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Research Article

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Appraisal of Thrips Population Dynamics in Mango using Weather Based Indices

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Abstract

The aim of this investigation was to assess the dynamics of mango thrips population across 20 mango orchards based on thermal indices under subtropical Lucknow condition during 2013 and 2014. Wide variations in thrips populations were observed across different critical crop phenological stages and seasons. The thrips population was observed between 13th SMW to 24th SMW during 2013 cropping season, whereas it was found from 15th SMW to 28th SMW in the subsequent year. The mean thrips population across standard weeks was highest (6.18 ± 0.14) during 15th SMW followed by 3.13 ± 0.15 in 16th and 1.87 ± 0.06 in 17th SMW during 2013, whereas in the next year (2014), the highest values were 4.67 ± 0.09 followed by 4.19 ± 0.10 and 4.07 ± 0.15 in 16th, 17th and 18th SMW respectively. Step wise regression analysis revealed that maximum temperature, minimum temperature, maximum relative humidity, minimum relative humidity, sunshine hours and evaporation could explained 55 per cent variations in thrips population. Different thermal indices *viz*., growing degree days (GDD), heliothermal units (HTU), photothermal units (PTU), were cumulated up to peak population density and a positive and significant correlation was revealed. The best fit polynomial regression analysis indicated that thrips population could be predicted up to 95 per cent using these thermal indices. Thus, it was concluded that use of all these robust indices may be useful in assessing the pest-weather dynamics of mango growing region and serve as a basis for real time pest management advisory.

Keywords

Thermal indices; GDD; Mango; Thrips; Prediction model

Introduction

Mango (*Mangifera indica* L.), one of the major fruit crops of India, is known as the king of fruits for its sweetness, excellent flavour, delicious taste and high nutritive value [1]. It is attacked by several pests during its vegetative and reproductive phases [2]. During the reproductive phase of the crop, pests like hoppers and thrips pose a threat to mango production. Under the era of changing climatic situation, thrips are becoming serious pest on mango. Several species of thrips are observed in mango orchards in Florida, the Caribbean, Central and South America, and Asia [3-5]. Among the thrips species, *Scirtothrips dorsalis* and *Thrips hawaiiensis* were recorded as severe pests of various vegetables, fruits and ornamental crops in eastern Asia [6,7]. In India, *Thrips palmi* was recorded on mango inflorescence [8], from Andhra Pradesh three species of thrips *viz*., *Megalurothrips distalis* (Karny), *Thrips hawaiiensis* and *Haplothrips tenuipennis* are reported on mango [9-11]. Two species of thrips *Scirtothrips mangiferae* Hood and *S. dorsalis* Hood were reported by Kumar and Bhatt [12] respectively, from Gujarat on mango. Kumar et al. [13] reported from Cuttack that *Scirtothrips mangiferae*, *S. dorsalis*, *Rhipiphorothrips cruentatus* Hood are occurring on mango. From Haryana *R. cruentatus* was reported by Dahiya and Lakra [14]. Patel et al. [15] reported three species of thrips on mango rootstock viz., *Pantachaetothrips* sp., *Selenothrips rubrocinctus* Giard, *Caliothrips impurus* Priesner, besides *Scirtothrips dorsalis*. From Kerala Ananthakrishnan and Muraleedharan [16] reported *Selenothrips rubrocinctus* on mango. Recently *Frankliniell schultzei* and *Thrips subnudula* reported on inflorescence of mango from Tamil Nadu [17]. Thrips pose an increasing threat to mango production, which can cause considerable economic loss in mango orchards. Indiscriminate use of synthetic insecticides for routine thrips control is detrimental to non-target organisms and causes pesticide residues on food and in the environment. Other destructive consequences include the development of resistant pest populations, pest resurgence and the outbreak of secondary pest infestations [18,19]. To minimize harmful effects of synthetic pesticides, development of non-polluting plant protection strategies is necessary. For rational use of synthetic pesticides forewarning/prediction models for the destructive pest like thrips are need of the hour.

Thermal characteristics may vary among species, populations, developmental stages, and with other ecological factors such as food source [20-23]. This effect of temperature can be described by specific rate functions of temperature for development (thermal models), which are used in predicting insect pests interaction with biotic and abiotic factors [24]. The pest forecasting models facilitate better preparedness to combat outbreaks of serious insect pests by developing effective pest management strategies well in advance. The temperature-response phenology models simulate the variability in insect development times within a population based on the detailed laboratory assessments of the insect's life history and thus, can provide better results on future pest activity [25]. In this context this study aimed to develop weather based prediction models for mango thrips.

Materials and Methods

A field experiment was conducted for two consecutive seasons (2013 and 2014) on a *Typic ustochrepts* soil in Lucknow, Uttar Pradesh, India at 22 locations. The climate of the experimental site is semi-arid subtropical with hot dry summers and cold winters. Orchards of Mango cv. *Dashehari* of 20-35 years age were selected with planting 7.5×7.5 to 10×10 mt. Each orchard had at least 25 trees. Data on thrips population was recorded on weekly basis from 5 randomly selected trees in four direction of the tree. Thrips count was taken after gently tapping shoot or panicle by holding white paper in the palm. For analysis, mean count per shoot or panicle was taken and expressed as number of thrips per shoot or panicle. Daily weather data of temperature (maximum and minimum), relative humidity (morning and evening), rainfall, wind speed, bright sunshine hours

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and evaporation rates were recorded in the agromet observatory located within the experimental site. Temperature, solar radiation and day length data were used to compute agro climatic models. These models were calculated as follows:

Growing Degree days (GDD) = $\Sigma(T_{Max} + T_{Min})$ /2-T_{Base}

Where T_{Max} and T_{Min} are the maximum and minimum temperatures (^{0}C) of the day and T_{Base} is base temperature which was taken as 15^{0}C [26].

Heliothermal units (HTU) = GDD × actual bright sunshine hour (n)

Photothermal units (PTU) = GDD × day length (N)

Where N indicates maximum possible bright sunshine hours or day length and calculated as

$N = (24/\pi) \times Ws$

Ws is the sunset hour angle (Radian) = Arc Cosine [-tan (Φ) × tan (σ)]

Φ= Latitude in radian,

σ = Solar declination in radiation, calculated as follows

$\sigma = 0.409 \times \text{Sine} [(2 \times \pi \times J)/d-1.39]$

Where J= Julian days (1 to 365/366) and d = No. of days in the year

These models were computed on daily basis taking 1st September as base for each year since mango is harvested during June and July in Northern India and post harvest vegetative phase started. The thrips occurrence was also plotted against these models and cumulated up to peak/maximum thrips incidence and severity for generating regression based prediction models. Statistical analysis viz., regression equations, were carried out using MS Excel and SPSS packages (Version 12.0). The required statistically significant graphs were drawn using MS Excel/Power Point software packages.

Results and Discussion

Weather situation during study period

Weather parameters particularly maximum and minimum temperatures, rainfall, pan evaporation, relative humidity etc. has profound influence on mango crop phenology in turn pest-weather dynamics. Henceforth, analyses of weather paramneters are essential in assessing the pest population dynamics. The analysis showed maximum temperature ranged between 29.8 to 40.3^{0}C during 2013 crop season and 25.7 to 43.4^{0}C during 2014 crop season at the time of first appearance of thrips population on mango and its peak values. However, the minimum temperature was recorded lower in 2014 season as compared to 2013. A range of 9.5 to 26.8^{0}C was observed in both the seasons. The rainfall was widely distributed in 2013 than 2014 fruiting season. Higher pan evaporation was recorded in 2014 as compared to 2013 (Figure 1).

Population dynamics of mango thrips

A wide variation in thrips occurrence on the mango crop at its different phenological stages was revealed in 20 mango fixed orchards during two consecutive mango cropping season (2013 and 2014). The first appearance of thrips population was observed on 13th standard meteorological week (SMW) and 15th SMW in 2013 and 2014 fruiting season respectively (Table 1). The infestation of thrips on mango crop observed till 24th SMW during 2013 and up to 28th SMW during 2014. Among the 20 mango orchards, highest thrips population density (13.6 /panicle) was recorded in 15th SMW at Kakori orchard (II), followed by 10.5/ panicle and 10.3/panicle in Kakori (I) and NB Dhanewa (I) orchard in 2013 season. The higher values of thrips population density were recorded in 15th and 16th SMW in 2013 while in the next season, it was observed from 17th to 20th SMW. Some of the mango orchards viz., Malihabad (9.45 and 9.15/panicle), Kanar-II (9.4/panicle) [21] and Allupur-I (8.8/panicle) showed higher thrips infestation at flowering and initial fruit setting stage. In 2014 mango season, highest thrips infestation was recorded in CISH Block II as 13.0 /panicle followed by 10.1 /panicle (Allupur (II). Mango orchards

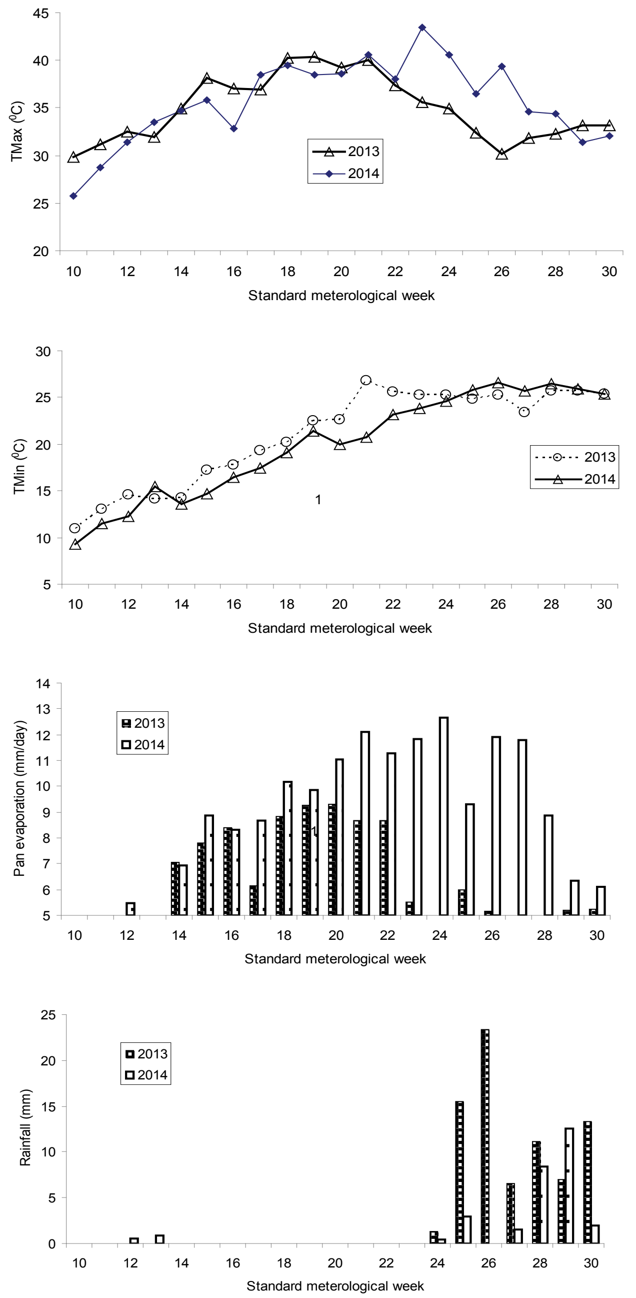

Figure 1: Weather dynamics during study period (2013-14).

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of CISH Block III had thrips density of 8.95 to 9.3/panicle followed by Ulrapur-II (8.85/panicle) and Mahmood Nagar-I (8.75 /panicle). Such wide spatio-temporal variations in thrips populations across 20 mango orchards and seasons may be due to differences in cultural practices adopted by the mango growers and weather dynamics. The mean thrips population across standard weeks was highest (6.18 ± 0.14) during 15th SMW followed by 3.13 ± 0.15 in 16th and 1.87 ± 0.06 in 17th SMW during 2013, whereas in the next year (2014), the highest values were 4.67 ± 0.09 followed by 4.19 ± 0.10 and 4.07 ± 0.15 in 16th, 17th and 18th SMW respectively (Table 2). Although there were significant variations in thrips population in SMW and orchards, a range of 0.15 to 13.6 in 2013 and 0.15 to 13.0 in 2014 was found. Peak occurrence of thrips was found during the flowering and fruiting developmental stages of mango. Appearance of thrips population on mango was delayed one week during the year 2014 compared to 2013 (Figure 2), this is attributed to the maximum temperature which was higher and influenced the faster growth and development of thrips. Higher temperature also play key role in the development of vegetative as well as reproductive growth of the mango. Prolonged lower night temperature (minimum temperature) may be responsible factor for the longer stay of thrips on mango for one more month in 2014 cropping season. The peak infestation of thrips on mango was synchronized with the flowering, fruit development and vegetative flushes of mango in the Lucknow region. Changes in the phenology of crop may also influence the pest occurrence. The impact of temperature and rainfall on the mango crop phenology was observed in Lucknow region [27] and pest-weather dynamics during critical crop phenological stages was also reported by Ravishankar et al. [28]. It is obvious that abiotic factors had profound influence on the dynamics of thrips population across regions. In a study in

Table 1: Mean density of mango thrips population in 20 orchards during 2013 and 2014 at Lucknow, Uttara Pradesh.

Year	2013												2014													
	Standard meteorological weeks																									
Location	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
Malihabad (Fixed I)	0	4.55	9.15	0.85	0.65	0.4	1	0.5	1	1.1	0	0.4	0	3.95	4.25	4.9	1.75	1.25	0.6	1.2	1	0	0.65	0.75	0.4	0
Malihabad (Fixed II)	0	5	9.45	2.15	0.55	0.25	0	0.8	0.65	1	0	0	1.05	4.45	4.6	6.95	1.45	0.5	0.4	1	1	0.4	0.5	0	0.5	0
Navipana (Fixed I)	0	3.35	3.95	1.15	0.6	0	0	0	0.6	0.25	0	0.6	6.9	5.05	2.35	0.7	0.75	0	0.8	0.65	1.5	0.4	0	0.65	0	0
Navipana (Fixed II)	0	5.85	6.2	3.1	0.75	0	0	0.35	1.2	0.5	0	0.85	6.75	6.6	2.5	1.85	1.75	1	0.75	1	1	0.65	0	0	0	0
Methe Nagar (Fixed I)	0	1.35	5.65	3.45	2.35	0.6	0.15	0.95	1.05	0	0.7	1	0	6.4	3.3	0.95	2.8	1	1	0	0.75	0.6	0	0	0	0
Methe Nagar (Fixed II)	0	2.75	5.6	0.6	2.05	0.8	0	0.55	1.3	2.5	1.15	1.15	2.7	5.5	4.7	3.65	1.2	0.5	0.25	0.8	1.15	0	0	0	0	0
Hafizkhera (Fixed I)	0	0	5.3	1.85	4.25	0.85	0.35	1.15	0.95	0.55	0.25	1.05	1.4	5.7	3.15	0.15	0.5	1	0.5	0.85	1.15	0	0	0	0	0
Hafizkhera (Fixed II)	0	0	4.25	1.55	4.8	1.2	0.25	1.3	1.05	0.65	0.45	0.85	3.1	5.3	3.15	2.75	3	1.15	3.7	0.9	0.75	0.85	0.6	0	0	0
Mahmood Nagar (Fixed I)	0	6	6.9	2.75	1.8	1.15	0.4	0.6	1	1	0	0.4	1.05	3.65	4.55	8.75	2.85	0.65	0.75	1.25	0.75	0	0	0.4	1.1	0
Mahmood Nagar (Fixed II)	0	2.15	7.55	1.2	0.25	0.9	0.65	0.75	1	0.75	0	0	0	4.95	2.75	5.2	1.8	0	0.6	1.15	0	1	0	0.4	0	0
Kakori (Fixed I)	0	6.4	13.6	10.5	3.25	0.85	0.7	0.65	2.5	1	0.9	0	0	0	4.3	7.3	3.25	0	0.4	1	0.6	0	0	0	0	0
Kakori (Fixed II)	0	0.7	8.15	4.55	1.35	1.55	0.95	0.75	1.15	1	0.95	0.25	2.7	5.05	5.95	4.4	3.3	1	1.1	1.55	1.25	1.15	0.9	0.9	1	0
Ulrapur (Fixed I)	0	3.95	1.1	1.4	2.5	0.6	0	0.7	1.25	1.05	0.8	0	5	2.9	7.85	4	1.45	0.8	3	1.25	0.6	0.35	0.4	0	0	0
Ulrapur (Fixed II)	0	3.75	6.45	1.2	3.1	0.25	0.35	0.35	0.25	0.65	0.6	0.4	2.65	3.05	8.85	0	1.3	0.65	0.35	1.65	1	0	0	0	4	0
Kanar (Fixed I)	0	1.1	4.5	5.8	2.3	0.7	1.1	0.65	0.65	0.6	1	0.4	0	5.05	4.4	4.6	1.1	1	0.5	1	0.9	0.9	0	0.25	0	0
Kanar (Fixed II)	0	1.55	7.3	9.4	0.8	0.55	0.55	0.6	1.15	1.5	1.35	0	1.1	4.1	4.85	3.4	1.55	0.25	1.3	0.5	0	0.75	0.75	0	0	0
NB Dhanewa (Fixed I)	1.6	2.75	10.3	1.65	1.95	0.6	1.45	1.05	0.5	1.2	0	1.1	5.1	8.2	1.75	1.5	1	1.25	1.65	0.75	0.75	0.8	0.85	0.4	0	0
NB Dhanewa (Fixed II)	1.75	2.65	6.6	2.25	1.05	0.25	2.25	0.6	1.05	0.55	0	0.75	5.95	5.55	2.4	0.75	0	0	1.15	0	0.85	0	0	0.65	0	0
CISH Block-III (Fixed I)	3.35	7.15	1	1.2	2.25	0.25	2.95	6.2	1.4	1.35	1.65	0	7.4	6.65	8.95	9.3	7.45	6.5	5.35	2	0	0	1.35	0	1.4	0.4
CISH Block-II (Fixed II)	0	1.4	3.8	2.7	3.05	1.85	0.4	0.6	6.2	2.25	0.75	0	1.5	3.9	2.85	3.15	4.1	13	2.75	4.65	1	1	0.9	4.25	0	0
Allupur (Fixed I)	0	1.05	4.9	0.65	0.85	0.8	0.4	1.05	0.85	1.4	0.75	0	0	1.7	2.55	5.15	0.65	0.35	0.95	1.35	2	0	0.65	0.9	0.4	0
Allupur (Fixed II)	0	1.55	4.2	8.8	0.55	1.25	0	0.5	0.6	1	0.8	0	1.95	4.95	2.1	10.1	5.25	2.55	2.5	1.6	1.25	0	0.75	1.15	0	0.9

Table 2: Univariate statistical analysis for the population of mango thrips across the standard meteorological weeks (SMW) during 2013 and 2014 at Lucknow, Uttara Pradesh.

			2013					2014	
SMW	**Mean**	**Range**	**Skeweness**	**Kurtosis**	**SMW**	**Mean**	**Range**	**Skeweness**	**kurtosis**
13	0.30 ± 0.04	3.35-1.60	2.91	8.43	15	2.56 ± 0.13	7.40 - 1.05	0.74	-0.79
14	2.95 ± 0.11	7.15-0.70	0.50	-0.83	16	4.67 ± 0.09	8.20 - 1.70	-0.69	1.51
15	6.18 ± 0.14	13.60-1.00	0.51	1.04	17	4.19 ± 0.10	8.95 - 1.75	1.23	0.82
16	3.13 ± 0.15	10.50-0.60	1.61	1.55	18	4.07 ± 0.15	10.10 - 0.15	0.52	-0.54
17	1.87 ± 0.06	4.80-0.55	0.74	-0.11	19	2.19 ± 0.09	7.45 - 0.65	1.57	2.96
18	0.71 ± 0.02	1.85-0.25	0.61	0.18	20	1.56 ± 0.14	13.00 - 0.35	3.45	12.60
19	0.63 ± 0.04	2.95-0.15	1.85	3.50	21	1.38 ± 0.07	5.35 - 0.40	1.80	3.06
20	0.94 ± 0.06	6.20-0.35	4.25	19.19	22	1.19 ± 0.05	4.65 - 0.40	2.64	10.17
21	1.24 ± 0.06	6.20-0.25	3.76	15.67	23	0.88 ± 0.02	2.00 - 0.60	-0.12	1.09
22	0.99 ± 0.03	2.50-0.25	1.02	1.67	24	0.40 ± 0.02	1.15 - 0.35	0.38	-1.51
23	0.55 ± 0.03	1.65-0.25	0.38	-0.81	25	0.38 ± 0.02	1.35 - 0.40	0.60	-0.79
24	0.42 ± 0.02	1.15-0.25	0.46	-1.35	26	0.49 ± 0.05	4.25 - 0.25	3.54	14.40
	-	-	-	-	27	0.40 ± 0.05	4.00 - 0.40	3.33	12.52
	-	-	-	-	28	0.06 ± 0.01	0.90 - 0.40	3.76	14.53

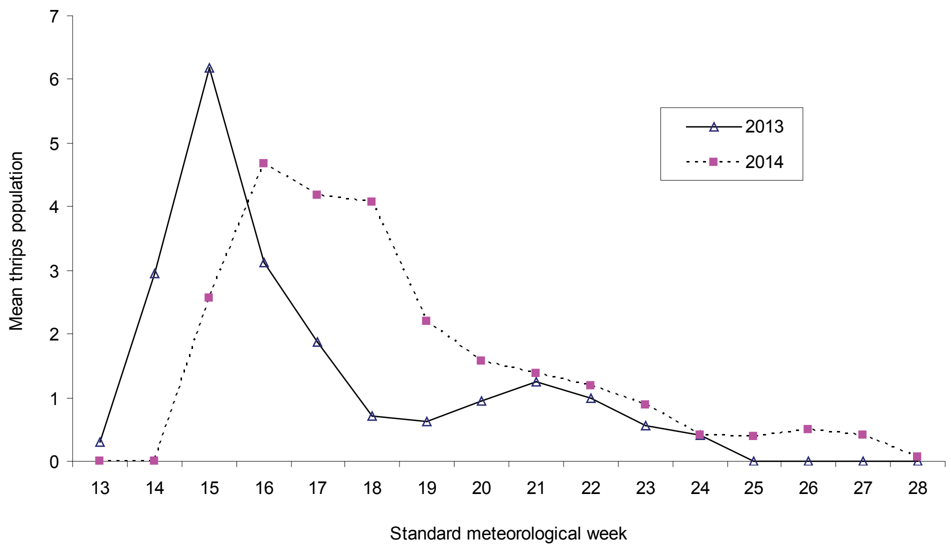

Figure 2: Mean thrips population across different standard meteorological weeks during the study period (2013-14).

Malaysia, three peak populations of mango thrips were recorded and the population was significantly influenced by abiotic factors like temperature, relative humidity on thrips population dynamics [29].

Thrips population relationship with weather parameters

For development of efficient pest management approach, understanding of association between pest population and weather parameters is pre-requisite for any particular location [30-33]. Many workers have reported that weather factors as one amongst the major contributing factor to the outbreak of pests on mango across the country, workers have described the relationship of ecological factor with the pest population under specific location [34-37]. Weather variables including rainfall, temperature, relative humidity and wind have been reported as important factors that significantly affect thrips population [38,39]. In our study thrips population was found negatively correlated with maximum relative humidity (r = -0.792**) and minimum relative humidity (r = -0.670**) during the year 2013. Whereas during the year 2014 thrips population was found negatively correlated with minimum temperature (r = -0.865**), minimum relative humidity (r = -0.634**), maximum relative humidity (r = -0.577**) and evaporation (r = -0.581**) (Table 3). Similar results were reported by Duraimurugam and Jagadish [40], Shukla [41], Panickar and Patel [42], Nandini et al. [43] and Vanisree et al [44], Meena et al. [45] on various crops. Step wise regression analysis revealed that maximum temperature, minimum temperature and maximum relative humidity, minimum relative humidity, sunshine

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hours and evaporation could explained 55 per cent variations in thrips population (p<0.009) (Table 4). Similar finding was reported in case of coffee borer [46] where correlation studies indicated that different weather parameters influence pest population differently across seasons.

Relationship between thermal indices of mango *vis-à-vis* thrips population

Different thermal indices (growing degree days, Photothermal units and heliothermal unit) were calculated for mango based on the weather data of experimental station. It was estimated that the thermal heat accumulation (GDD) and two other indices (HTU and PTU) were 1007.28^{0}Cday, and 8951.67 and 12608.22 at the time of peak occurrence of thrips population during 2013 while the corresponding values were 1123.04, 8273.42 and 14256.98 of GDD, HTU and PTU respectively during 2014 crop season (Table 5). The significantly positive relationship was observed between thermal indices of mango viz., growing degree days (r = 0.946**), Photothermal units (r = 0.915**) and heliothermal unit (r = 0.940**) with the thrips population. The different thermal indices of mango along with thrips population were subjected for the regression analysis to develop prediction models. This revealed that different regression equation (Linear, Logarithmic and exponential) had explained good amount of variation. During the year 2013 exponential model had explained highest variation for GDD ($y = 0.0421e^{0.0024x}$; R^2=0.97**), HTU ($y = 0.0394e^{0.0003x}$; R^2=0.90**) and PTU ($y = 0.0616e^{0.0002x}$; R^2 = 0.90**) compare to linear and logarithmic models. During the year 2014, compared to exponential and logarithmic models linear models for GDD ($y = 0.0033x - 3.8391$; R^2 = 0.91**), HTU ($y = 0.0004x - 3.6391$; R^2 = 0.90**) and PTU ($y = 0.0002x - 3.3693$; R^2 = 0.90**) had explained highest variation (Table 6). Stepwise regression analysis between different thermal indices and thrips population had explained considerable amount of variation. Growing degree days of mango along with photothermal units ($y = 0.046X_1-0.002X_3-9.56$; R^2= 0.97**) had explained about 97 per cent of variation. All thermal indices parameters together had also explained up to 97 per cent of variation (Thrips population = 0.042×GDD - 0.0003×HTU - 0.002×PTU - 8.97; R^2 = 0.97**) (Table 7). It indicated that GDD and PTU are important thermal indices play a key role for prediction of mango thrips population. Based on three years study (2011-14) at Lucknow, Uttar Pradesh Region with 20-35 years old mango orchards of *cv. Dashehari*, it was found that mango hopper populations could be predicted 80 to 90% using thermal indices [47,48].

Table 3: Correlation coefficients (r) between mango thrips population and weather parameters.

Weather parameter	2013	2014
Temperature (Min)	NS	-0.865**
Relative humidity (Max)	-0.792**	-0.634*
Relative humidity (Min)	-0.670*	-0.577*
Evaporation	NS	-0.581*
**. Correlation is significant at the 0.01 level (2-tailed).		
*. Correlation is significant at the 0.05 level (2-tailed).		

Table 4: Step-wise regression analysis for mango thrips population with weather parameters.

Regression equation	**R^2**	**F**	**Sig.**
$y = 8.76+0.17X_1-0.22X_2-0.09X_3+0.02X_4-0.29X_5-0.10X_6$	0.55	3.99	p<0.009
$y= 8.91+0.12X_1-0.25X_2-0.08X_3+0.03X_4-0.24X_5$	0.54	4.85	p<0.004
$y=9.48+0.03X_1-0.23X_2-0.09X_3+0.05X_4$	0.52	5.76	P<0.002
$y=10.77-0.05X_1-0.12X_2-0.06X_3$	0.50	7.60	p<0.001
$y=4.23++0.08X_1-0.27X_2$	0.44	9.24	p<0.001
Y= Population ; X_1 = Temperature (max) ; X_2= Temperature (min); X_3 = Relative humidity (max); X_4= Relative humidity (min); X_5= Sunshine hours; X_6= Evaporation			

Table 5: Thermal indices during the incidence of mango thrips across two consecutive seasons.

	2013				2014				
Std. week	Thrips Population	GDD	Helio thermal unit	Photothermal Unit	Std. week	Thrips Population	GDD	Helio thermal unit	Photothermal unit
13	0.30	870.0214	6694.368	10567.99	15	2.56	1052.11	9675.61	13168.96
14	2.95	930.3071	9265.216	11473.83	16	4.67	1123.04	8273.42	14256.98
15	6.18	1007.286	8951.676	12608.22	17	4.19	1197.54	12301.28	15408.25
16	3.13	1096.25	8888.737	13917.22	18	4.07	1295.87	12484.18	16883.10
17	1.87	1178.986	10749.92	15169.45	19	2.19	1395.37	12743.66	18388.41
18	0.71	1283.707	14010.01	16724.74	20	1.56	1499.96	15589.56	19968.88
19	0.63	1391.707	13303.82	18340.2	21	1.38	1606.84	15983.27	21580.19
20	0.94	1505.086	15319.32	20037.27	22	1.19	1714.41	17596.56	23190.68
21	1.24	1623.95	15449.41	21810.18	23	0.88	1835.74	18933.47	24967.19
22	0.99	1753.864	15990.74	23724.45	24	0.40	1966.50	15888.69	26840.67
23	0.55	1859.586	13759.69	25291.35	25	0.38	2079.82	8703.79	28432.51
24	0.42	1969.121	11779.05	26876.4	26	0.49	2200.33	18683.86	30067.42
					27	0.40	2318.12	9914.10	31600.91
					28	0.06	2420.79	10717.02	32857.57

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Table 6: Linear and non- linear regression analysis for prediction of thrips population as a function of thermal indices.

	2013			2014		
	Equation	R^2	r	Equation	R^2	r
GDD						
Linear	y = 0.004x - 3.7961	0.75	0.867	y = 0.0033x - 3.8391	0.91	0.958
Logarithmic	y = 5.067ln(x) - 34.772	0.67	0.802	y = 5.2482ln(x) - 37.092	0.85	0.925
Exponential	$y = 0.0421e^{0.0024x}$	0.97	0.986	$y = 0.0146e^{0.0025x}$	0.88	0.939
HTU						
Linear	y = 0.0004x - 3.5193	0.60	0.776	y = 0.0004x - 3.6391	0.90	0.948
Logarithmic	y = 4.4634ln(x) - 40.121	0.52	0.724	y = 5.0615ln(x) - 46.168	0.84	0.917
Exponential	$y = 0.0394e^{0.0003x}$	0.90	0.950	$y = 0.0169e^{0.0003x}$	0.86	0.932
PTU						
Linear	y = 0.0003x - 3.1569	0.75	0.866	y = 0.0002x - 3.3693	0.90	0.951
Logarithmic	y = 4.3919ln(x) - 41.188	0.65	0.812	y = 4.6993ln(x) - 45.193	0.83	0.912
Exponential	$y = 0.0616e^{0.0002x}$	0.97	0.986	$y = 0.02e^{0.0002x}$	0.89	0.943

y= Population; GDD – Growing degree days; HTU- Heliothermal units; PTU- Photothermal units;

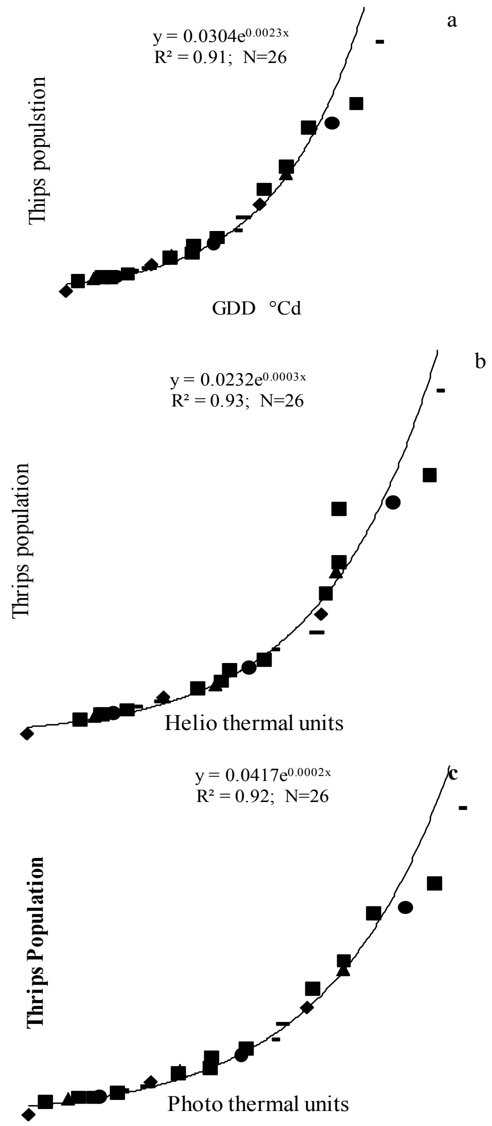

Figure 3: Prediction models for mango thrips using different thermal indices.

Table 7: Step-wise regression analysis between the thrips population and weather based indices.

Linear Regression equation	R^2	F	Sig.
$y = 0.003X_1-3.58$	0.89	205.38	p<0.000
$y = 0.00042X_2-3.73$	0.83	123.35	p<0.000
$y = 0.00023X_3-3.07$	0.88	181.00	p<0.000
$y = 0.009X_1-0.0007X_2-2.93$	0.93	166.36	p<0.000
$y = 0.046X_1-0.002X_3-9.56$	0.97	375.27	p<0.000
$y = 0.00068X_2-0.0005X_3-1.74$	0.91	117.03	p<0.000
$y = 0.042\ X_1-0.0003X_2-0.002X_3-8.31$	0.97	311.80	p<0.000

y= Population X_1 = Growing degree days (GDD) ; X_2= Heliothermal units (HTU); X_3 = Photothermal units (PTU)

Prediction models for mango thrips

Positive relation between thrips populations up to its peak value was observed against these thermal indices, the progressive changes in peak thrips incidence and population. Henceforth, cutting across the years, the peak thrips population were pooled (Figure 3), and was predicted by exponential regression equations of following types;

Mango thrips population = $0.0304e^{0.002\times GDD}$ (n = 26, R^2 = 0.91**)

Mango thrips population = $0.0232e^{0.0003\times HTU}$ (n = 26, R^2 = 0.93**)

Mango thrips population = $0.0417e^{0.0002\times PTU}$ (n = 26, R^2 = 0.92**)

The thermal indices during the reproductive stages particularly, during flowering and fruit set, varied across the seasons and thereby influences the thrips populations. Normally with the progress of reproductive phase in mango *viz.*, flowering, panicle emergence, fruit set and development, hopper started shoots up based on exiting hydrothermal conditions. Application of thermal indices in this study confirmed that variations in thrips populations may be predicted >93 %. Thus, it was concluded that use of all these robust indices may be useful in assessing the pest-weather dynamics of region [48]. Based on all these information, region specific crop simulation dynamics models may be developed to predict and forecast the thrips population so that farmers can adopt control measures well in advance to save the fruit crop being lost.

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