

Potential changes in number of generations of oriental fruit fly, *Bactrocera Dorsalis* (Diptera: Tephritidae) on mango in India in response to climate change scenarios

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ABSTRACT

The oriental fruit fly, *Bactrocera dorsalis* (Hendel) is a major pest of mango crop in India and the present studies conducted to estimate the number of generations in relation to changing temperature on mango fruits across eight different geographically isolated major mango growing locations of India. The prediction of insect pest generations and generation time was done for baseline (1961 to 1990), present (1969 to 2005), near future (2021 to 2050) and distant future (2071 to 2098) periods using A1B emission scenario data from the regional circulation model (RCM), Providing Regional Climates for Impacts Studies (PRECIS) model. The degree days models using minimum and maximum temperature were used to obtain cumulative degree days (DD) for each generation of *B. dorsalis* using a temperature threshold of 13°C. It was estimated that faster accumulation of degree days would make possible for occurrence of one or two additional generations with shortened mean life cycle (5 to 7 days less) in near and distant future climate change periods compared to baseline and present periods at majority of locations. Increased number of generations and reduction of generation time at majority of mango growing locations of India suggest that the incidence of *B. dorsalis* may likely to increase due to projected increase in temperatures during future climate change scenarios.

Key Words : Mango, *B. dorsalis*, climate change scenarios, degree days, generation time, generations

Global temperatures have increased by 0.78°C (0.72°C to 0.85°C) between the average of the 1850-1990 periods and future increase predicted by 2100 was set at 1.8-4°C (IPCC, 2013). Future predictions of temperatures are varying with models and emission scenarios and extent of increase is expected to be varying across geographical locations. Climate change projections made for India indicate an overall increase in temperature by 2-4°C and precipitation by 9-16% towards 2050s (Krishna Kumar *et al.*, 2011). Annual mean temperature data analysis for period 1901 to 2005 by India meteorological department (IMD) evidenced for an increase of 0.51°C temperature during the period. This increased temperature is mainly due to increase in maximum temperature over a large part across the country (Srinivasa Rao *et al.*, 2014b).

Being poikilothermic organisms, the developmental rate in insects is highly dependent on external temperature conditions. Hence, temperature is normally considered the single most significant environmental factor influencing behaviour, distribution, development, survival and

reproduction in insects. Knowledge on the temperature-dependent population growth potential of insect pests is highly essential for understanding their population dynamics and for implementing region specific pest control strategies, especially in the context of predicted global warming (Briere *et al.*, 1999; Jarvis and Baker, 2001). Each and every insect has its own 'threshold temperature' ranges within which its development occurs (Srinivasa Rao *et al.*, 2015). So, increased temperatures will accelerate the development of insects, possibly leads to more generations (and crop damage) per year. More number of generations means an increase in the number of reproductive events per year and it would ultimately influence the intensity of crop-insect interactions (Yamamura and Yokozawa, 2002). Growing degree day (GDD) is a measure of the amount of heat that accumulates above a specified base temperature during a 24 h period and it is a valuable tool for predicting pest activity.

India is the highest mango producer in the world and also has the richest collection of mango cultivars and ranks first among mango producing countries accounting for 50

Table 1: Details of locations, period considered and annual temperature variations over the base line period for probable infestation of *B. dorsalis* on mango in particular region of India

Location (State)	Latitude (°N)	Longitude (°E)	Period considered (SMW)	Temperature variation over base line					
				PR period		NF period		DF period	
				Tmax	Tmin	Tmax	Tmin	Tmax	Tmin
Paria (Gujarat)	20°50'	73°14'	9 th -30 th	1.46	0.11	1.71	2.20	3.10	4.35
Vengurle (Maharashtra)	15°85'	73°63'	4 nd -25 th	1.78	-0.11	1.64	1.89	3.14	3.93
Lucknow (Uttar Pradesh)	26°85'	80°94'	12 th -33 th	1.49	-0.55	1.78	2.00	4.69	4.57
Sangareddy (Telangana)	17°61'	78°08'	11 th -32 th	1.38	0.5	1.85	2.19	3.69	4.57
Bhubaneswar (Odisha)	20°29'	85°82'	4 nd -25 th	0.07	1.99	1.62	3.87	3.88	4.11
Ranchi (Jharkhand)	23°34'	85°30'	12 th -33 th	1.00	0.11	2.05	2.02	4.46	4.63
Bengaluru (Karnataka)	12°97'	77°59'	12 th -33 th	0.17	0.71	2.08	2.06	4.01	4.36
Mohanpur (West Bengal)	21°84'	87°42'	12 th -33 th	0.28	0.97	2.11	2.01	4.59	4.55

per cent of the world's production. The oriental fruit fly, *Bactrocera dorsalis* (Hendel) is a polyphagous and destructive insect pest of mango fruits which causes yield losses ranging from 5 to 80 per cent (Stonehouse, 2001). Presently, it has been recorded throughout South, South East, Far East Asia and some pacific islands including Hawaii and recently its widespread presence was reported from many countries of African continent (Kapoor 1993; Choudhary *et al.*, 2016). With its broad host range, short life cycle, high mobility and high fecundity, *B. dorsalis* population growth is expected to respond strongly to temperature changes.

Considering the importance of mango and the *B. dorsalis*, present study is aimed to understand the climate change particularly increased temperature effects on number of generations of *B. dorsalis* using degree-day models on mango fruits considering four time periods (base line, present, near future and distant future) of eight major mango production locations of India.

MATERIALS AND METHODS

Weather data

In present study, we considered four climatic time periods viz., base line (BL, 1961 to 1990), present period (PR, 1969 to 2005), near future (NF, 2021 to 2050) and distant future (DF, 2071 to 2098) to collect the daily minimum and maximum temperatures. Historical daily temperatures for eight study locations (Table 1) were collected from a 1X1° grid database provided by IMD.

For future temperature data, we developed the projections obtained at a resolution of 50 X 50 km grid using PRECIS, where the daily data on maximum temperature,

minimum temperature and rainfall are available for the period 1961 to 2098. The A1B scenario is the most appropriate scenario for simulating the monsoon climate over India and characterized by rapid economic growth, quick expansion of new and efficient technology, moderate population growth and balanced use of energy sources. The future temperatures obtained were classified near future (NF, 2021 to 2050) and distant future (DF, 2071 to 2098) as followed earlier Srinivasa Rao *et al.* (2014b).

The selection of period for predicting the number of generations and generation time of *B. dorsalis* on mango was considered based on fruiting of mango across the selected region. The details of locations and period for *B. dorsalis* probable infestation are given in Table 1. The probability of *B. dorsalis* infestation on mango in particular area comprises mainly 145-150 days due to staggered flowering in selected region.

Degree-day model and number of generation

Degree-day models 'ingen' software (Srinivasa Rao *et al.*, 2014a) downloaded from ICAR-NICRA (National Innovations in Climate Resilient Agriculture) (www.nicra.in) were used to calculate the generation number and generation time. This software is developed to estimate the number of insect generations using degree day approach on maximum and minimum temperature (Tmax and Tmin) data for a given temperature threshold specific to the insect following the horizontal cut-off (degree day accumulations above the upper threshold do not count) method. Detailed information on this software can be found in Srinivasa Rao *et al.* (2014a). In the present study, the number of generations of *B. dorsalis* was estimated using lower threshold temperature of 13.0°C (Stephens *et al.*, 2007). The number of degree days

Table 2: Variation in number of generations (mean \pm standard deviation) of *B. dorsalis* at mango fruiting season in eight major mango growing regions of India under A1B climate change scenario.

Name of location	Current climate situation		Future climate change situation	
	Base line period	Present period	Near future period	Distant future period
Paria	4.69 \pm 0.20 (-3.88)**	4.84 \pm 0.11	5.22 \pm 0.19 (9.50)**	5.75 \pm 0.21 (23.80)**
Vengurle	4.30 \pm 0.17 (-2.23) ^{NS}	4.39 \pm 0.12	4.80 \pm 0.17 (10.76)**	5.38 \pm 0.16 (34.17)**
Lucknow	5.95 \pm 0.34 (9.37)**	5.34 \pm 0.19	6.52 \pm 0.36 (16.45)**	7.20 \pm 0.32 (23.74)**
Sangareddy	5.08 \pm 0.23 (-3.66)**	5.25 \pm 3.56	5.61 \pm 0.29 (6.22)**	6.31 \pm 0.31 (17.12)**
Bhubaneswar	5.54 \pm 0.33 (15.56)**	4.54 \pm 0.15	6.07 \pm 0.40 (21.22)**	6.74 \pm 0.29 (35.25)**
Ranchi	5.36 \pm 0.37 (6.35)**	4.91 \pm 0.18	5.87 \pm 0.40 (12.60)**	6.52 \pm 0.31 (21.87)**
Bengaluru	4.12 \pm 0.28 (-2.60) ^{NS}	4.24 \pm 0.11	4.72 \pm 0.28 (8.81)**	5.40 \pm 0.28 (21.54)**
Mohanpur	5.64 \pm 0.36 (10.08)**	4.98 \pm 0.14	6.14 \pm 0.40 (16.41)**	6.77 \pm 0.31 (27.39)**

** Statistically significant over the present period at $p < 0.01$ level and NS, not significant; Values in parenthesis are 't' values when compared over present period.

required for completing life cycle of *B. dorsalis* (egg to adult) was taken as 470 degree days (Stephens *et al.*, 2007). Degree-day models need a calendar start date after which degree-days begin accumulating and an end date after which degree-days stop accumulating (Ziter *et al.*, 2012). Number of generations and generation time of *B. dorsalis* during mango fruiting was estimated in four climate periods including two future periods across major mango growing locations.

Statistical analysis

The data on mean number of generations of *B. dorsalis* over the present period for base, near future and distant future periods were compared using two-sample t-test assuming equal variances. The models are deterministic; therefore, it was not necessary to use ANOVA to make statistical inferences (Ziter *et al.*, 2012). A non-parametric statistical test Mann-Kendall test was used for the analysis of trend in insect generations in time series for the four specified periods. The Mann-Kendall test confirm the existence of a positive or negative trend for a given confidence level (Kendall, 1975). Magnitude of trend in insect generations in time series (change per unit time) was estimated and determined by Theil-Sen's slope estimator. Statistical analysis were done by using SPSS version 21.0, Past version 3 and MAKESENS version 1.0.

RESULTS AND DISCUSSION

Significant variation in generation time and number of generations of *B. dorsalis* was observed across eight locations of India with A1B emission scenario in different time periods during mango fruiting season (Table 2). *B.*

dorsalis accumulated lowest thermal degree days of 1937.89 DD with 4.24 generations at Bengaluru in comparison to highest 2509.42 DD with 5.34 generations at Lucknow during the present period (Table 2 & 3). The mean growing degree days of *B. dorsalis* was in range of 470 \pm 0.30 DD as the units that have not changed with locations. At Lucknow, the possible number of generations is expected to increase from 5.34 under the present scenario to 7.20 under distant future scenario. The number of degree days is expected to increase 3065.08 DD during near future and 3382.49 DD during distant future making it to possible the complete two more additional generations as compared to the current climatic conditions at Lucknow (2509.42 DD). Similar situation is also predicted for other locations also, where one or two more generation over four to five generations would be expected to occur during near and distant future climate change scenarios as compared to base line and present periods on mango crop in major mango growing regions of India. Increase in number of generations of *B. dorsalis* with shortened generation time over base line period was predicted to occur in near and distant future periods (Table 2 & 3). The average length of time to complete life cycle of *B. dorsalis* at Sangareddy was recorded to be 25 and 23 days during near and distant future compared to 27 and 26 days during the base level and present climatic periods, respectively. The similar decrease in generation time is marked across the other locations also (Table 3). The increased number of generations is obviously due to shortening of the time taken to complete a generation for the insect made possible by faster accumulation of required heat units (Srinivasa Rao *et al.*, 2014b). Generation time is expected to be shortened by

Table 3: Mean generation time and total accumulated degree days (TDD) of *B. dorsalis* at mango fruiting season in major mango growing regions of India under A1B climate change scenario

Name of location	Base line period			Present period		
	Mean GT	Mean GDD	TDD	Mean GT	Mean GDD	TDD
Paria	30.61±4.19	470.11±0.24	2203.44±92.91	28.91±2.78	470.00±0.29	2276.34±51.56
Vengurle	32.84±2.60	469.91±0.30	2018.75±78.90	32.18±4.43	469.91±0.30	2063.29±55.36
Lucknow	23.79±4.30	470.00±0.23	2794.97±159.98	26.34±3.15	470.00±0.25	2509.42±90.39
Sangareddy	27.25±5.96	469.69±0.26	2385.68±109.67	26.60±3.56	469.94±0.28	2466.83±68.64
Bhubaneswar	24.38±9.09	469.98±0.26	2601.53±158.06	31.74±7.53	470.00±0.29	2133.43±69.30
Ranchi	26.81±3.57	469.97±0.24	2520.59±178.47	28.79±2.69	470.01±0.29	2307.31±81.68
Bengaluru	33.11±3.41	469.87±0.37	2003.03±49.01	33.89±5.34	469.98±0.31	1937.89±92.91
Mohanpur	25.32±3.19	496.93±0.22	2651.36±172.25	28.33±1.20	469.98±0.25	2341.99±63.70
	Near future			Distant future		
	Mean GT	Mean GDD	TDD	Mean GT	Mean GDD	TDD
Paria	26.74±2.65	469.99±0.30	2454.47±90.11	24.49±2.30	469.97±0.22	2700.17±97.01
Vengurle	28.97±2.24	470.01±0.28	2255.45±80.73	26.16±1.51	470.04±0.24	2530.35±74.30
Lucknow	21.80±3.47	469.97±0.17	3065.08±172.81	19.57±3.15	470.00±0.21	3382.49±153.74
Sangareddy	25.22±5.10	469.93±0.21	2636.98±136.18	22.55±3.98	469.98±0.17	2636.98±136.18
Bhubaneswar	21.96±7.05	470.02±0.22	2854.93±189.17	20.69±5.59	470.01±0.17	3170.01±139.67
Ranchi	24.09±3.15	469.97±0.24	2758.29±192.51	21.80±2.65	469.94±0.21	3064.72±150.22
Bengaluru	29.8±3.78	470.08±0.28	2218.01±135.25	25.94±3.01	469.92±0.25	2535.75±135.39
Mohanpur	23.46±3.07	469.98±0.22	2885.58±189.38	20.90±2.50	469.95±0.20	3182.29±145.94

GT: generation time; GDD: growing degree days; TDD: total degree days

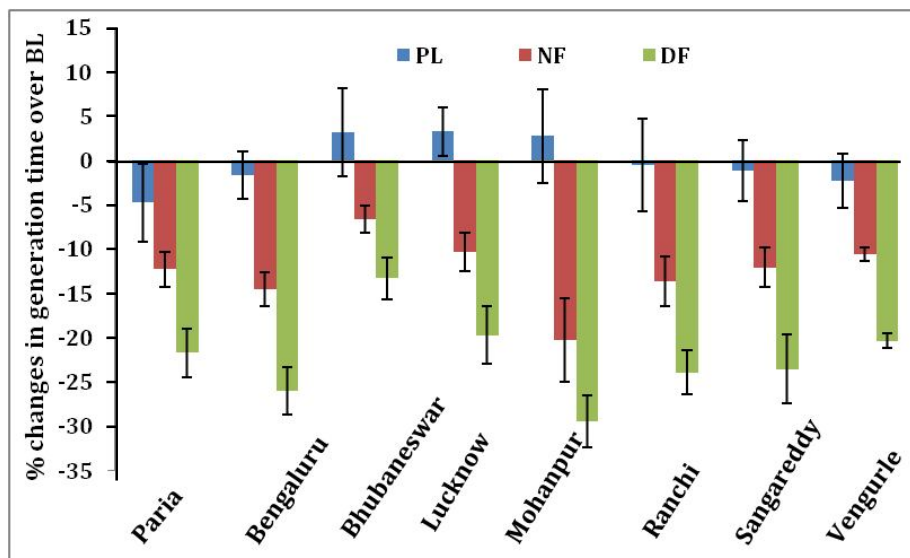


Fig 1: Per cent change in generation time of *B. dorsalis* during mango fruiting season under climate change scenarios

6.59-14.46 per cent in near future and 13.28-29.43 per cent during distant future across all the regions (Fig. 1). The highest per cent reduction in generation time over baseline is predicted for distant future (29.43%) at Mohanpur followed by Bengaluru (25.97%). Analysis of number of generations among climate change scenarios over the present periods

using t-test showed that variation was significant ($p < 0.01$) at all the selected locations except Vengurle and Bengaluru where no significant difference was noticed among base and present period generation numbers (Table 2).

The Mann Kendall (MK) test was applied on a yearly

Table 4: Temporal trends in number of generations of *B. dorsalis* across eight major mango growing regions during fruiting season.

Name of location	Climate scenarios	No. of data points	Tau correlation co-efficient	Mann Kendall statistics (s)	Normalized test statistics (Z)	Sen's slope estimates (Q)	Trend
Paria	BL	30	0.28*	122	2.16	0.009	↑
	PR	37	0.15	101	1.31	0.003	NS
	NF	30	0.34**	146	2.59	0.008	↑
Vengurle	DF	28	0.33*	123	2.41	0.012	↑
	BL	30	0.34**	146	2.59	0.011	↑
	PR	37	0.10	68	0.88	0.002	NS
Lucknow	NF	30	0.44**	191	3.39	0.013	↑
	DF	28	0.20	78	1.52	0.006	NS
	BL	30	-0.03	-14	-0.23	-0.003	NS
Sangareddy	PR	37	0.006	4	0.03	0.000	NS
	NF	30	0.38**	164	2.90	0.021	↑
	DF	28	0.20	75	1.46	0.013	NS
Bhubaneswar	BL	30	0.06	27	0.46	0.001	NS
	PR	37	0.11	76	0.98	0.002	NS
	NF	30	0.50**	218	3.87	0.022	↑
Ranchi	DF	28	0.33*	124	2.43	0.016	↑
	BL	30	0.01	6	0.08	0.000	NS
	PR	37	0.03	21	0.26	0.001	NS
Bengaluru	NF	30	0.46**	200	3.55	0.026	↑
	DF	28	0.26	99	1.94	0.014	NS
	BL	30	-0.08	-37	-0.64	-0.006	NS
Mohampur	PR	41	-0.10	-86	-0.96	-0.002	NS
	NF	30	0.24	105	1.86	0.017	NS
	DF	28	0.14	55	1.07	0.008	NS
Bengaluru	BL	30	0.06	26	0.45	0.002	NS
	PR	37	0.27	178	2.31	0.004	↑
	NF	30	0.59**	256	4.55	0.024	↑
Mohampur	DF	28	0.36**	134	2.63	0.019	↑
	BL	30	-0.12	-56	-0.98	-0.007	NS
	PR	41	0.14	120	1.33	0.002	NS
Bengaluru	NF	30	0.23	101	1.78	0.014	NS
	DF	28	0.14	55	1.07	0.008	NS

* Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed); Symbol ↑ indicating increasing trend

data to detect trends in number of generations of *B. dorsalis* in different climate scenarios and the values of the Mann-Kendall statistic and Sen's slope are presented in Table 4. Non significant temporal variation of *B. dorsalis* was observed during BL and PR periods at all the locations except Paria, whereas significant increasing trend was predicted to occur during base level period ($p < 0.05$; Sen's Slope (Q) = 0.009). The number of generations of *B. dorsalis* during mango fruiting season for NF periods at Paria, Vengurle, Lucknow, Sangareddy, Bhubaneswar and Bengaluru exhibited significant increasing trends ($p < 0.01$) with the respective Sen's slope (Q) 0.008, 0.013, 0.021, 0.022, 0.026 and 0.024 whereas, non significant trends were observed for Ranchi and Mohanpur locations. In general, research findings indicate that there would be an increasing trend of number of generations during future climate change scenarios at all the tested locations of mango regions. Similar result of number of generation model fit with time period was observed by Hu *et al.* (2015) during 2021-2050 in case of brown planthopper, *Nilaparvata lugens*, in China.

Majority of studies showed that prediction of number of generations, development time and estimation of the sensitivity of impact predictions to differences in geographical locations in relation to temperature could be possible through degree day's models (Srinivasa Rao *et al.*, 2014b; 2015). Present study also brings out the impact of climate change on *B. dorsalis* following similar approaches related above. Increase in the number of generations annually with extreme temperatures in insect species was well known and is a regular phenomenon with gradual increase of temperature as observed in present study.

CONCLUSION

Present study indicated additional number of generations of *B. dorsalis* on mango fruits as an effect of climate change particularly increased temperatures with an expected aggravated population on mango at majority of major mango growing region of India during future climate change periods. The present results may call for better decision making management strategies in future on mango plant protection. Even though there may be great uncertainty inherent in present single model and scenario combination approach, the results depict a possible highest increase in number generations of the *B. dorsalis* without considering crop phenology, pest phonology and multi-species interactions.

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