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Original Research Paper

Prediction of number of generations of serpentine leaf miner, *Liriomyza trifolii* (Burgess) (Agromyzidae: Diptera) in India assessed by CLIMEX under climate change scenario

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ABSTRACT

The serpentine leaf miner, *Liriomyza trifolii*, is an invasive pest that affects plants, causing damage to the leaves and reducing crop yield. Number of generations of serpentine leaf miner was assessed under current and expected future climate change scenarios. The assessment was done for Representative Concentration Pathway (RCP 8.5), a future climate change scenario in India. *L. trifolii* would have had 16-19 generations, in base line and 17-24 in 2050-time frame under future climate change in Andhra Pradesh conditions. Under Arunachal Pradesh conditions, it would have had 6-14 generations in base line and is expected to complete the same number of generations in 2050, scenario. Under Sikkim conditions 3 - 4 and 5 number of generations were assessed for present and future climate change scenario. Suitability of the localities was expressed in terms of Ecoclimatic index (EI) ranging from 0 to > 20 by combining the interaction effect of various stress indices and growth indices for the development of *L. trifolii*. It was observed that in temperate areas the pest incidence may increase in future, in contrast to the decreasing trend in areas where already the prevailing temperatures are near upper thresholds. It is therefore expected that number of generations of *L. trifolii* would increase with the rising temperatures under climate change situations.

Keywords: Climate change, CLIMEX, India, *Liriomyza trifolii*, RCP 8.5

INTRODUCTION

Climate exerts powerful effects on the distribution and abundance of the insect species, and climate warming is expected to generate changes for many insect populations and the ecosystems they inhabit (Stange & Ayres, 2010). Several phenology models based on temperature are used to predict exotic pest establishment (Herms, 2004; Nietschke et al., 2007; Shi, 2010) as it plays a major role in the growth and development of insects, compared to other abiotic factors. The amount of heat required to complete a generation in *poikilothermic* organisms like insects is fairly constant, with a species-specific optimum temperature range restricted with lower and upper threshold temperatures. This optimum range can be used to calculate the degree-day units for the target insect and subsequently predict insect development under present and future climate change scenarios (Roltsch et al., 1999).

Leaf miner, *Liriomyza trifolii* (Burgess) (Diptera: Agromyzidae) an invasive polyphagous pest on variety of vegetables and ornamental foliage causing significant economic loss in India (Kaur et al., 2010; Chakraborty, 2011). Though, the insect was reported in India in early 1990's (Anonymous, 1991), it has spread and established across India with peak infestation during summer months in different parts of the country (Singh, 2005; Durairaj, 2007). Basic developmental biology of *L. trifolii* including thermal degree days requirement was studied by Liebee (1984). The number of generations of *L. trifolii* for both the current and future climate change time periods in India was estimated while considering climate change into account. Possible number of generations of *L. trifolii* was estimated also for the time frame prior to the introduction of the insect into India, for the sake of comparing it with successive future time frames.

Prediction of number of generations of *L. trifolii* are estimated for IPCC (Inter-governmental Panel on

Climate Change) Representative Concentration Pathway (RCP 8.5 scenario). RCP 8.5 assumes a pathway of high greenhouse gas emissions, particularly carbon dioxide (CO_2), resulting from continued reliance on fossil fuels, deforestation, and other human activities that release greenhouse gases into the atmosphere. Under the RCP 8.5 scenario, global temperatures are projected to increase significantly compared to pre-industrial levels. This could lead to substantial warming by the end of the century, with potential consequences such as more frequent and intense heatwaves, altered precipitation patterns, and rising sea level (IPPC, 2023).

MATERIALS AND METHODS

The CLIMEX model for *L. trifolii* was fitted to the known geographic range using the procedure described in the user's guide (Sutherst et al., 2007) under the reference climate. Using this method, the model parameters (Table 1) were manually iteratively adjusted until the simulated geographical distribution indicated by the Ecoclimatic Index (EI) values agreed with the species known native distribution. To mimic the climate in CLIMEX, we used the Climond 302 gridded data (https://www.climond.org/CLIMEX.aspx) (Kriticos et al., 2012). The Climond 302 is a long-term average of the minimum and maximum monthly temperatures (Tmin & Tmax), the total amount of precipitation (Ptotal), and the relative humidity at 9:00 and 15:00 (RH09:00 and RH15:00) (Kriticos et al., 2012). Historical climate data has been collected from the Climond 302 gridded resolution dataset (1950-2000). The reference climate dataset was used in CLIMEX to project the threat posed by *L. trifolii* under current climate conditions. The future climate change scenario RCP 8.5 risk was gauged using climate projections of increase of 4.3^{o}C raise in temperature by 2100.

Parameter setting

In the present study, the majority of initial parameters except for cold stress were obtained from previous reports or biological data sets. The parameters for cold stress were manually iteratively adjusted until the simulated geographical distribution indicated by the EI and (Cold stress) CS values was consistent with the distribution characteristics of the species.

Table 1 : Parameters used in the CLIMEX model for *L. trifolii*

Parameter	Mnemonic	Value
Limiting low temperature	DV0	9.7
Lower optimal temperature	DV1	15.0
Upper optimal temperature	DV2	32.0
Limiting high temperature	DV3	35.0
Limiting low soil moisture	SM0	0.2
Lower optimal soil moisture	SM1	0.4
Upper optimal soil moisture	SM2	0.8
Limiting high soil moisture	SM3	1.5
Cold stress temperature rate	TTCS	-5.0
Cold stress temperature rate	THCS	-0.002
Heat stress temperature threshold	TTHS	38
Heat stress temperature rate	THHS	0.005
Dry stress threshold	SMDS	0.2
Dry stress rate	HDS	-0.01
Wet stress threshold	SMWS	1.5
Wet stress rate	HWS	0.001
Degree-days per generation	PDD	314

Temperature index

Lower and upper threshold temperatures of 9.7 and 35ºC and thermal degree day unit requirement for egg-egg development for *L. trifolii as* 314 DD per generation was used (Leibee, 1984). Based on thermal requirements, potential number of generations of *L. trifolii* per year was calculated for different parts of India under climate change scenario using CLIMEX software. The minimum temperature for development (DV0) was set to 9.7°C (Table 1). The lower optimum temperature (DV1) and the optimum temperature (DV2) were set to 15°C and 32°C, respectively. The maximum temperature for development (DV3) was set to 35°C (Leibee, 1984). The weekly temperature index (TIW) was calculated using the DV0-DV3 parameters described by Kriticos et al. (2015). The number of degree-days per generation (PDD) was set to 314 as recommended by (Leibee, 1984).

Moisture Index

The limiting low soil moisture (SM0) and lower optimal soil moisture (SM1) thresholds were set to 0.2 and 0.4, respectively. Also, we adopted the upper optimal soil moisture threshold (SM2) and limiting high soil moisture threshold (SM3), which were set to 0.8 and 1.5, respectively.

Cold stress and heat stress

The stress indices in CLIMEX are set to limit the species' ability to survive during adverse seasonal conditions, and thus determine its geographical distribution (Kriticos et al., 2015). Cold temperature was the most significant factor affecting the seasonal distribution of *L. trifolii.* The parameters of heat stress temperature threshold (TTHS) and heat stress temperature rate (THHS) were used in the threshold temperature mode to calculate the heat stress (HS), and set to 38°C and 0.005 week^{-1}, respectively. The weekly HS was calculated by accumulating THHS when the average weekly maximum temperatures (Tmax) exceeded TTHS. Also, wet stress threshold (SMWS) and wet stress rate (HWS) for wet stress (WS) were set to 1.5 and 0.001, respectively. Wet stress (WS) was accumulated if the soil moisture level (SM) exceeds the SMWS. The difference between SMWS and the SM was multiplied by the HWS to obtain the resultant WS. Dry stress (DS) accumulates when the soil moisture level falls below the dry stress threshold (SMDS) (Kriticos et al., 2015). The difference between SMDS and weekly soil moisture level was multiplied by the dry stress rate (HDS) to obtain the resultant DS for the week. The SMDS and HDS were set to 0.2 and -0.01, respectively.

RESULTS AND DISCUSSION

Present and future number of generations that *L. trifolii* can produce per year is shown in Table 2. The model prediction in different locations yielded the following number of generations of *L. trifolii* per year in different states in India. Among all locations in India, a greater number of annual generations of *L. trifolii* was likely to occur in Andhra Pradesh (16-19), Gujarat (15-19) and Maharashtra (15-19). Moderate levels would be experienced by Karnataka

Table 2 : Number of generations of *L. trifolii* under present and climate change scenarios in India

Location	No. of generations	
	Present climate	Future climate change scenario
Andhra Pradesh	16-19	17-24
Chhattisgarh	14-18	20-22
Karnataka	15-17	20-22
Maharashtra	15-19	20-23
Orissa	16-18	18-21
Assam	12-16	17-19
Arunachal Pradesh	6-14	6-14
Manipur	9-14	14-16
Meghalaya	11-16	13-18
Mizoram	10-16	17
Nagaland	7-14	9-16
Tripura	16-18	18
Bihar	15-17	19-20
Jharkhand	15-15	17-20
Sikkim	3-4	5
Uttar Pradesh	15-17	20
West Bengal	15-18	15-21
Goa	19	22
Gujarat	15-19	20-23
Rajasthan	17-19	18-22
Haryana	16-18	18-20
Himachal Pradesh	7-12	13
Punjab	16-18	19-20
Jammu and Kashmir	11-15	13-16
Uttarakhand	12-17	14-17
Kerala	15-18	19-21
Tamil Nadu	16-19	20-23
Madhya Pradesh	15-18	18-21

(15-17), Chhattisgarh (14-18) Kerala (15-18), Madhya Pradesh (15-18) and Odisha (16-18) North Eastern states like Manipur (9-14), Meghalaya (11-16), Mizoram (10-16), Nagaland (7-14) states experience a smaller number of generations per year under present climatic conditions. The highest additional generations possible were recorded in Rajasthan, Gujarat, Andhra Pradesh, Tamil Nadu and Maharashtra. Lowest number of generations was observed in Sikkim, which can be attributed to extreme lower temperatures in winter and fatal temperatures during summer.

Temperature is a factor causing large differences in development of *L, trifolii* (Leibee, 1984; Miller & Isger, 1985; Vercambre & Thiery, 1983). The generation time decreases with temperature from 48 days at 15°C to 24 days at 25°C. At 20°C a population may multiply more than 25 times per generation (Minkenberg, 1988). Similar observations were made by Parella (1987) who found that longevity decreased with an increase in temperature. Abolmaaty et al. (2010) estimated increase in number of generations of *Tuta absoluta* (Meyrick) for 2050 and 2100 future climates for A1 scenario in Egypt based on degree day's units. The results are comparable with similar predictions for clover root weevil, *Sitona lepidus* Gyll. (Arbab and Mcneill, 2011).

Climate change scenario

Under future climate change scenario, a gradual increase in the number of generations is expected in India by 2050 (Table 2). Andhra Pradesh 17-24, Arunachal Pradesh 6-14, Assam 17-19, Bihar 19-20, Chhattisgarh 20-22, Goa 22, Gujarat 20-23, Haryana 18-20, Himachal Pradesh 13, Jharkhand 17-20, Karnataka 20-22, Kerala 19-21, Madhya Pradesh 18-21, Maharashtra 20-23, Manipur 14-16, Meghalaya 13-18, Mizoram 17, Nagaland 9-16, Odisha 18-21, Punjab 19-20, Rajasthan 18-22, Sikkim 5, Tamil Nadu 20-23, Tripura 18, Uttar Pradesh 20, Uttarakhand 14-17 and West Bengal 15-21 generations per year. The present results emphasize the usage of degree-day models like mathematical models to describe the relationship between temperature and development rate for future prediction of pests. However, a multi-factorial approach incorporating other biotic and abiotic factors determining the development of *poikilotherms* is recommended (Sharpe & DeMichele, 1977; Schmaedick & Nyrop, 1993; Arbab & Mcneill, 2011; Rao et al., 2012). Insecticide efficacy may be enhanced through the proper timing of applications at critical developmental stages of the insect pest, assessed through thermal degree-days. Temperature plays an important role in the life cycle of insects with higher temperature causing faster completion of life cycle, thus leading to more generations (Zhang et al., 2009).

Several studies indicate an increase in global average temperatures leading to regional climate changes that may have immediate effect mainly on the population dynamics of insects which are poikilothermic, affecting their development and distribution. The present results show rapid development of *L. trifolii* during higher temperatures with increased number of generations, both under present conditions as well as under climate change situations. Various authors have predicted 15 generations per year for *L. trifolii* with life-cycle completion in 23.6 – 25.6 days at 20°C; 24 generations at 25°C (15.0-16.5 days) (Lanzoni et al., 2002, Sakamaki et al., 2003, Tokumaru & Abe, 2003; Andersen & Hofsvang, 2010). However, phenological models based on degree-day accumulation have been developed to support the integrated pest management of many insects (Fettig et al., 2004; Arbab & Mcneill, 2011).

CONCLUSION

This study predicts the number of generations of the serpentine leaf miner*, L. trifolii*, in India under current and future climate change scenarios using the CLIMEX modelling approach and also explains the complex relationship between climate change and pest populations, specifically the potential for increased pest activity in temperate regions as temperatures rise. In regions where temperatures are already near the upper thermal limits for pests, populations may decline or stabilize. However, in cooler temperate zones, warmer temperatures could create more favourable conditions for *L. trifolii*, allowing them to thrive and complete more generations per season. Thus, it can be concluded that temperature played a significant role in the development period of leaf miner and showed an inverse relationship with temperature

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