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Prediction of pest scenarios of maize aphid *Rhopalosiphum maidis* (f.) during future climate change period under the effect of elevated co_2 and temperature

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Abstract
The objective of this study was to predict the future pest scenarios of maize aphid *Rhopalosiphum maidis* (F.) across six maize growing locations of the India *viz*., Bhubaneswar (Odisha), Coimbatore (Tamil Nadu), Karimnagar (Telangana), Ludhiana (Punjab), Kanpur (U.P.) and Ranchi (Jharkhand) by using life table parameter data and future climate data. The future data was obtained using Providing Regional Climates for Impacts Studies (PRECIS) A_1B model. Among the all locations, lowest intrinsic rate of increase (r_m) and finite rate of increase (λ) values were recorded in Coimbatore at elevated CO_2 (eCO_2) during near future (NF) (0.354 and 1.49 day^{-1}), distant future (DF) (0.306 and 1.43 day^{-1}) compared to that of baseline period. Among the all locations, lowest net reproductive rate (R_o) was recorded in Coimbatore at eCO_2 during NF (34.23 and 27.00 nymphs/female), DF (24.97 and 19.34 nymphs/female) and very distant future (VDF) (8.65 and 7.33 nymphs/female) compared to that of baseline period due to decreased range of r_m and increased range of temperature. The results showed that increased r_m and λ with varied R_o of *R. maidis* at 6 maize growing regions of India.

Keywords: pest scenarios, climate data, maize, *Rhopalosiphum maidis* and life tables

1. Introduction
Maize aphid *Rhopalosiphum maidis* Fitch (Aphididae: Hemiptera), a phloem feeding hemipteran insect and causes significant yield losses about 20.1 to 25 percent. It is a polyphagous species occurring worldwide on sorghum, barley and wheat besides maize [12]. It is now distributed worldwide in the tropics and warmer temperate regions [2]. In an anholocyclic life cycle female aphid produce nymphs without fertilization from the males. Aphids cause mechanical harm and malnutrition to plants by the removal of phloem sap.

Agriculture is one of the most vulnerable sectors to the anticipated climate change with an adverse effect on crop yields. The increased levels of atmospheric CO_2 concentrations can have a direct effect on the growth rate of crop plants. Temperature has an indirect influence on morphological and biochemical constituents of plants. The predicted changes in temperature and CO_2 concentration affect the insect pest population dynamics of various crops.

The future estimations of ambient CO_2 concentration predict an increase up to 550 ppm within a few decades and the average increase in temperature was found to be 0.87 °C for the decade of 2006-2015 [9]. Such rise in CO_2 levels affects the biological system of living organisms, including insects [6]. Temperature has a direct influence on insect activity and their rate of development. Climate change could profoundly affect the population dynamics and the status of insect pests of crops [10]. Excessively high temperatures reduce the reproductive period, fecundity, longevity and population growth [11]. Insect generation time was strongly related to temperature [1]. Hence, in the present study was to predict the future pest scenarios of maize aphid *Rhopalosiphum maidis* (F.) by using life table parameter data and future climate data across six maize growing locations of the India.

2. Materials and methodology
2.1 Maintenance of maize crop and growth conditions
Seeds of maize plants (DHM-117) were sown in OTCs and growth chambers and typical representative alfisols with red soil type were maintained. The maize plants were raised under respective set conditions of elevated and ambient concentrations of CO_2 (550 and 380ppm ± 25 ppm, respectively) at six constant temperatures of 20, 25, 27, 30, 33 and 35 ± 1ºC. The leaves were detached from these plants and were used for the maintenance of the *R. maidis* culture for experimentation. Planting density *i.e.*, the number of plants within a given unit of area (5 plants/m^2) was maintained to avoid congestion in the area. Fully grown foliage (30 days after sowing) obtained from respective set conditions was used for feeding trials and the crop was maintained at insecticide free condition throughout the experiment to understand the impact of eCO_2 and temperature on insect pests.

2.2 Maintenance of *R. maidis* culture
The test insect, corn leaf aphids, *R. maidis* (family: Aphididae; Order: Hemiptera) were collected from the field and maintained in the entomology laboratory of ICAR-CRIDA. The nymphs and adults were reared individually in petridishes of 110 mm diameter of 10 mm height to obtain the mass culture for experiments. The culture was maintained for a number of generations by adopting agar-leaf method in growth chambers at elevated and ambient concentrations of CO_2 (550 and 380ppm ± 25 ppm, respectively)

at six constant temperatures of 20, 25, 27, 30, 33 and 35 ± 1ºC and a photoperiod of 14L: 10D. Light intensity of 30,000 Lx was provided by 26 W fluorescent bulb inside the chambers during the 14 hours light period with relative humidity of 60 % (day) and 70 % (night).

2.3 Impact of *e*CO_2 and temperature on life-table parameters of *R. maidis*

Experiments on life-tables of *R. maidis* were conducted at elevated and ambient concentrations of CO_2 (550 and 380 ppm ± 25 ppm, respectively) at six constant temperatures of 20, 25, 27, 30, 33 and 35 ± 1 ºC. In order to construct life-tables, newly hatched 50 first instar nymphs were collected carefully from the stock culture with the help of wet camel hair brush and transferred individually into each petridish containing maize leaves obtained from respective set conditions with 50 replications per each treatment. Each nymph was examined daily and the life-table parameters *viz*., intrinsic rate of increase (r_m), Finite rate of increase (λ) and Net reproductive rate (Ro) were calculated [3].

2.4 Prediction of pest scenarios of *R. maidis*

Future pest scenarios of *R.maidis* were predicted across six maize growing locations of the country *viz*., Bhubaneswar (Odisha), Coimbatore (Tamil Nadu), Karimnagar (Telangana), Ludhiana (Punjab), Kanpur (U.P.) and Ranchi (Jharkhand) by using life table parameter data and future climate data. For this purpose the methodology adopted earlier by [14] and the future temperature data thus obtained were classified into three categories *viz.*, 'near future- 2020' (NF), 'distant future-2050' (DF) and 'very distant future-2080' (VDF). The future data was obtained using Providing Regional Climates for Impacts Studies (PRECIS) model. Projections obtained at a resolution of 50 X 50 km grid using the PRECIS model was chosen, where the daily data on maximum temperature (T_{max}), minimum temperature (T_{min}) and rainfall (RF) were available. The predictions were made to NF, DF and VDF climate change periods. The daily data during the crop duration of 110 days was considered for predicting the life table parameters of *R. maidis* in future as pest scenarios.

2.5 Statistical analysis

Processing and analysis of raw data was facilitated by a computer program; TWOSEX-MS Chart [4]. Life table parameters *viz*., intrinsic rate of increase (r_m), finite rate of increase (λ), and net reproductive rate (R_o) were calculated and factors were analyzed by Two factorial analysis was adopted to the duration of each insect stage considering the CO_2 and temperatures levels as main and sub-factors deployed in a split-plot design. The mean values of life table parameters of *R. maidis* across maize growing locations for the three period's *viz.*, near, distant and very distant future periods were compared over baseline and the differences between means were determined using least significant difference (LSD) test.

3. Results and discussion

3.1 Effect of *e*CO_2 and temperature on life table parameters of *R. maidis*

3.1.1 Intrinsic rate of increase (r_m)

The r_m of *R. maidis* significantly varied among the two levels of CO_2 and six different temperatures. The r_m of *R. maidis* was 0.2749, 0.4235, 0.4693, 0.4630, 0.3433 and 0.099 day^{-1} under *e*CO_2 conditions whereas it was 0.2083, 0.297, 0.3644, 0.3485, 0.2425 and 0.057 day^{-1} under *a*CO_2 conditions at 20, 25, 27, 30, 33 and 35°C, respectively. Thus, the r_m increased with increase in temperatures from 20-27°C but declined with further increase in temperature. The r_m was higher under *e*CO_2 compared with *a*CO_2 conditions across the temperatures (Fig 1).

3.1.2 Finite rate of Increase (λ)

The λ of *R. maidis* was significantly varied among the two levels of CO_2 and six different temperatures. The λ of *R. maidis* was 1.316, 1.527, 1.599, 1.589, 1.409 and 1.104 day^{-1} under *e*CO_2 conditions whereas it was 1.231, 1.347, 1.439, 1.417, 1.274 and 1.059 day^{-1} under *a*CO_2 conditions at 20, 25, 27, 30, 33 and 35 °C, respectively. Thus, the λ was higher with higher temperatures from 20 – 27 °C and decreased with further increase in temperature. The λ was higher under *e*CO_2 compared with *a*CO_2 conditions across the temperatures (Fig 1).

3.1.3 Net reproductive rate (Ro)

The R_o of *R. maidis* was more under *e*CO_2 was 44.38, 65.28, 75.42, 36.74, 7.42 and 1.68 nymphs/female whereas it was lower resulted 36.68, 54.00, 60.36, 22.78, 4.60 and 1.38 nymphs/female under *a*CO_2 conditions at 20, 25, 27, 30, 33 and 35 °C, respectively. Thus, the R_o was increased with increasing temperatures from 20 to 27 °C but declined with further increase in temperature. The R_o was more under *e*CO_2 compared with that of *a*CO_2 conditions across the temperatures (Fig 1).

The present life table parameters of *R. maidis* were in conformity with the findings of, who reported that the r_m, λ and Ro of groundnut aphid, *Aphis craccivora* was increased with increase in temperature from 20 °C-27 °C and later started declining from 30 °C-35 °C.

The Ro was higher at 27 °C temperature by recording 84.23 nymphs per female at *e*CO_2. The results are in agreement with the findings of [13], who reported that the *R. maidis* fed on barley leaves had the highest r_m and Ro under the *e*CO_2 and temperatures and concluded that the interactive effect of both *e*CO_2 and temperatures on aphid biology may exacerbate aphid damage on barley leaves. Similar results were observed by[8], who reported that the soybean aphid, *Aphis glycines* had the highest finite rate of increase and intrinsic rate of increase at 27 °C (2.128 and 0.533 day-1) than at 22 °C (1.897 and 0.445 day-1) due to greater proportion of the offspring produced when compared to 22 °C.

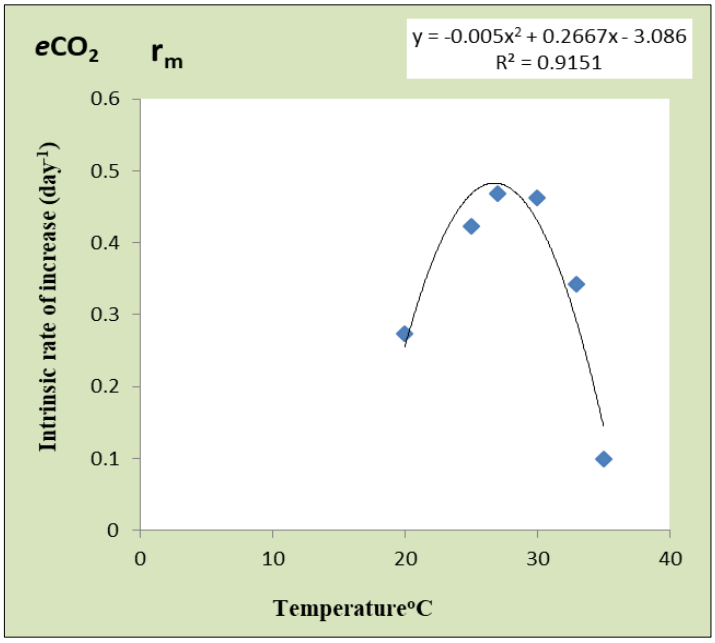
3.2 Prediction of pest scenarios of *R. maidis*

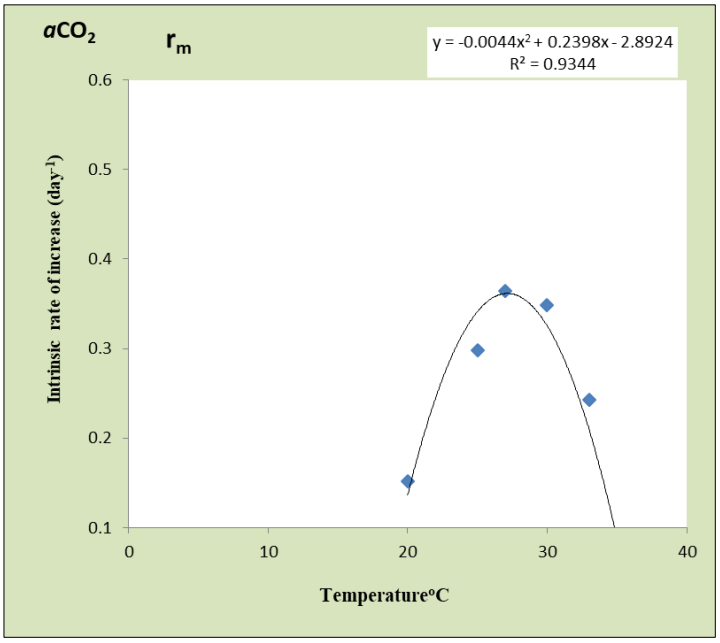
Future pest scenarios of *R. maidis* were predicted across six maize growing locations of the country *viz*., Bhubaneswar (Odisha), Coimbatore (Tamil Nadu), Karimnagar (Telangana), Ludhiana (Punjab), Kanpur (U.P.) and Ranchi (Jharkhand) by using life table parameter data and future climate data. The mean temperatures of near, distant and very distant future climate periods at six maize growing locations were depicted in table 1. An increase (1.76-4.54 ºC) in T_{min} and T_{max} was expected to occur at majority of locations during base line (BL), near future (NF), distant future (DF) and very distant future (VDF) climate change scenarios and the rise in both the maximum and minimum temperatures would result in higher temperatures of mean temperatures. The mean annual temperatures during BL, NF, DF

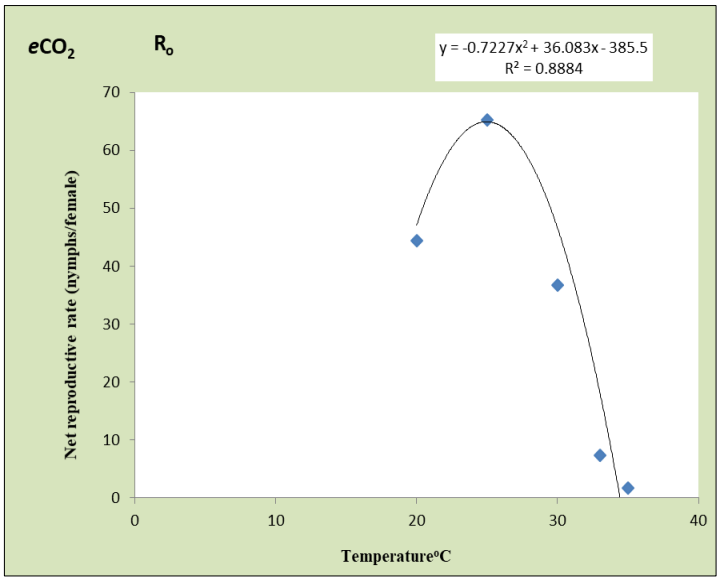
and VDF in maize growing locations in India *viz*., Bhubaneswar (27.241, 28.995, 30.068 and 31.546 ºC), Coimbatore (29.489, 31.453, 32.377 and 33.761 ºC), Karimnagar (27.334, 28.516, 29.645 and 31.077ºC), Ludhiana (25.851, 26.603, 28.114 and 29.925 ºC), Kanpur (24.066, 25.311, 26.800 and 28.546 ºC) and Ranchi (25.267, 26.395, 27.627 and 29.354 ºC), respectively. The variation in annual mean temperature is expected to be significant and would be 1-4 ºC higher than baseline period. Results pertaining to the prediction of life table parameters of *R. maidis* at six maize growing locations during future climate change periods were presented in Table 2, 3 and 4.

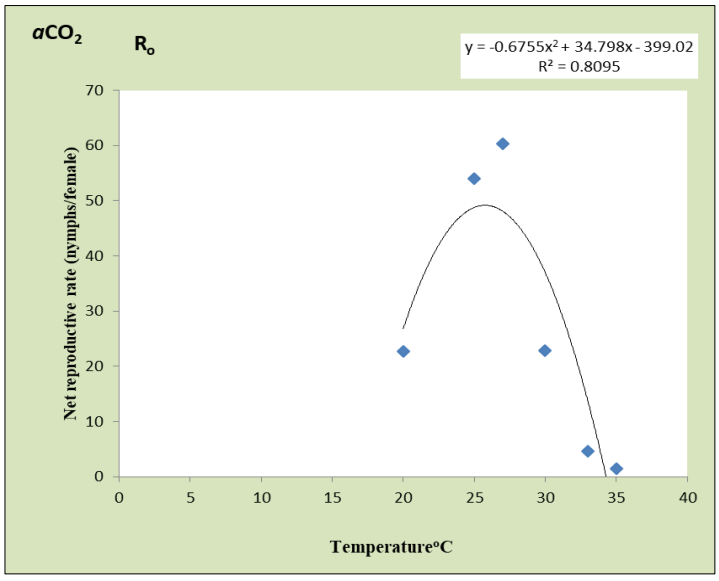
3.2.1 Intrinsic rate of increase (r_m)

The r_m was lower during NF climate change period in both eCO_2 (0.442, 0.354 and 0.452 day^{-1}) and aCO_2 (0.360, 0.296 and 0.367 day^{-1}) conditions at Bhubaneswar, Coimbatore and Karimnagar compared to the baseline period in both eCO_2 (0.466, 0.429 and 0.466 day^{-1}) and aCO_2 (0.373, 0.351 and 0.373 day^{-1}) conditions, respectively.









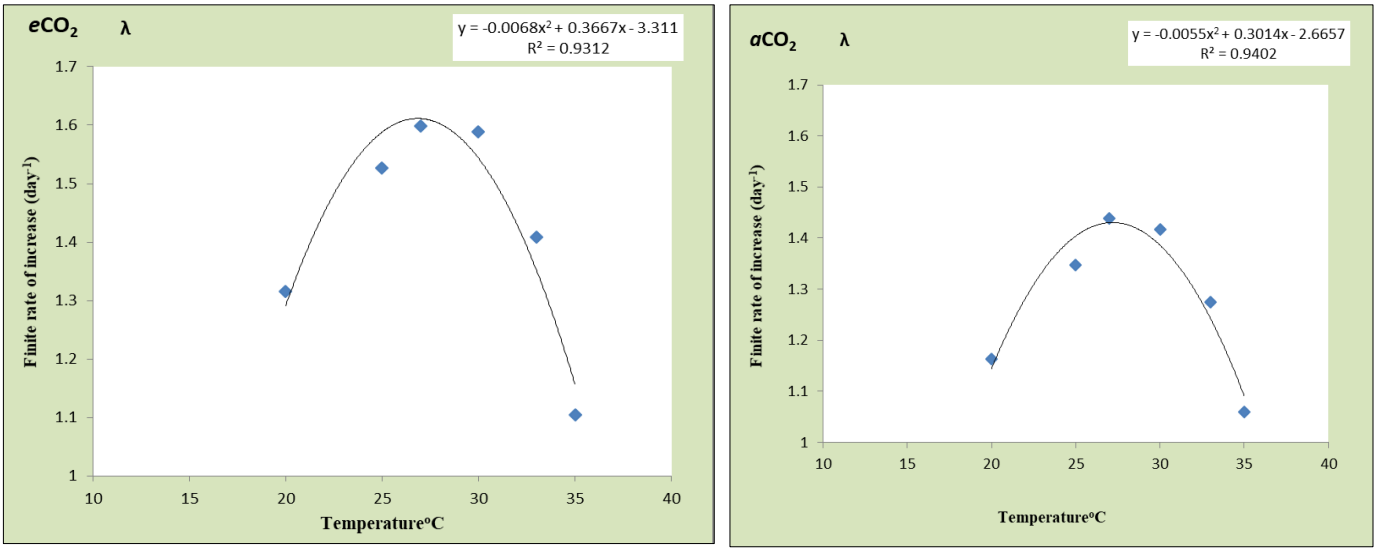


Fig 1: Effect of elevated $CO_2$and temperature on intrinsic rates of increase (r_m), net reproductive rate (R_o) and finite rate of increase (λ) of R. *maidis* on maize.

Table 1: Variation in annual mean temperature during near future, distant future and very distant future climate change periods at six maize growing locations of India

Locations	BL annual mean temperature (ºC)	NF annual mean temperature (ºC)	DF annual mean temperature (ºC)	VDF annual mean temperature (ºC)
Bhubaneswar	27.241±0.721	28.995±0.545	30.068±0.570	31.546±0.638
Coimbature	29.489±0.577	31.453±0.577	32.377±0.547	33.761±0.676
Karimnagar	27.334±0.727	28.516±0.515	29.645±0.460	31.077±0.763
Kanpur	25.851±1.058	26.603±0.578	28.114±0.778	29.925±0.986
Ludhiana	24.066±0.644	25.311±0.555	26.800±0.752	28.546±1.066
Ranchi	25.267±0.787	26.395±0.708	27.627±0.842	29.354±0.787

All values are mean ± standard deviation
NF: Near future
DF: Distant future
VDF: Very distant future

Table 2: Prediction of intrinsic rate of increase (r_m) of *R. maidis* during near, distant and very distant future climate change periods at maize growing locations of India

Locations		BL		NF		DF		VDF	
		aCO_2 (380ppm)	*e*CO_2 (550 ppm)	*a*CO_2 (380 ppm)	*e*CO_2 (550 ppm)	*a*CO_2 (380 ppm)	*e*CO_2 (550 ppm)	*a*CO_2 (380 ppm)	*e*CO_2 (550ppm)
r_m	Bhubaneswar	0.373±0.002	0.466±0.005	0.360±0.008	0.442±0.012	0.339±0.015	0.411±0.021	0.350±0.031	1.367±0.024
	Coimbature	0.351±0.012	0.429±0.017	0.296±0.021	0.354±0.027	0.258±0.025	0.306±0.032	0.217±0.049	1.239±0.049
	Karimnagar	0.373±0.003	0.466±0.004	0.367±0.005	0.452±0.009	0.349±0.010	0.425±0.014	0.371±0.034	1.386±0.026
	Kanpur	0.360±0.013	0.462±0.009	0.372±0.004	0.469±0.003	0.369±0.004	0.466±0.009	0.413±0.032	1.423±0.023
	Ludhiana	0.329±0.018	0.435±0.017	0.357±0.009	0.460±0.007	0.372±0.005	0.468±0.002	0.447±0.019	1.450±0.012
	Ranchi	0.354±0.014	0.458±0.011	0.370±0.006	0.468±0.004	0.371±0.004	0.463±0.009	0.431±0.022	1.439±0.015
	F. test	10.58**		18.66**		9.40**		1.34**	
	S.Em±	0.009		0.003		0.005		0.005	
	LSD(p =0.05)	0.017		0.007		0.011		0.011	
	LSD (p =0.01)	0.023		0.009		0.014		0.014	
	CV%	3.08		2.88		3.47		2.55	

All values are mean ± standard deviation ** Significant @ 1% level of significance NS=Not-significant

The r_m was higher during NF climate change period in both *e*CO_2 (0.469, 0.460 and 0.468 day^{-1}) and *a*CO_2 (0.372, 0.357 and 0.370 day^{-1}) conditions at Kanpur, Ludhiana and Ranchi compared to the baseline period in both *e*CO_2 (0.462, 0.435 and 0.458 day^{-1}) and *a*CO_2 (0.360, 0.329 and 0.354 day^{-1}) conditions, respectively. The r_m was declined during DF climate change period in both *e*CO_2 (0.411, 0.306 and 0.425 day^{-1}) at Bhubaneswar, Coimbatore and Karimnagar and *a*CO_2 (0.339, 0.258 0.349 day^{-1}) conditions at Bhubaneswar, Coimbatore and Karimnagar compared to the baseline period in both *e*CO_2 (0.466, 0.429 0.466 and day^{-1}) and *a*CO_2 (0.373, 0.351 0.373 day^{-1}) conditions, respectively. The r_m was increased during DF climate change period in both *e*CO_2 (0.466, 0.468 and 0.463 day^{-1}) at Kanpur, Ludhiana and Ranchi and *a*CO_2 (0.369, 0.372 and 0.371 day^{-1}) conditions at Kanpur,

Ludhiana and Ranchi compared to the baseline period in both eCO_2 (0.462, 0.435 and 0.458 day^{-1}) and aCO_2 (0.360, 0.329 and 0.354 day^{-1}) conditions, respectively. The r_m was increased during VDF climate change period at eCO_2 (1.367, 1.239, 1.386, 1.423, 1.450 and 1.439 day^{-1}) conditions at Bhubaneswar, Coimbatore, Karimnagar, Kanpur, Ludhiana and Ranchi compared to the baseline period at eCO_2 (0.466, 0.429, 0.466, 0.462 and 0.458 day^{-1}) conditions, respectively. Increased r_m at aCO_2 (0.413, 0.447 and 0.431 day^{-1}) conditions at Kanpur, Ludhiana and Ranchi compared to the baseline period at aCO_2 (0.360, 0.329 and 0.354 day^{-1}) conditions, respectively. The r_m was reduced during VDF climate change period at aCO_2 (0.350, 0.217 and 0.371 day^{-1}) at Bhubaneswar, Coimbatore and Karimnagar compared to the baseline period at aCO_2 (0.373, 0.351 and 0.373 day^{-1}) conditions. Among the all locations, lowest r_m values at eCO_2 and aCO_2 conditions, respectively were recorded in Coimbatore during NF (0.354 and 0.296 day^{-1}), DF (0.306 and 0.258 day^{-1}) and VDF (1.239 and 0.217 day^{-1}) compared to that of baseline period due to the presence of highest mean temperature (31.91ºC) was recorded in Coimbatore.

3.2.2 Net reproductive rate (R_o)

The R_o was decreased during NF climate change period in both eCO_2 (52.94, 34.23 and 55.59 nymphs/female) and aCO_2 (41.86, 27.00 and 43.82 nymphs/female) conditions at Bhubaneswar, Coimbatore and Karimnagar compared to the baseline period in both eCO_2 (60.77, 49.86 and 60.45 nymphs/female) and aCO_2 (47.19, 39.34 and 47.28 nymphs/female) conditions, respectively. The R_o was increased during NF climate change period in both eCO_2 (63.53, 64.59 and 64.38 nymphs/female) and aCO_2 (48.44, 48.80 and 48.53 nymphs/female) conditions at Kanpur, Ludhiana and Ranchi compared to the baseline period in both eCO_2 (62.72, 54.82 and 62.08 nymphs/female) and aCO_2 (48.43, 46.94 and 48.51 nymphs/female) conditions, respectively. The R_o was declined during DF climate change period in both eCO_2 (45.85, 24.97 and 48.91 nymphs/female) at Bhubaneswar, Coimbatore, Karimnagar and Kanpur and aCO_2 (36.38, 19.34 and 38.79 nymphs/female) conditions at Bhubaneswar, Coimbatore and Karimnagar compared to the baseline period in both eCO_2 (60.77, 49.86 and 60.45 nymphs/female) and aCO_2 (47.19, 39.34 and 47.28 nymphs/female) conditions, respectively. The R_o was increased during DF climate change period in both eCO_2 (57.32, 64.01 and 63.07 nymphs/female) at Kanpur, Ludhiana and Ranchi and aCO_2 (48.43, 48.05 and 48.51 nymphs/female) conditions at Kanpur, Ludhiana and Ranchi compared to the baseline period in both eCO_2 (54.82, 54.82 and 62.08 nymphs/female) and aCO_2 (48.43, 46.94 and 48.51 nymphs/female) conditions, respectively. The R_o was decreased during VDF climate change period at eCO_2 (33.29, 8.65 and 37.48 nymphs/female) and aCO_2 (26.23, 7.33 and 29.64) conditions at Bhubaneswar, Coimbatore and Karimnagar, compared to the baseline period at eCO_2 (60.77, 49.86 and 60.45 nymphs/female) and aCO_2 (47.19, 39.34 and 47.28 nymphs/female) conditions, respectively. The R_o was higher during VDF climate change period at eCO_2 (54.91, 59.30 and 62.75 nymphs/female) and aCO_2 (49.12, 46.98 and 48.62 nymphs/female) conditions at Kanpur, Ludhiana and Ranchi, compared to the baseline period at eCO_2 (54.82, 54.82 and 62.08 nymphs/female) and aCO_2 (48.43, 46.94 and 48.51 nymphs/female) conditions, respectively. Among the all locations, lowest R_o values at eCO_2 and aCO_2 conditions, respectively were recorded in Coimbatore during NF (34.23 and 27.00 nymphs/female), DF (24.97 and 19.34 nymphs/female) and VDF (8.65 and 7.33 nymphs/female) compared to that of baseline period were recorded in Coimbatore during NF, DF and VDF climate change periods due to decreased r_m values and increased range of temperature.

Finite rate of Increase (λ)

The λ was decreased during NF climate change period in both eCO_2 (1.60, 1.49 and 1.61 day^{-1}) and aCO_2 (1.448, 1.371 and 1.455 day^{-1}) conditions at Bhubaneswar, Coimbatore and Karimnagar compared to the baseline period in both eCO_2 (1.63, 1.59 and 1.63 day^{-1}) and aCO_2 (1.46, 1.44 and 1.46 day^{-1}) conditions, respectively. The λ was higher during NF climate change period in both eCO_2 (1.63, 1.61 and 1.63 day^{-1}) and aCO_2 (1.458, 1.438 and 1.455 day^{-1}) conditions at Kanpur, Ludhiana and Ranchi compared to the baseline period in both eCO_2 (1.62, 1.57 and 1.61 day^{-1}) and aCO_2 (1.44, 1.40 and 1.43 day^{-1}) conditions, respectively.

The λ was declined during DF climate change period in both eCO_2 (1.57, 1.43 and 1.58 day^{-1}) and aCO_2 (1.423, 1.326 and 1.435 day^{-1}) conditions at Bhubaneswar, Coimbatore and Karimnagar compared to the baseline period in both eCO_2 (1.63, 1.59 and 1.63 day^{-1}) and aCO_2 (1.46, 1.44 and 1.46 day^{-1}) conditions, respectively. The λ was more during DF climate change period in both eCO_2 (1.62, 1.63 and 1.63 day^{-1}) and aCO_2 (1.458, 1.459 and 1.460 day^{-1}) conditions at Kanpur, Ludhiana and Ranchi compared to the baseline period in both eCO_2 (1.62, 1.57 and 1.61 day^{-1}) and aCO_2 (1.44, 1.40 and 1.43 day^{-1}) conditions, respectively. The λ was reduced during VDF climate change period at eCO_2 (1.49, 1.32 and 1.51 day^{-1}) conditions at Bhubaneswar, Coimbatore and Karimnagar and aCO_2 (1.367, 1.239 and 1.386 day^{-1}) conditions at Bhubaneswar, Coimbatore and Karimnagar compared to the baseline period at eCO_2 (1.63, 1.59 and 1.63 day^{-1}) conditions and aCO_2 (1.46, 1.44 and 1.46 day^{-1}) conditions, respectively. The λ was higher during VDF climate change period in both eCO_2 (1.62, 1.61 and 1.63 day^{-1}) and aCO_2 (1.451, 1.450 and 1.439 day^{-1}) and at Kanpur, Ludhiana and Ranchi compared to the baseline period in both eCO_2 (1.62, 1.57 and 1.61 day^{-1}) and aCO_2 (1.44, 1.40 and 1.43 day^{-1}) conditions, respectively. Among the all locations, lowest λ values at eCO_2 and aCO_2 conditions, respectively were recorded in Coimbatore during NF (1.49 and 1.371 day^{-1}), DF (1.43 and 1.326 day^{-1}) and VDF (1.32 and 1.239 day^{-1}) compared to that of baseline period due to the presence of highest mean temperature 31.91ºC was recorded in Coimbatore.

The present results are in conformity with [7], who reported that the r_m and λ increased with increase in temperature from 20ºC and later started declining from 33ºC. An increase in mortality with decrease or increase in temperature indicates the non-linear relationship.

The present results were in agreement with [5], who reported that the R_o of *Spodoptera litura* was higher at 27ºC temperature by recording maximum offspring and R_o decreased with increase in temperature and at higher temperatures less fecundity was recorded. Similar results were observed by[13], who reported that the increase of r_m (0.281-0.478 day^{-1}) and λ (1.325-1.613 day^{-1}) with varied R_o (43.73-84.23 nymphs/female) of *A. craccivora* from 20-27ºC.

4. Conclusion

The present results were concluded that the future pest status based on Providing Regional Climates for Impacts Studies (PRECIS). A1B model showed that increased r_m and λ with varied R_o of *R. maidis* at 6 maize growing regions of India. These findings suggest that pest incidence would be higher during future climate periods.

Table 3: Prediction of net reproductive rate (R_o) of *R. maidis* during near, distant and very distant future climate change periods at maize growing locations of India

	Locations	BL		NF		DF		VDF	
		aCO_2 (380ppm)	*e*CO_2 (550 ppm)	*a*CO_2 (380 ppm)	*e*CO_2 (550 ppm)	*a*CO_2 (380 ppm)	*e*CO_2 (550 ppm)	*a*CO_2 (380 ppm)	*e*CO_2 (550ppm)
R_o	Bhubaneswar	47.19±1.505	60.77±2.422	41.86±2.281	52.94±3.601	36.38±3.494	45.85±4.391	26.23±4.907	33.29±5.980
	Coimbature	39.34±3.004	49.86±3.873	27.00±4.348	34.23±5.313	19.34±4.976	24.97±5.950	7.33±7.512	8.65±8.792
	Karimnagar	47.28±1.397	60.45±2.307	43.82±1.850	55.59±2.567	38.79±2.470	48.91±3.169	29.64±5.499	37.48±6.754
	Kanpur	48.43±0.630	54.82±1.505	48.44±0.826	63.53±1.546	48.43±2.126	57.32±3.156	49.12±5.508	54.91±7.016
	Ludhiana	46.94±1.508	54.82±5.366	48.80±0.320	64.59±0.481	48.05±0.936	64.01±0.922	46.98±3.885	59.30±3.281
	Ranchi	48.51±0.587	62.08±1.836	48.53±0.698	64.38±0.490	48.51±2.179	63.07±1.482	48.62±3.870	62.75±5.038
	F. test	33.35**		19.11**		7.03**		12.18**	
	S.Em±	0.382		0.663		1.070		0.875	
	LSD(p =0.05)	0.751		1.314		2.134		1.730	
	LSD (p =0.01)	0.990		1.737		2.833		2.284	
	CV%	3.65		4.45		6.07		9.98	

All values are mean ± standard deviation ** Significant @ 1% level of significance NS = Not-significant

Table 4: Prediction of finite rate of increase (λ) of *R. maidis* during near, distant and very distant future climate change periods at maize growing locations of India

	Locations	BL		NF		DF		VDF	
		aCO_2 (380ppm)	*e*CO_2 (550 ppm)	*a*CO_2 (380 ppm)	*e*CO_2 (550 ppm)	*a*CO_2 (380 ppm)	*e*CO_2 (550 ppm)	*a*CO_2 (380 ppm)	*e*CO_2 (550ppm)
λ	Bhubaneswar	1.46±0.003	1.63±0.005	1.448±0.009	1.60±0.014	1.423±0.018	1.57±0.026	1.367±0.028	1.49±0.039
	Coimbature	1.44±0.014	1.59±0.021	1.371±0.025	1.49±0.034	1.326±0.031	1.43±0.041	1.239±0.049	1.32±0.064
	Karimnagar	1.46±0.004	1.63±0.004	1.455±0.006	1.61±0.010	1.435±0.012	1.58±0.017	1.386±0.031	1.51±0.043
	Kanpur	1.44±0.018	1.62±0.017	1.458±0.005	1.63±0.004	1.458±0.004	1.62±0.009	1.451±0.027	1.62±0.039
	Ludhiana	1.40±0.024	1.57±0.026	1.438±0.012	1.61±0.012	1.459±0.007	1.63±0.005	1.450±0.013	1.61±0.022
	Ranchi	1.43±0.018	1.61±0.018	1.455±0.009	1.63±0.007	1.460±0.004	1.63±0.009	1.439±0.017	1.63±0.026
	F. test	8.24**		17.25**		10.94**		17.80**	
	S.Em±	0.003		0.004		0.007		0.007	
	LSD(p =0.05)	0.006		0.009		0.013		0.013	
	LSD (p =0.01)	0.008		0.012		0.018		0.017	
	CV%	1.06		0.97		1.12		1.79	

All values are mean ± standard deviation** Significant @ 1% level of significance NS = Not-significant

5. References

1. Bale JS, Masters GJ, Hodkinson ID, Awmack C, Bezemer TM, Brown VK, *et al.* Herbivory in global climate change research: direct effects of rising temperature on insect herbivores. Global Change Biology. 2002; 8:1-16.
2. Blackman RL, Eastop VF. Aphids on the world's crops: An Identification and Information Guide. 2nd fed: John Wiley & Sons, New York, 2000, 466.
3. Chi H, Su HY. Age-stage, two-sex life tables of *Aphidius gifuensis* (Hymenoptera: Braconidae) and its host *Myzus persicae* (Homoptera: Aphididae) with mathematical proof of the relationship between female fecundity and the net reproductive rate. Environmental Entomology. 2006; 35:10-21.
4. Chi H. TWO-SEX MS Chart; computer programe for age-stage two-sex life table analysis. National Cheung Hsing University, Taichung, Taiwan. (http://140.120.197.173/ecology/prod/02.htm), 2005.
5. Guang HS, Cheng XN, Zhang XX. Simulation on developmental and survival rate of brown plant hopper nymphs. Chinese Journal of Rice Science, 2000; 14(3):157-160.
6. Guerenstein PG, Hildebrand JG. Roles and effects of environmental carbon dioxide in insect life. Annual Review of Entomology. 2008; 53:161-178.
7. Hardev SS, Garegg SN, Susan EW, Ronald HG, Robert AG. Temperature-dependent reproductive and life table parameters of *Elasopalpus lignosellus* (Lepidoptera: Pyralidae) on sugarcane. Florida Entomologist. 2013; 96:380-390.
8. Hirano K, Honda K, Miyai S. Effects of temperature on development, longevity and reproduction of the soybean aphid, *Aphis glycines* (Homoptera: Aphididae). Applied Entomology and Zoology. 1996; 31(1):178-180.
9. IPCC. Summary for Policymakers. In: Global warming of 1.5 °C. Contribution of Working Group-I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. World Meteorological Organization, Geneva, Switzerland, 2018, 32.
10. Kun SB, Li HJ, HU CX, Lin HM. Interactive effects of elevated CO_2 and temperature on rice plant hopper, Nilaparvata lugens. Journal of Integrative Agriculture. 2014; 13(7):1520-1529.

11. Kuo MH, Chiu MC, Perng JJ. Temperature effects on life history traits of the corn leaf aphid, Rhopalosiphum maidis (Homoptera: Aphididae) on corn in Taiwan. Applied Entomology and Zoology. 2006; 41(1):171-177.
12. Smith CM, Boyko EV. The molecular bases of plant resistance and defence responses to aphid feeding: current status. Environmental and Experimental Botany. 2007; 122:1-16.
13. Srinivasa Rao M, Shaila O, Vennila S, Rama Rao CA. Impact of eCO_2 and temperature on Aphis craccivora koch. On groundnut and future pest status during climate change scenarios. Journal of Plant Physiology and Pathology. 2017; 5:4.
14. Srinivasa Rao M, Swathi P, Rama Rao CA, Rao KV, Raju BMK, Srinivas K, et al. Model and Scenario Variations in Predicted Number of Generations of Spodoptera litura Fab. On Peanut during Future Climate Change Scenario. PLoS ONE. 2015; 10(2):1-12.