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Influence of Climate Factors on Population Density and Damage of Peach Twig Borer, *Anarsia lineatella* Zeller (Lep.,: Gelechidae), in Saman Orchards, Iran

Zarir Saeidi[1]*

ABSTRACT

The effect of climate factors on the population changes and damage of Peach Twig Borer (PTB), *Anarsia lineatella* Zeller., was studied during 2007-2017 in Saman Orchards, Iran. Time series data of climate and pest population were subjected to the Mann-Kendall trend analysis. Seasonal flight of the pest was studied using pheromone traps from May to October. The percentage of infested twigs was calculated during May and September, while the percentage of infested fruits was determined twice a month from July to September. Results showed increasing trends in the mean temperature of annual, winter and autumn seasons (Kendall's statistics were 0.63, 0.49 and 0.42, respectively). Moreover, there were significant increasing trends in annual mean minimum, mean maximum, and absolute minimum temperatures (0.53, 0.63 and 0.46, respectively). The number of annual and January frost days (-0.55 and -0.51, respectively) and mean relative humidity of Jun, July, August, September and October showed decreasing trend. PTB population and damage showed significant and increasing trends during the studied years. According to stepwise regression analysis, the percentage of relative humidity, mean annual minimum temperature and mean annual temperature were the most statistically significant variables influencing the percentage of infested branches ($r= 0.94$, $r^2= 0.88$, $F(3,6)= 14.40$, $P= 0.004$) and pest population ($r= 0.98$, $r^2=0.96$, $F(4, 5)= 3.18$, $P= 0.001$). The pest population and damage will increase under the studied climate change scenarios (A1F, A1T, A1B, A2, B1 and B2) in the future, which is more significant in A1F than others.

Keywords: Climate scenarios, Infestation, Pests seasonal flight, *Prunus persicae* Batsch, Trend analysis.

INTRODUCTION

Peach Twig Borer [PTB], *Anarsia lineatella* Zell. (Lep.: Gelechiidae), is the most important pest in peach (*Prunus persicae* Batsch) orchards as well as other stone fruits such as almond, apricot, plum and nectarine (Mamya *et al.,* 2014). Larvae of the overwintering generation burrow into developing shoots, while in subsequent generations, as twig tissue hardens, they cause considerable losses in quantity and quality of the fruits (Roshandel, 2019). Studies showed that climate factors (temperature, precipitation, and humidity) are the most critical factors influencing distribution and seasonal activity of the insects under field conditions (Ullah *et al*., 2012; Bayu *et al.,* 2017). Moreover, the population growth parameters of the insects and mites such as developmental rate, reproduction, survival, and longevity vary with the climate factors (Riahi *et al.,* 2013; El-Halawany and Abdel-wahed, 2013). According to Kocmánková *et al.* (2010), temperature is probably the most important environmental variable affecting population dynamics of the insects.

Agricultural crops and their corresponding pests' population and damages are affected directly and indirectly by changes in temperature and other climate factors (Skendzic *et al.,* 2021). Climate factors

[1]Department of Plant Protection, Agricultural and Natural Resources Research and Education Center, AREEO, Chaharmahal va Bakhtiari, , Shahrekord, Islamic Republic of Iran. e-mail: z.saeidi@areo.ac.ir

directly influence the pests' life table parameters, whereas they indirectly affect the relations between pests, host plants, environment, and other insect species (Prakash *et al.,* 2014). Liang and Elbakidze (2011) reported significant relationship between outbreak of the pests and changes in the environmental factors. Various studies investigated the impact of climate changes on the distributions, migration, population changes, and damage of insect pests such as the onion thrips, *Thrips tabaci* Lindeman (Bergant *et al.,* 2005), Lepidoptera species (Sparks *et al.,* 2007), the plain tiger, *Anosia chrysippus* L. (Sudan *et al.,* 2015), and the leopard moth, *Zeuzera pyrina* L. (Fekrat and Farashi, 2022, Saeidi *et al.,* 2022 and 2023).

Considering the importance of the climate variables, this study was conducted to investigate the effect of climate factors on the population changes and damage of PTB in Saman Orchards, Chaharmahal va Bakhtiari Province, Iran. The results are helpful for predicting the pest population in the future under different climate change scenarios and applying suitable tactics to reduce the pest-induced crop losses, and sustainable management of *A. lineatella* in peach orchards.

MATERIALS AND METHODS

Meteorological Data

Meteorological data of the Saman Synoptic Station were obtained from Iran Meteorological Organization, Chaharmahal va Bakhtiari Province. The geographical coordinates of the studied station were: latitude 32.44 N, longitude 50.87 E and altitude 2,057 m. The studied climate variables were: mean temperature of different months and seasons, annual mean of temperature, annual mean of maximum and minimum temperature, annual absolute maximum and minimum temperature, annual relative humidity, annual precipitation, and the number of frost days per year.

Seasonal Activity of the Pest

Seasonal flight of the adults was studied during 2007-2017 using sex pheromone traps. Four peach orchards with 5 km distances were selected. Peach trees were approximately 4-6 years old, and planted at 3×4 m distances between and along the rows. No insecticide was applied on experimental plots during the period of study. The pheromone dispensers, type of trap and installation height followed Roshandel (2019). The geographical coordinates of the studied orchards and their distance from the Saman Synoptic Station are given in Table 1.

The traps were set up in the peach orchards from April 20 (before the emergence of adult males) to October 30 (the end of the adults' flight) to monitor the pest population. In each orchard, four sex pheromone traps were installed at 50 meters distance to avoid interference between them. All traps were set at a height of 1.5-2 m above the ground level and leaves and branches were removed around their entrances. Pheromone traps were checked twice a week until the first capture of adults, then, once a week to record the number of captured moths. The pheromone lures and the sticky sheets were replaced every 30 and 15 days, respectively.

Twig Infestation

Twig damage was determined at the early spring (5th and 20th April and 5th of May) and early fall (1st and 15th of October). For this purpose, in each orchard, 10 trees were selected randomly and 10 random twigs, from different side of the tree at mid height, were examined and the infestation ratio was calculated.

Fruit Infestation

Percentage of infested fruits was determined twice a month from the July 5 to

Table 1. Geographical coordinates of the studied orchards and their distance from Saman Synoptic Station, Chaharmahal Bakhtiari Province, Iran.

Orchard location	Geographical coordinates (latitude and longitude)	Altitude (m)	Distance from the station (km)
Shoorab	32.49 N, 50. 95 E	1970	9
Cham khorram	32.47 N, 50.95 E	1641	5.5
Cham jangal	32.52 N, 50. 85 E	1703	12
Cham chang	32.52 N, 50.09 E	2280	8.5

September 5 (harvesting time). Percentage of infested fruits was determined by examining 10 randomly selected fruits from each tree (totally 10 trees were examined in each orchard) and recording the number of infested and non-infested fruits.

Prediction of the Pest Population Changes under Different Climate Change Scenarios

The population changes of PTB (Peach Twig Borer) was estimated under six main scenarios (A1F, A1T, A1B, A2, B1 and B2) defined by the Intergovernmental Panel on Climate Change (IPCC, 2007). These scenarios are based on the emission of greenhouse gases and global warming in the future. According to the IPCC, the temperature will increase at a rate of 0.4, 0.24, 0.28, 0.34, 0.18 and 0.24 °C per decade in A1F, A1T, A1B, A2, B1 and B2 scenarios, respectively. According to IPCC (2007), the multi-model mean Surface Air Temperature (SAT) warming and associated uncertainty ranges for 2090 to 2099 relative to 1980 to 1999, including B1: +1.8°C (1.1 to 2.9°C), B2: +2. °C (1.4 to 3.8°C), A1B: +2.8°C (1.7 to 4.4°C), A1T: 2.4°C (1.4 to 3.8°C), A2: +3.4°C (2.0 to 5.4°C) and A1F: +4.0°C (2.4 to 6.4°C).

Statistical Analysis

The Mann-Kendall trend test was run at 95% confidence level on time series data of both climate and pest population for the studied period, 2007 to 2017. The null hypothesis H0 (that assumes there is no trend, i.e. the data is independent and randomly ordered), was tested against the alternative hypothesis H1, which assumes there is a trend. If the p-value is less than the significance level α (Alpha= 0.05), H0 is rejected. Accepting H0 indicates no trend while rejecting H0 indicates a trend in the time series data (Kendall, 1975; Pohlert, 2016).

The software Addinsoft's XLSTAT 2018 was used for performing the statistical Mann-Kendall test. Pearson's correlation coefficient was used to determine the effect of each climate variable on the damage and population changes of PTB. Moreover, stepwise regression was used to find a set of climate variables that significantly influence the population and damage of PTB in peach orchards.

RESULTS

Comparison of Climate Factors

The average of annual mean temperature from 2007 to 2017 at Saman Synoptic Station was calculated as 13.35±0.25°C, ranging from 11.69 to 14.95°C. Therefore, the annual average temperature in the hottest year (2016-17) increased by 2.67°C compared to the coldest year (2012-13) (Table 2). The same trend was observed in different months, especially in winter months. January, February and March showed the highest increase (11, 7.4, and 5.8°C, respectively) in temperature in the hottest year compared to the coldest one

Table 2. Mean of different climate variables in Saman Synoptic Station, Chahrmahal & Bakhtiri Province, Iran, from 2007-2017.

Climate variables	Mean	SE	Range
No. of frost days	67	3.7	19 - 89
Annual absolute minimum temperature	-12.69	1.63	(-21.8) – (-6.8)
Annual absolute maximum temperature	36.68	0.24	35.6 – 38.5
Annual mean maximum temperature	20.56	0.28	18.23 – 22.25
Annual mean minimum temperature	6.24	0.35	2.95 – 7.62
Annual mean temperature	13.35	0.27	11.69 – 14.95
Annual precipitation	279.4	21.52	155.7 – 419.3
Annual relative humidity	34.73	0.73	30.95– 38.73
January mean temperature	1.05	1.09	(-5.8) – 5.7
February mean temperature	2.42	0.67	(-0.8) – 7.1
March mean temperature	7.08	0.50	3.34 – 9.13
April mean temperature	10.63	0.41	8.44 – 13.35
May mean temperature	15.96	0.36	13.77 – 17.60
Jun mean temperature	21.45	0.36	19.20 – 22.94
July mean temperature	24.98	0.28	22.4 – 26.1
August mean temperature	24.09	0.52	19.5 – 26.3
September mean temperature	21.42	0.31	18.75 – 22.92
October mean temperature	16.95	0.27	15.16 – 18.26
November mean temperature	10.39	0.48	7.80 – 13.19
December mean temperature	4.28	0.39	1.75 – 6.82
Autumn mean temperature	10.35	0.27	8.6 – 11.8
Winter mean temperature	3.44	0.6	(-0.6) – 6.7
Spring mean temperature	16.02	0.28	14.2 – 17.6
Summer mean temperature	23.59	0.35	20.2 – 24.9

(Table 2). The annual mean maximum temperature from 2007 to 2017 was 20.56 ±0.28°C, ranging from 18.23 to 22.25 °C, whereas, the annual mean minimum temperature was calculated as 6.24±0.35°C with the lowest and highest values of 2.95 and 7.62°C, respectively (Table 2). The annual mean maximum and minimum temperatures in the hottest year increased by 4.02 and 3.67°C compared to the coldest year, respectively (Table 2). The highest number of frost days was recorded during 2012-2013 growing season (45 days) and the lowest was related to 2016-2017 (6 days). The lowest annual absolute minimum temperature (-21.8°C) corresponds to the year 2007-2008, and the highest (-6.8) to the growing year 2016-2017 (Table 2). The annual rainfall from 2007 to 2017 ranged from 155.7 to 419.3 mm, with a mean of 279.4±21.52 mm. The mean annual relative humidity was recorded as 34.73±0.73% with a range of 30.95 and 38.73%, respectively (Table 2).

Changes in the Population of PTB

Seasonal flight of the adults using pheromone traps indicated that PTB completed three generations per year in peach orchards, Saman, Chaharmahal va Bakhtiari Province, Iran. Seasonal flight of the adult moths started in May and continued to the end of October, with three distinct peaks in the second decade of May, first decade of July, and the second decade of September. The average number of moths caught (in each trap) in different growing years, is shown in Table 3. The lowest (521.39) and highest (1349.10 per trap) numbers of moths caught were observed in 2012-13 and 2016-17, respectively.

Table 3. Mean number of moths caught (in each trap), the percentage of infected twigs/tree and percentage of infected fruits/tree during the studied years 2007-2017, in Saman Orchards, Iran.

Growing year	Moth population	Infected twigs%	Infected fruits%
2007-08	407.11	6.11	9.39
2008-09	454.08	6.82	10.47
2009-10	548.03	8.23	12.64
2010-11	782.90	11.75	18.05
2011-12	860.30	14.15	27.00
2012-13	521.40	9.85	16.15
2013-14	782.90	15.45	24.05
2014-15	938.50	17.25	27.45
2015-16	1173.10	18.95	29.95
2016-17	1349.10	20.90	33.50
Mean	781.74	12.95	20.86
SD	295.96	4.93	8.19
SE	89.41	1.49	2.47

The mean percentage of the infested twigs/ tree and infested fruits/ tree during the studied years were calculated as 12.95±1.49 and 20.86±2.47%, respectively. The highest infested fruits (33.50%) and infested twigs (20.90%) were observed in 2016-17, whereas the lowest (9.39 and 6.11%, respectively) were observed in 2007-08 (Table 3).

Trend Analysis

In the studied period, increasing trends were observed in the mean temperature of annual, winter, and autumn seasons (Kendall's statistics were, 0.63, 0.49 and 0.42, respectively), while the mean temperature of summer and spring (0.27 and 0.20, respectively) showed no trend. Therefore, among the seasons, the most considerable warming occurred in autumn and winter (Table 4). Mean minimum temperature of annual, winter, and autumn showed increasing trend (Kendall statistics were 0.53, 0.60, and 0.46, respectively), whereas, there was no trend in mean minimum temperatures of spring and summer seasons. Moreover, there were significant increasing trend in annual (0.63) and autumn (0.42) mean maximum temperatures. Annual and winter absolute minimum temperatures (0.46 and 0.45, respectively) showed significant increasing trend, and absolute maximum temperature of annual, autumn, winter, and summer seasons (0.38, 0.44, 0.38 and 0.53, respectively) showed increasing trend. Among the studied months, the highest increase occurred in January and February temperatures. The Kendall statistics for mean, minimum, maximum, absolute minimum and absolute maximum temperatures of January were calculated as 0.56, 0.56, 0.42, 0.46 and 0.38, respectively (Table 4). The number of annual and January frost days showed decreasing trends (Kendall statistics were -0.55 and -0.51, respectively) in the studied period. Total precipitation of annual and different months showed no trend, whereas, there were significant and decreasing trends in the mean relative humidity of June, July, August, September and October (Kendall statistics were -0.63, -0.74, -0.64, -0.45 and -0.53, respectively)

PTB population and damage showed significant and increasing trend during the studied years. The Kendall statistics for the pest population and damage in spring, summer, autumn and annual were 0.68, 0.66, 0.63 and 0.67, respectively (Table 4). Moreover, there was significant and increasing trend in the pest population in May, June, July, August, September and October (Kendall statistics; 0.71, 0.68, 0.67, 0.68, 0.68 and 0.65, respectively).

Table 4. Mann-Kendall trend analysis on time series data of climate variables in different months and peach twig borer population for the time period 2007 to 2017.[a]

Climate variable	Kendall`s tau/Trend	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Winter	Spring	Summer	Autumn	Annual
Mean temperature	Kendall`s tau	0.56**	0.31	-0.018	0.20	0.309	0.13	0.05	0.16	0.34	0.34	0.31	0.34	0.42*	0.27	0.20	0.49**	0.63**
	Trend	IT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	IT	NT	NT	IT	IT
Minimum temperature	Kendall`s tau	0.56*	0.42*	0.13	0.24	0.24	0.16	0.20	0.05	0.34	0.42	0.38	0.23	0.46*	0.20	0.055	0.60**	0.53**
	Trend	IT	IT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	IT	NT	NT	IT	IT
Maximum temperature	Kendall`s tau	0.42*	0.34	-0.12	0.16	0.309	0.09	0.20	0.055	0.45*	0.24	0.20	0.27	0.31	0.24	0.24	0.42*	0.63**
	Trend	IT	NT	NT	NT	NT	NT	NT	NT	IT	NT	NT	NT	NT	NT	NT	IT	IT
No. frost days	Kendall`s tau	-0.51**	-0.31	-0.02	---	---	---	---	---	---	---	---	-0.02	-0.55**	---	---	-0.019	-0.55**
	Trend	DT	NT	NT	---	---	---	---	---	---	---	---	NT	DT	---	---	NT	DT
Absolut minimum temperature	Kendall`s tau	0.46*	0.42*	-0.34	-0.16	-0.12	-0.15	0.018	0.09-	0.17	0.22	-0.13	0.12	0.45*	-0.16	0.17	0.12	0.46*
	Trend	IT	IT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	IT	NT	NT	NT	IT
Absolut maximum temperature	Kendall`s tau	0.38*	0.16	-0.22	0.37	0.17	-0.07	0.09	0.53**	0.05-	0.44*	0.43*	0.33	0.38*	-0.07	0.53**	0.44*	0.38*
	Trend	IT	NT	NT	NT	NT	NT	NT	IT	NT	NT	NT	NT	IT	NT	IT	IT	IT
Total precipitation	Kendall`s tau	0.27	-0.09	-0.018	0.01	0.24	-0.26	0.18	-0.28	-0.18	0.08	-0.20	-0.05	-0.05	-0.01	0.07	-0.20	-0.63**
	Trend	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	DT
Relative humidity%	Kendall`s tau	-0.27	-0.42*	0.31	0.09	-0.20	-0.63**	-0.74**	-0.64**	-0.45*	-0.53**	-0.31	-0.12	0.23	-0.38	-0.71**	-0.27	-0.49*
	Trend	NT	DT	NT	NT	NT	DT	DT	DT	DT	DT	NT	NT	NT	NT	DT	NT	DT
PTB population	Kendall`s tau	---	---	---	---	0.71**	0.68**	0.67**	0.68**	0.68**	0.65**	---	---	---	0.68**	0.66**	0.63**	0.67**
	Trend	---	--	--	---	IT	IT	IT	IT	IT	IT	--	---	---	IT	IT	**IT**	**IT**

[a] IT, DT and NT: Increasing Trend, Decreasing Trend and No Trend, respectively * and ** statistically significant at 5 and 1% probability level

Relation between Climate Factors and Population, and Damage of PTB

stepwise regression analysis showed that among the different climate variables, the percentage of relative humidity, mean annual minimum temperature and mean annual temperature were the most statistically significant variables influencing the percentage of infested twigs ($r= 0.94$, $r^2=0.88$, $F(3,6)= 14.40$, $P= 0.004$). Moreover, percentage of relative humidity, mean annual minimum temperature, mean annual temperature and July mean temperature($r= 0.98$, $r^2= 0.96$, $F(4,5)= 3.18$, $P= 0.001$) most closely related to the number of trapped male moths, while the percentage of infected fruits was most closely correlated with the percentage of relative humidity ($r= 0.65$, $r^2= 0.43$, $F(1,8)= 5.91$, $P= 0.04$) (Table 5).

Linear regression models for prediction of the PTB population changes based on the time series data of annual temperatures (mean, minimum, maximum, absolute minimum and absolute maximum temperatures), number of annual frost days, annual precipitation and annual mean relative humidity in Saman Region, Chaharmahal va Bakhtiari Province, are shown in the Table 6. Based on the results, the influence of annual mean, minimum and maximum temperatures were statistically significant and positive; whereas the effect of annual frost days and annual relative humidity were statistically significant and negative on PTB population changes (Figures 1 and 2).

Prediction of Pest Population Changes in the Future under Climate Change Scenarios

Based on the climate change scenarios (IPCC 2007), the pest population changes were predicted for the next 20, 40 and 50 years relative to 2017 (years; 2037, 2057 and 2067). Table 7 shows the estimated population of the PTB using the regression

Table 5. Stepwise regression analysis to determine the most statistically significant climate variables influencing the percentage of infested twigs, percentage of infected fruits and PTB population in Saman Orchards, Iran.[a]

PTB population and damage	Variables Entered	Model	R^2	Mean square	F	Significant level
Percentage of infested twigs	percentage of relative humidity, mean annual minimum temperature and mean annual temperature	$y= 186.38 -1.94 x_1 + 9.21 x_2 - 12.26 x_3$	0.88	71.18	14.40	0.004
Percentage of infected fruits	percentage of relative humidity	$y= 78.79 -1.69 x_1$	0.43	285.05	5.91	0.04
PTB population	percentage of relative humidity, mean annual minimum temperature, mean annual temperature and July mean temperature	$y= 13280.75 -116.36 x_1 + 681.13 x_2 - 811.12 x_3 - 77.99 x_4$	0.97	266162.22	20.62	0.001

[a] y= Pest population and x= Climate variable. x_1, x_2, x_3 and x_4: Are percentage of relative humidity, mean annual minimum temperature, mean annual temperature and July mean temperature, respectively.

Table 6. Linear regression models for prediction of peach twig borer population in relation to climate variables, in Saman Orchards, Iran (y= Pest population and x= Climate variable).

Climate variable	Model	R^2	Mean square	F	Significant level
Mean temperature	y= 419.86 x - 4903.55 **	0.77	344079.4	16.42	0.01
Minimum temperature	y= 463.37 x -2262.86 *	0.52	235213.06	5.50	0.05
Maximum temperature	y= 354.79 x - 6505.38 **	0.85	382826.03	28.98	0.003
No. frost days	y= -16.1 x +1195.82*	0.56	252908.12	6.45	0.05
Absolut minimum temperature	y= 11.69 x + 482.81	0.004	1813.11	0.02	0.89
Absolut maximum temperature	y= 46.47 x +1376.67*	0.45	205061.58	4.20	0.09
Total precipitation	y= -2.30 x + 1559.19	0.28	125775.68	1.94	0.22
Relative humidity%	y= -57.90 x + 2863.23*	0.56	251038.84	6.34	0.05

* and **: Significant at 5 and 1% level, respectively

Table 7. Prediction of peach twig borer population changes (no. moth/trap/year) in the future under different climate change scenarios for the next 20, 40 and 50 years relative to 2017.

Scenario	Increasing temperature/decade	Increasing temperature for the next years			PTB population increase for the next		
		20 years	40 years	50 years	20 years	40 years	50 years
A1F	0.4	15.51	16.31	16.71	1608.479	1944.367	2112.311
A1T	0.24	15.19	15.67	15.91	1474.123	1675.656	1776.423
A1B	0.28	15.27	15.83	16.11	1507.712	1742.834	1860.395
A2	0.34	15.39	16.07	16.41	1558.095	1843.6	1986.353
B1	0.18	15.07	15.43	15.61	1423.74	1574.89	1650.465
B2	0.24	15.19	15.67	15.91	1474.123	1675.656	1776.423

y= 419.86x-4903.55, Mean annual temperature in 2017= 14.71

model y= 419.86x-4903.55 (population changes to annual mean temperature). As the results show, by assuming the constant influence of other biotic and abiotic factors, the pest population will increase under all the tested scenarios, and is greater under A1F compared to others.

DISCUSSION

Insects and mites' life table parameters, distribution and seasonal activity are significantly influenced by climate factors under field conditions (Petzoldt and Seaman, 2006; Ullah *et al.,* 2012; Bayu *et al.,* 2017; Saeidi and Nemati, 2017 and 2020). Our results indicated that PTB population and damage are significantly affected by climate variables in Saman Orchards, Chaharmahal va Bakhtiari Province, Iran. The pest population was significantly increased by increasing temperatures, while they decreased by increasing the percentage of relative humidity and number of frost days. The effect of changes in temperature and humidity was reported on development and outbreak of many agricultural pests such as spider mites (Mandal *et al.,* 2006; Ahmed *et al.,* 2012; Kumar *et al.,* 2015), bark beetles (Bentz *et al.,* 2010; Yihdego *et al.,* 2019), whiteflies (Pathania *et al.,* 2020), *Thrips tabaci* (Bergant *et al.,* 2005), *Anosia chrysippus* (Sudan *et al.,* 2015) and Leopard moth, *Zeuzera pyrina* L. (Saeidi *et al.,* 2023). Beside the direct impact, climate factors may indirectly influence the pest population through changes in the

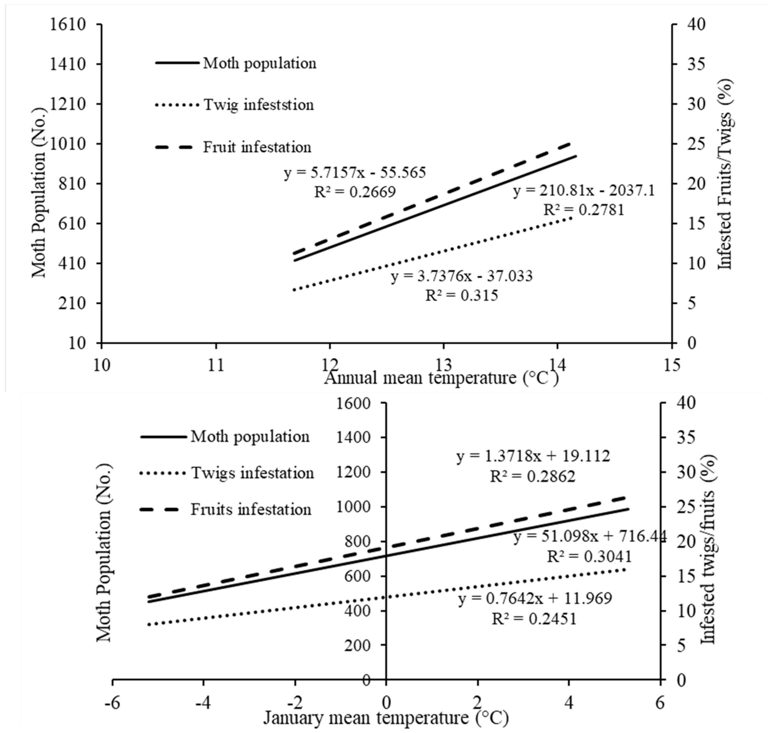

Figure 1. Relation between annual and January mean temperatures and PTB (Peach Twig Borer) population and damage in Saman orchards, Iran.

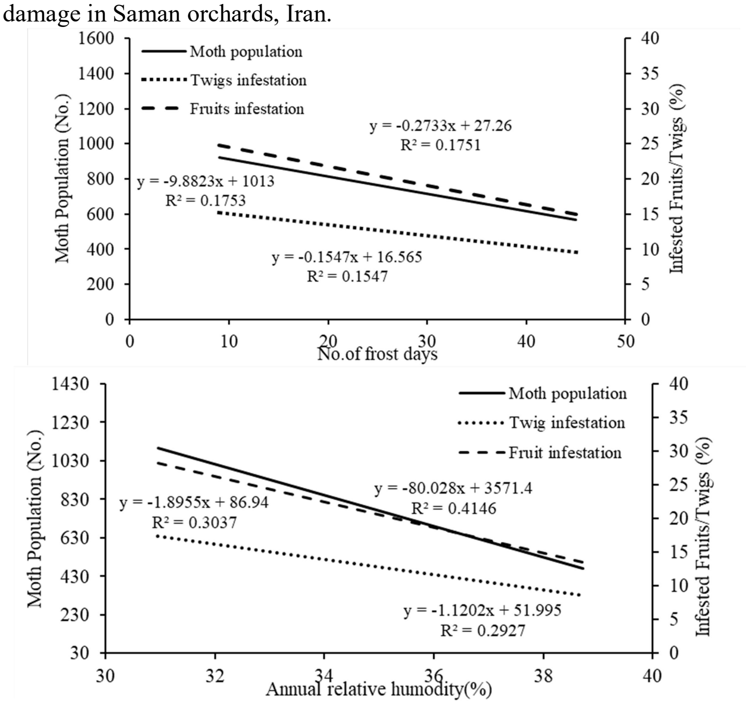

Figure 2. Relationship between number of frost days and annual relative humidity with PTB (Peach Twig Borer) population and damage in Saman Orchards, Iran.

physiology, existence of the host plants (Prakash *et al.,* 2014) and decreasing of the secondary metabolites (Yihdego *et al.,* 2019). Minimizing the environmental stress such as prolonged drought reported as one of the cultural methods to control of PTB in peach orchards (Roshandel *et al.,* 2022; Erhaft *et al.,* 2021) and wood borers in the forest (Rauault *et al.,* 2006).

Trend analysis using Mann-Kendall method (Nicolson and Palao, 1993; Xu *et al.,* 2003; Pohlert, 2016) indicated significant trends in the studied climate factors during 2007-2017. Mean temperatures of annual, different seasons and months showed significant and increasing trend, whereas number of annual frost days and percentage of relative humidity indicated decreasing trend. The phenomenon of climate change and increasing average temperature, or global warming, is a serious threat to the future of human life. According to Pachauari and Reisinger (2007), increase in greenhouse gases and climate changes is primarily due to human activities such as development of industrial activities and transportation systems, and it is expected the earth could experience global warming of 1.4 to 5.8°C over the next century. Our results indicated an increasing trend in the temperature during the studied period (2007-2017) in Saman (Chaharmahal va Bakhtiari Province) Meteorological Synoptic Station. According to Skendzick *et al.* (2021), one of the most important consequences of climate change is the increase in temperature, which ultimately affects other climatic phenomena and leads to changes in the agricultural pest population. Global climate warming could trigger an expansion of insect geographic range, increased overwintering survival, increased number of generations, increased risk of invasive insect species and insect-transmitted plant diseases, as well as changes in their interaction with the host plants and natural enemies (Skendzic *et al.,* 2021).

Our results indicated significant and increasing trend in the mean minimum temperatures of annual, winter, and autumn seasons (especially January and February months), which may significantly influence the twig damage and number of emerging PTB adults in the first generation. According to Hill (1987), winter is the most critical season for many insect pests, as low temperatures significantly increase mortality and reduce their populations in the following season. Pachauari and Reisinger (2007) indicated that global warming is most pronounced in winter at high latitudes, therefore, insects that undergo a winter diapause are likely to experience the most significant changes in their thermal environment (Bale and Hayward, 2013). Considering that PTB overwinters in the form of the first to second instar larvae inside the twigs and shoots (Roshandel *et al.,* 2022; Erhaft *et al.,* 2021), low temperatures may kill the young larvae in the soft, thin and none-woody branches and reduce the number of emerged PTB adults in the spring generation. According to Erhaft *et al.* (2021), the spring moth emergence (1st flight) started from third decade of April and peaked on the second decade of May. In another study, Kujawski (2011) reported the warmer winter reduces the mortality of the pests over-wintering stages and, as a result, their population increase sharply in the next season. Based on the evidence obtained from fossils, the insect species diversity and feeding intensity have a direct relationship with temperature (Kujawski, 2011). Biological activities and the number of pest generations are significantly affected by the rising temperature; therefore, warmer March and April allow overwintering PTB larvae to start their feeding in early spring and cause more damage. Erhaft *et al.* (2021) reported that the overwintered larvae started their feeding when the mean daily temperature increased to 10 °C in April. Moreover, increasing temperature (up to optimum) during spring and summer seasons favors faster development and emerging of PTB adults. Previous studies showed the pest could complete 2-4 generations depending on climate conditions. Studies have shown that PTB complete three generations per year in Sanliurfa Province, Turkey (Mamay *et al.,* 2014), in Romania (Iacob,1970) and Saman, Chaharmahal va Bakhtiari Province, Iran (Erhaft *et al.,* 2021), while two generations in the Czech Republic (Kocourek *et al.,* 1996) and four generations in northern Utah, USA (Alston and Murray, 2007).

As the results showed, climate variables especially rising temperatures, decreasing the number of frost days, and reducing percentages of relative humidity strongly affect population and damage of PTB in the peach orchards. Rising temperature not only affects the behavior, population dynamics, distribution, growth and development, survival and reproduction of insects (Petzoldt and Seaman, 2006; Skendzic *et al.,* 2021), but also may increase the survival of overwintering stages of insects at higher elevations, and lead to expansion of their geographic range (Pareek *et al.,* 2017).

Therefore, our findings are useful for predicting PTB population and damage in the future under different climate change scenarios to reduce pest-induced crop losses using suitable integrated pest management tactics. Appling of efficacious control methods such as pheromone traps (for monitoring, mass trapping, or mating disruption), cultural techniques (removing infested twigs and minimizing drought stress) and insecticides application (at the proper time and dosage) basically depend on our knowledge about changes in seasonal activity, population dynamic, and distribution of PTB.

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تأثیر عوامل اقلیمی بر تراکم جمعیت و خسارت کرم سرشاخه‌خوار هلو، (***Anarsia lineatella*** **Zeller Lep.,: Gelechidae**)، در باغ های سامان، ایران

زریر سعیدی

چکیده

تأثیر عوامل اقلیمی بر تغییرات جمعیت و خسارت کرم سرشاخه‌خوار هلو، *Anarsia lineatella* Zeller، طی سال‌های ۱۳۸۶ تا ۱۳۹۶ در باغ‌های شهرستان سامان (ایران) مورد بررسی قرار گرفت. داده های سری زمانی اقلیمی و جمعیت آفت تحت تجزیه و تحلیل روند Mann-Kendall قرار گرفتند. پرواز فصلی آفت با استفاده از تله‌های فرمونی از اردیبهشت تا مهر بررسی شد. درصد سرشاخه‌های آلوده در اردیبهشت و شهریور محاسبه شد، در حالی که درصد میوه‌های آلوده به صورت دو بار در ماه از تیر تا شهریور تعیین شد. نتایج نشان دهنده روند افزایشی در میانگین دمای سالانه، زمستان و پاییز بود (آماره کندال به ترتیب ۰/۶۳، ۰/۴۹ و ۰/۴۲

بود). همچنین روند افزایشی معنی داری در دماهای میانگین حداقل، میانگین حداکثر و حداقل مطلق سالانه (به ترتیب ۰/۵۳، ۰/۶۳ و ۰/۴۶) مشاهده شد. تعداد روزهای یخبندان سالانه و دی‌ماه (به ترتیب ۰/۵۵- و ۰/۵۱-) و میانگین رطوبت نسبی خرداد، تیر، مرداد، شهریور و مهر روند کاهشی را نشان دادند. جمعیت و خسارت سرشاخه‌خوار هلو در طول سال‌های مورد مطالعه روند افزایشی و معنی داری را نشان داد. بر اساس تحلیل رگرسیون گام به گام، درصد رطوبت نسبی، میانگین دمای حداقل سالانه و میانگین دمای سالانه از نظر آماری معنی‌دارترین متغیرهای تأثیرگذار بر درصد شاخه‌های آلوده ($P=$ ۰/۰۰۴، $F(3,6)=$ ۱۴/۴۰، $r^2=$۰/۸۸ ، $r=$۰/۹۴) و جمعیت آفت ($P=$ ۰/۰۰۱ ، $F(4,5)=$ ۳/۱۸ ، $r^2=$۰/۹۶ ، $r=$۰/۹۸) بودند. جمعیت و خسارت آفت تحت سناریوهای تغییر اقلیم مورد مطالعه (A1F، A1T، A1B، A2، B1 و B2) در آینده افزایش خواهد یافت، که این افزایش در سناریوی A1F نسبت به سایرین بیشتر است.