 2.57	523.14 ± 5.60	1994.94 ± 96.64	31.01 ± 0.77	524.90 ± 5.58	2234.71 ± 40.04

Name of the location	Climate change scenario					
	Near future			Distant future		
	Mean GT	Mean GDD	TDD	Mean GT	Mean GDD	TDD
Jalgaon	29.41 ± 0.98	525.08 ± 3.32	2393.23 ± 86.75	25.80 ± 2.54	524.87 ± 4.42	2689.09 ± 144.18
Raichur	28.29 ± 2.50	523.58 ± 4.59	2407.09 ± 115.37	25.53 ± 1.64	524.37 ± 4.87	2722.43 ± 140.61
Kadiri	26.93 ± 0.65	524.24 ± 4.55	2556.55 ± 92.29	24.13 ± 0.22	524.68 ± 5.01	2873.01 ± 103.56
Bhubaneswar	27.20 ± 0.38	523.40 ± 5.98	2534.18 ± 70.71	24.83 ± 0.72	524.58 ± 5.69	2800.50 ± 79.57
Tirupathi	27.39 ± 1.03	524.96 ± 4.11	2511.76 ± 91.39	24.38 ± 0.97	525.11 ± 5.23	2826.93 ± 99.56
Hayathnagar	30.29 ± 1.00	524.95 ± 4.34	2302.89 ± 102.44	26.11 ± 1.54	524.83 ± 5.24	2650.29 ± 127.47
Jagityal	32.04 ± 1.11	525.35 ± 4.83	2212.13 ± 91.84	26.85 ± 3.00	524.26 ± 4.98	2543.11 ± 135.76

Mean GT: Mean generation time, Mean GDD: Mean growing degree days, Mean TDD: Mean total degree days.

Table 2. Variation in number of generations (mean ± standard deviation) of *S. litura* across seven peanut growing locations.

Name of the location	Current climate period		Climate change scenario	
	Base line	Present	Near future	Distant future
Jalgaon	4.25 ± 0.23 (0.87) NS	4.20 ± 0.11	4.58 ± 0.17 (8.06)**	5.14 ± 0.28 (12.74)**
Raichur	4.09 ± 0.25 (3.34) **	4.31 ± 0.07	4.61 ± 0.22 (5.05)**	5.21 ± 0.27 (11.78)**
Kadiri	4.43 ± 0.18 (1.87)**	4.53 ± 0.09	4.89 ± 0.18 (7.48)**	5.50 ± 0.20 (17.85)**
Bhubaneswar	4.50 ± 0.08 (0.22) NS	4.49 ± 0.10	4.85 ± 0.14 (8.96)**	5.36 ± 0.15 (19.90)**
Tirupathi	4.36 ± 0.17 (8.86)**	4.77 ± 0.09	4.81 ± 0.17 (0.71) NS	5.41 ± 0.19 (12.19)**
Hayathnagar	4.02 ± 0.23 (8.32) **	4.54 ± 0.07	4.41 ± 0.20 (2.44)**	5.07 ± 0.24 (8.27)**
Jagityal	3.81 ± 0.18 (9.11) NS	4.28 ± 0.08	4.23 ± 0.18 (0.84) NS	4.87 ± 0.26 (8.60)**

Figures in parentheses are ’t’- values, and BL, NF and DF were compared over PR. ** Indicate the statistical significance compared over present period at p<0.01 and NS: not significant.

Mann-Kendall test was performed to evaluate the trend in the number of generations of *S. litura* during the crop season under different climate change scenarios indicated a very high positive value of Mann-Kendall statistic (S), at Bhubaneswar denoting an increasing trend under the four climatic conditions being significant for NF (p= <0.01; tau C= 0.51) and DF (p= <0.01; tau C= 0.30) scenarios. Similar increasing trend during NF and DF climate change scenarios at all centers except at Jalgaon with non significant trend in NF scenario (p= 0.16 (>0.01); tau C= 0.18). Non significant temporal variation of *S. litura* was observed during BL and PR periods at Kadiri, Tirupathi and Hayathnagar, whereas, significant increasing trend was predicted to occur during NF (p= <0.01; tau C= 0.33, p= <0.01; tau C= 0.30 and p= <0.01; tau C= 0.37) and DF (p= <0.01; tau C= 0.34, p= <0.01; tau C= 0.30 and p= <0.01; tau C= 0.42) climatic scenarios. Overall, it is expected that there would be an increasing trend of number of generations (by one or two generations) during future climate change scenarios at majority of locations including Raichur and Jalgaon (Table 3) peanut growing centers.

Table 3. Temporal trends in number of generations of *S. litura* across seven peanut growing locations using Mann Kendall Test.

Name of the location	Climate scenario	No. of data points	Tau correlation co-efficient	Mann Kendall statistic (s)	Normalized test statistic (Z)	Probability	Trend
Jalgaon	**BL**	30	0.16	69	1.215	0.23	NS
	PR	15	-0.24	-25	-1.19	0.23	⬇
	NF	30	0.18	80	1.419	0.16	NS
	DF	28	0.29	112	2.199	0.03*	⬆
Raichur	**BL**	30	0.25	111	1.96	0.05*	⬆
	PR	15	0.12	13	0.59	0.55	NS
	NF	30	0.23	101	1.78	0.07*	⬆
	DF	28	0.29	112	2.19	0.03*	⬆
Kadiri	**BL**	30	0.18	77	1.36	0.17	NS
	PR	15	0.18	19	0.89	0.37	NS
	NF	30	0.33	142	2.52	0.012*	⬆
	DF	28	0.34	128	2.51	0.01*	⬆
Bhubaneswar	**BL**	30	0.25	111	1.96	0.05*	⬆
	PR	15	0.52	55	2.67	0.007*	⬆
	NF	30	0.51	221	3.96	0.0001*	⬆
	DF	28	0.301	115	2.25	0.02*	⬆
Tirupathi	**BL**	30	0.13	59	1.03	0.30	NS
	PR	15	0.31	33	1.58	0.11	NS
	NF	30	0.30	132	2.34	0.02*	⬆
	DF	28	0.30	114	2.23	0.02*	⬆
Hayathnagar	**BL**	30	0.20	87	1.53	0.13	NS
	PR	15	0.01	1	0.00	1.00	NS
	NF	30	0.37	163	2.89	0.004*	⬆
	DF	28	0.42	160	3.14	0.002*	⬆
Jagityal	**BL**	30	0.19	83	1.46	0.14	NS
	PR	15	-0.37	-39	-1.88	0.06*	⬇
	NF	30	0.40	175	3.10	0.002*	⬆
	DF	28	0.37	140	2.75	0.006*	⬆

BL- Base line, PR- Present, NF- Near future and DF- Distant future. *Significance at $p<0.01$ and NS- not significant. ⬆Indicates increasing trend.

Mean number of generations and generation time

The increase in number of generations is obviously due to the reduction in the time taken to complete a generation for the insect made possible by the faster accumulation of required heat units. Variations in mean generation time of *S. litura* during different climate scenarios at four peanut growing locations which represents different states of the country are depicted in Figure 1. The average length of time taken to complete life cycle of *S. litura* at Jalgaon was found to be 29 and 26 days during the near and distant-future compared to 31 and 32 days during the BL and PR climatic periods, respectively. The similar reduction of generation time is evident across three generations also recorded. The first generation took longer time with 31 days during both BL and PR periods and was expected to complete 29 days in NF and 26 days in DF scenarios. Second and third generations were predicted to occur in shorter time than in BL and PR periods. The results of climate change scenario (DF) at same centre indicated one additional generation with a reduced life cycle of 25 days of the pest would be possible. At Raichur the generation time of *S. litura* was found to be 32 and 31 days in BL and PR periods and it is expected that life cycle of pest would be reduced by 5 days during NF and DF future climatic scenarios. Similar trend is reflected across generation wise also. The reduction of generation time was evident at first generation of *S. litura* during NF (29 days) and DF (26 days) scenarios than BL period (33 days) and reduction of generation time was would occur in second and third generations also.

The average life cycle of *S. litura* was found to be 30 and 29 days during BL period and PR climatic conditions

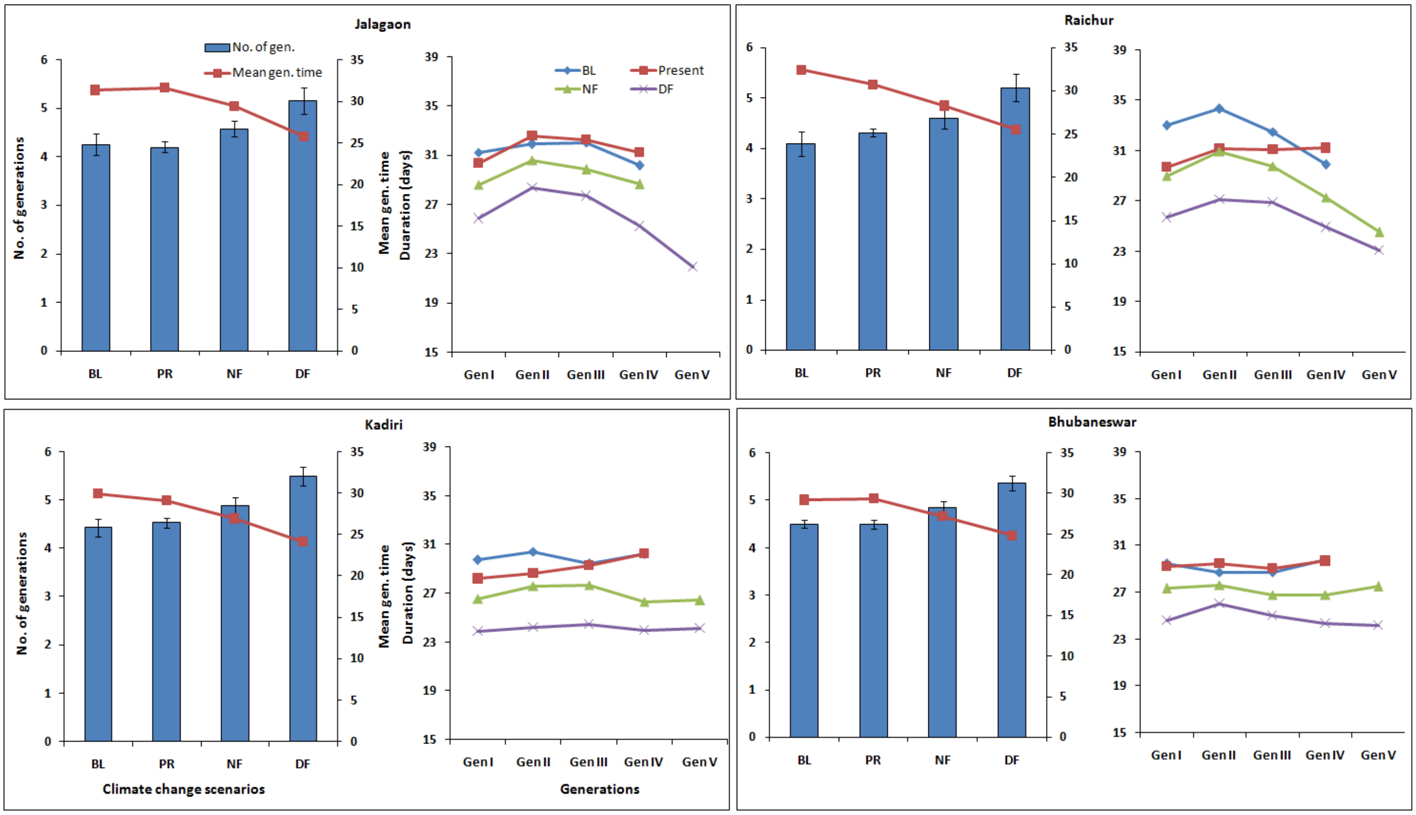

Figure 1. Variation in number of generations and mean generation time of *S. litura* on peanut under CCS.

at Kadiri and Bhubaneswar locations. The shortened life cycle of 27 and 25 days indicating the reduction of life cycle by 3 and 4 days was expected in NF and DF climatic scenarios, respectively. Similarly, inter-generic variation is concerned with the shortened life cycle in first generation of insect that represented a duration of 24 days in DF and 27 in NF than 30 days in BL period at Kadiri location and parallel reduction of generation timeat Kadiri and Bhubaneswar locations. The shortened life cycle of 27 and 25 days indicating the reduction of life cycle by 3 and 4 days was expected in NF and DF climatic scenarios, respectively. Similarly, inter-generic variation is concerned with the shortened life cycle in first generation of insect that represented a duration of 24 days in DF and 27 in NF than 30 days in BL period at Kadiri location and parallel reduction of generation time was expected to take place with second and third generations also. At Bhubaneswar, the generation time across all generations varied from 24 to 28 days and accelerated development is expected with shortened life cycle during both future climate change scenarios. Inter-generic variation across 4 to 5 generations was evident and the number of days per generation in NF and DF climate change scenarios is expected to be shortened by 2 and 5 days, thereby a significant advancement of completion of life cycle was predicted, resulting in more number of generations (5) at all seven locations.

The percent reduction of generation time of *S. litura* at corresponding locations during NF and DF scenarios over BL along with present period was depicted in Figure 2. It was predicted that the percent decrease would be higher during (14 to 22%) DF and (3 to 11%) NF scenarios over BL period indicating the shortened life cycle than BL period to accommodate the more number of generations under CCS.

It is well known that accelerated development of insect**s** is possible due to increased temperature which would result in more cycles of generations / crop losses during the season or year. Prediction of developmental time or mean generation time of insect pests in relation to temperature can be an important tool for pest management (Roy et al., 2002). Insects develop more rapidly during periods of time with suitable warmer temperatures. Increased temperature will accelerate the development of insects possibly resulting in more cycles of generations per year. It s predicted that the projected climate warming would influence the multivoltine species in different ways at different magnitudes. Insects of Aphididae and some Lepidoptera, e.g. *Pieris brassicae*, which are multivoline in nature, undergo faster

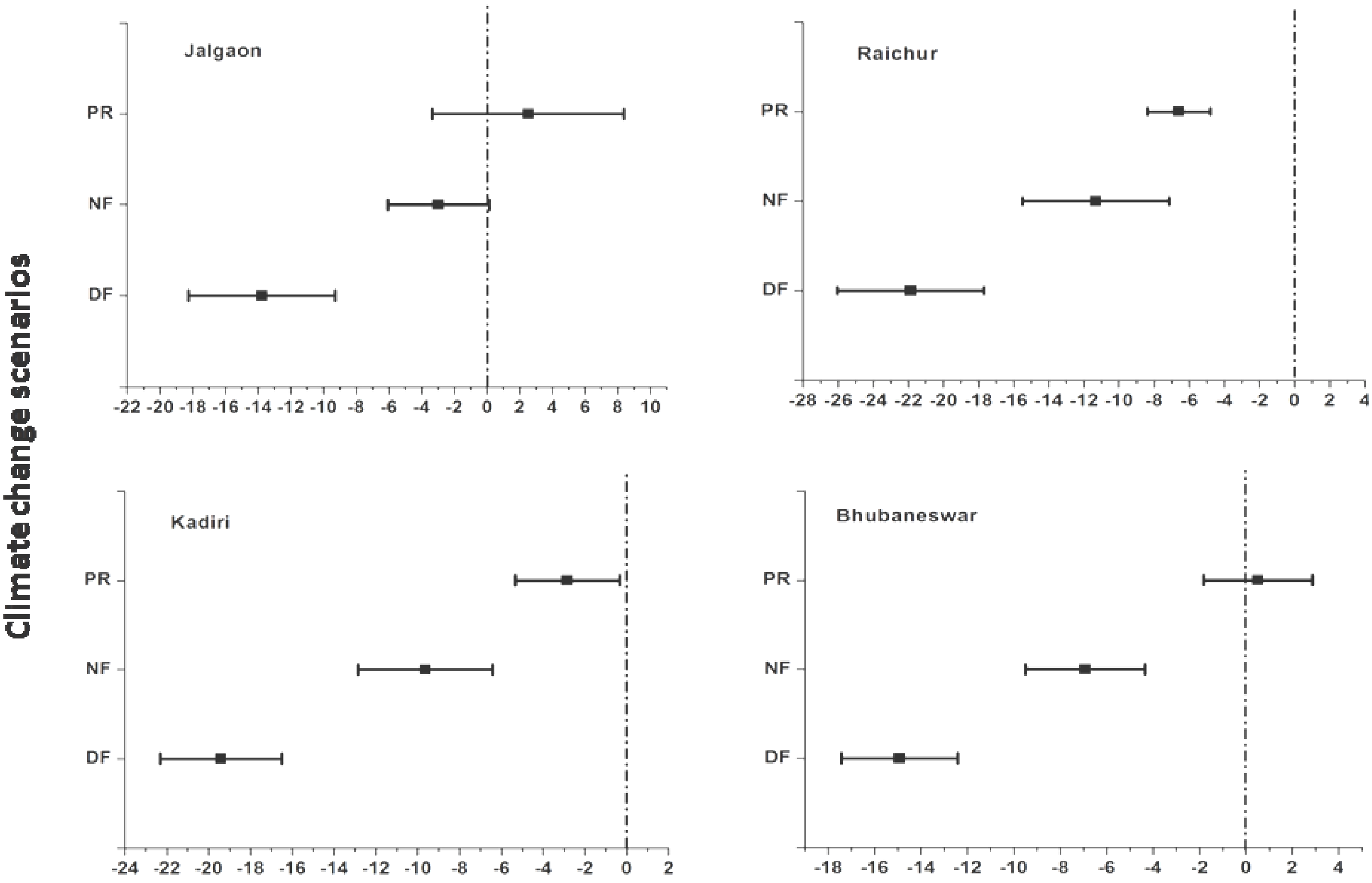

Figure 2. Per cent change in generation time (days) of *S. litura* on peanut under CCS over Baseline period.

development time at higher temperatures, allowing for additional generations within a year (Pollard and Yates, 1993). Many of these species will expand their geographical ranges to higher latitudes and altitudes, as has already been observed in a number of common butterfly species (Parmesan et al., 1999). The occurrence of insect population varies from year to year and its dynamics can be predicted using the approach of Growing Degree-days (GDD).

Predictions of *S. litura* development on peanut were attempted under current (BL and PR periods) and expected future climate change (near and distant future) scenarios. The cumulated thermal heat units were expressed as degree days (DD); the number of generations and mean generation time of *S. litura* were estimated through selection of seven representative peanut growing locations of India. Locations like Raichur, Jalgaon, Bhubaneswar and Kadiri were compared for inter-state and Hayathnagar, Tirupati and Jagityal were selected for intra-state (AP) differences. The influence of temperature on development and survival of *S. litura* would affect the population dynamics of pest and such influence can be estimated and quantified by calculating the number of generations. The findings of the present study shows that one additional generation would occur at majority of locations during future climatic scenarios. The insect was predicted to have significant advancement of completion of life cycle, resulting in more number of generations (5) at all seven locations.

Production of more number of generations annually with extreme temperatures in case of majority of insect species was well known and this phenomenon becomes regular with gradual warming (Lastuka, 2008) and our results add *S. litura* on peanut in India to the list as a case in point. The information on occurrence of additional generations with increase in temperature was well documented across various insect orders *viz*; lepidopterans - *Nephotettix cincticeps* (Yamamura et al., 2006), *Plutella xylostella*, (Kiritani, 2006), *Cydia pomonella* (Marchioro and Foerster, 2011; Hirschi et al., 2012), *Phthorimaea operculella* (Abolmaaty et al., 2011) and other orders (Khalil et al., 2010; Hlasny et al., 2011). It was found that a substantial proportion of the 263 multivoltine lepidopteran species in his dataset exhibited an increased frequency of second and subsequent generations since 1980, with 44 species displaying a stable increase in the number of generations after 1980 (Altermatt, 2010). Our findings are in corroboration with those of earlier reviews, indicating that the insects respond to higher temperature with increased rates of development, more number of generations with less time between generations (Das et al., 2011).

Current investigations for locations from seven different agro-ecological zones of the country (inter and intra state level differences) have shown significant variation in developmental time, number of generations and thermal requirements of *S. litura* on peanut. While these results consider the effect of temperature only, other factors such as host plant response to changing climate, thermal adaptation and rainfall distribution may also influence the rate of insect development. Rise in temperature boosts the carrying capacity of the insect species and thus gives scope for more numbers of generations and individuals (Messer, 2013).

The additional number of generations of *S. litura* on peanut across locations of Indian condition implies the direct and definitive impact of projected increasing in temperature in the near and distant future climate change scenarios. On the other hand, the effects of such increased temperature combined with CO_2 on increasing the biomass of peanut crop may offset the damage caused by *S. litura*. Nevertheless, peanut pest management can always account for the anticipated higher number of generations in the future. Further studies of crop phenology, pest (*S. litura*) phenology and multi-species interactions including *S. litura* parasitoid associations under CCS would aid in understanding the confounding climatic impacts comprehensively besides being prepared for a better decision making on peanut plant protection.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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