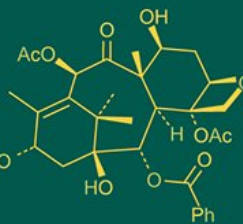
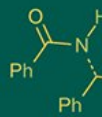


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Population dynamics and weather associations of major sucking insect pests on chilli (*Capsicum annuum* L.) under open-field conditions

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Abstract

Background: Sucking insect pest are one of the major biological challenges to chilli (*Capsicum annuum* L.) productivity, and their seasonal incidence is strongly affected by prevalent weather conditions. Assessment of pest and weather associate is vital for development of weather-based pest forecasting and integrated pest management (IPM) approaches. This study examined the seasonal population dynamics of major sucking insect pests and their associations with abiotic factors under open field conditions.

Methods: The investigation was carried out during the *Rabi* season at the Vegetable Research Centre, G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India. Counts on aphids (*Aphis gossypii*), thrips (*Scirtothrips dorsalis*), and whiteflies (*Bemisia tabaci*) were taken at fortnight intervals from transplanting to harvest of the crop. The ANOVA (analysis of variance) was employed to analyse population dynamics along with Pearson's correlation and simple linear regression analyses to evaluate the associations between pest populations and seven weather parameters.

Results: All three sucking insect pests displayed varied seasonal fluctuations, with populations increasing progressively from the early crop stage, attaining a peak during the 2nd Standard Meteorological Week, and decreasing thereafter. Aphid incidence displayed significant negative correlations with maximum and minimum temperatures with a significant positive correlation with morning relative humidity. Thrips incidence exhibited a significant positive association with morning relative humidity, whereas maximum and minimum temperatures displayed marginally significant negative correlations. In contrast, whitefly incidence exhibited weak, non-significant associations with all measured weather parameters. Further, regression analysis reinforced maximum temperature as the strongest predictor of aphid incidence ($R^2=0.521$, $P=0.028$), while morning relative humidity was found as the primary predictor of variation in thrips incidence ($R^2=0.472$, $P=0.041$). None of the individual weather parameters significantly correlated with whitefly incidence.

Conclusion: The results suggest that temperature and relative humidity are consistent predictors of aphid and thrips incidence and may aid for developing weather-based pest forecasting models for chilli under open field conditions. Nonetheless, forecasting whitefly incidence may require the integration of additional crop and biotic factors. Further investigations are required to validate these associations and improve integrated pest management strategies.

Keywords: Abiotic factors; Aphids; Correlation; Regression analysis; Thrips; Weather parameters; Whitefly.

Introduction

Chilli (*Capsicum annuum* L.) is amongst the most economically significant vegetable and spice crops in the world, prized for both for its culinary versatility as well as for its bioactive compounds (capsaicinoids and flavonoids). It supports a global market for chilli and pepper with an estimated value of USD 1.3 billion in 2025 (Ali *et al.*, 2025) ^[1]. India cultivated 965,612 ha of dry chilli (*Capsicum* spp. and *Pimenta* spp.) with a total production of 2,909,844 tonnes and an average productivity of 3,013.5 kg/ha. In contrast, green chilli employed 479,679 hectares, producing 5,317,989.29 tonnes with a significantly higher average productivity of 11,086.6 kg/ha (FAOSTAT, 2024). Millions of smallholder farmers in the tropics and subtropics relies on the chilli production of for their livelihoods, so even slight, recurrent losses in fruit quality or yield leads to significant economic losses at the farm and national levels. Insect pests remain one of the major yield-limiting biotic factors on

Chilli (Yadav *et al.*, 2022) [8]. sap-sucking pests, aphids, thrips, and whiteflies, together with boring pests like pod or fruit borer, cause injury to crops, and their populations exhibit seasonal fluctuations in accordance with the abiotic factors (Borgohain *et al.*, 2024; Kumar *et al.*, 2020) [9, 10]. Worldwide, a significant amount of potential crop production is already thought to be damaged by insect pests (Oerke, 2006) [5], and this pressure is anticipated to surge in the coming decades in response to rising temperatures and changing rainfall patterns (Deutsch *et al.*, 2018) [2]. Understanding pest responses to abiotic factors is essential for developing reliable, locally adapted pest forecasting and integrated pest management (IPM) strategies, rather than merely describing pest occurrence. Characterizing pest-weather relationships with a systematic approach involves weather-associated population monitoring throughout standard meteorological weeks and correlating pest population with weather data. Research on sucking pests in chilli and related solanaceous crops report that different pest species under the same weather conditions may respond in varied, sometimes in opposite ways (Khatun *et al.*, 2023) [3]. This heterogeneity in response to weather conditions necessitates pest- and location-specific weather correlation investigations to improve forecasting precision, rather than relying on generalized assumptions. Although the observations of the present study were recorded a decade ago, the sustained significance of such systematically documented dataset is evident as it provides a valuable historical baseline for understanding pest and weather relationships. As regional climates continue to change, the temperature and humidity thresholds for pest outbreaks are estimated to change in chilli crop, demanding a strong historical baseline for assessment with future observations (Lawton *et al.*, 2022) [4]. Furthermore, varying pest groups react differently to transient weather changes and prolonged host-plant phenology, suggesting that climate change may enhance certain pest populations higher than others. Consequently, it is vital to retain previously quantified information of pest weather interactions as baseline for future studies. The study analysed the population dynamics of major sucking insect pests viz., aphid, thrips, whitefly affecting chilli (*Capsicum annuum* L.) cv. Commando under open field conditions during Rabi cropping season. It aims to characterize seasonal population dynamics, evaluate relationships with abiotic factors and identify the key weather predictors for each pest utilizing simple linear regression. This will establish a quantitative reference dataset for weather-based pest advisories on chilli, pliable to changing regional climatic conditions.

Materials and Methods

Experimental site

The experiment was conducted at the Vegetable Research Centre (VRC), G.B. Pant University of Agriculture & Technology, Pantnagar, U. S. Nagar, Uttarakhand, India, during the 2015–16 Rabi season.

Observations on insect pest incidence and meteorological data

Population dynamics of the major sucking insect pest namely aphids (*Aphis gossypii*), thrips (*Scirtothrips dorsalis*), and whiteflies (*Bemisia tabaci*) were recorded at fortnight interval from transplanting until the final harvest of the crop. Counts of insects per five leaves from five

randomly selected plants were taken and then expressed as the mean number of insects per leaf. Related meteorological data were procured from the Department of Meteorology, G.B. Pant University of Agriculture and Technology, Pantnagar, U.S. Nagar, Uttarakhand, India, for further correlation and regression analysis.

Statistical analysis

To determine significant differences between Standard Meteorological Weeks (SMWs), the data on the population dynamics of sucking insect pests on chilli were assessed using analysis of variance (ANOVA). The treatment means for each insect species were compared using the critical difference (CD) test at the 5% level of significance. The Pearson's correlation analysis was employed to assess the interaction between seven abiotic weather parameters and pest populations, while simple linear regression analysis was utilised to evaluate the influence of individual weather parameters on the population of sucking insect pests under open field conditions.

Results

Population dynamics of sucking insect pests in chilli under open field conditions

The populations of aphids, thrips, and whiteflies showed noticeable seasonal fluctuations during the study period (Table 1). The population of aphids varied from 0.23 to 1.77 aphids/leaf, with an overall mean of 0.98 ± 0.51 aphids/leaf. The population of aphids was lowest during the 46th Standard meteorological week (SMW) (0.23 aphids/leaf), then increased gradually through the cropping season, and attained a peak during the 2nd SMW (1.77 aphids/leaf). Next, the population of aphids declined continuously to 0.63 aphids/leaf by the 10th SMW.

Table 1. Population dynamics of major sucking insect pests on chilli (*Capsicum annuum* L.) cv. Commando at different Standard Meteorological Weeks (SMWs).

S.No.	Standard Meteorological Week No.	Mean number of insects per leaf		
		Aphids	Thrips	Whitefly
1	46	0.23 ^f (0.48)	0.29 ^e (0.54)	0.19 ^e (0.43)
2	48	0.72 ^{de} (0.85)	0.64 ^c (0.80)	0.31 ^d (0.55)
3	50	1.31 ^b (1.14)	0.97 ^b (0.99)	0.41 ^c (0.64)
4	52	1.67 ^a (1.29)	1.29 ^a (1.14)	0.61 ^b (0.78)
5	2	1.77 ^a (1.33)	1.32 ^a (1.14)	0.69 ^a (0.83)
6	4	1.08 ^c (1.04)	0.64 ^c (0.80)	0.04 ^g (0.20)
7	6	0.76 ^d (0.87)	0.53 ^{cd} (0.73)	0.16 ^e (0.40)
8	8	0.68 ^{de} (0.82)	0.44 ^d (0.66)	0.16 ^e (0.40)
9	10	0.63 ^f (0.79)	0.43 ^d (0.65)	0.12 ^f (0.35)
Mean±SD		0.98±0.51	0.73±0.38	0.30±0.23
Sem±		0.171	0.126	0.076
CD at 5%		0.056	0.057	0.026

(Note: Values in parentheses are square root transformed. Means followed by the same letter(s) within a column are not significantly different (CD, $P=0.05$.)

A similar pattern was observed for thrips. The population varied from 0.29 to 1.32 thrips/leaf, with a mean population of 0.73 ± 0.38 thrips/leaf. The lowest population was recorded during the 46th SMW (0.29 thrips/leaf), after which it increased gradually peaking at 1.32 thrips/leaf during the 2nd SMW. Thereafter, the thrips population declined steadily, reaching 0.43 thrips/leaf by the 10th SMW. However, whitefly populations were comparatively lower

throughout the study period, ranging from 0.04 to 0.69 whiteflies/leaf, with an overall mean of 0.30 ± 0.23 whiteflies/leaf. The minimum population was recorded during the 4th SMW (0.04 whiteflies/leaf), whereas the maximum population (0.69 whiteflies/leaf) occurred during the 2nd SMW. Following the peak population, whitefly population declined and remained low during the later observation period, reaching 0.12 whiteflies/leaf by the 10th SMW. Overall, the populations of all three sucking insect pests exhibited a similar seasonal trend, characterized by a progressive increase from the early observation period to a peak during the 2nd SMW, followed by a consistent decline towards the end of the observation period. Aphids attained the highest mean population, followed by thrips, whereas whiteflies remained the least abundant pest throughout the study period in chilli under open field conditions.

Prevailing weather conditions during the study period

During the experimental period, the maximum temperature ranged from 17.90 to 30.40°C, while the minimum temperature varied between 4.10 to 13.40°C. The morning relative humidity remained consistently high, (86 to 95%), whereas evening relative humidity ranged from 37 to 64%. Additionally, rainfall was negligible throughout the study period, with only 2.50 mm received during 8th SMW. The sunshine hours ranged between 2.10 to 8.40 hours per day; however, wind velocity ranged from 2.70 to 6.30 km per hour. Overall, the study period was marked by cool to moderately warm temperatures, with high morning relative humidity, negligible rainfall and moderate wind velocity and sunshine (Fig 1).

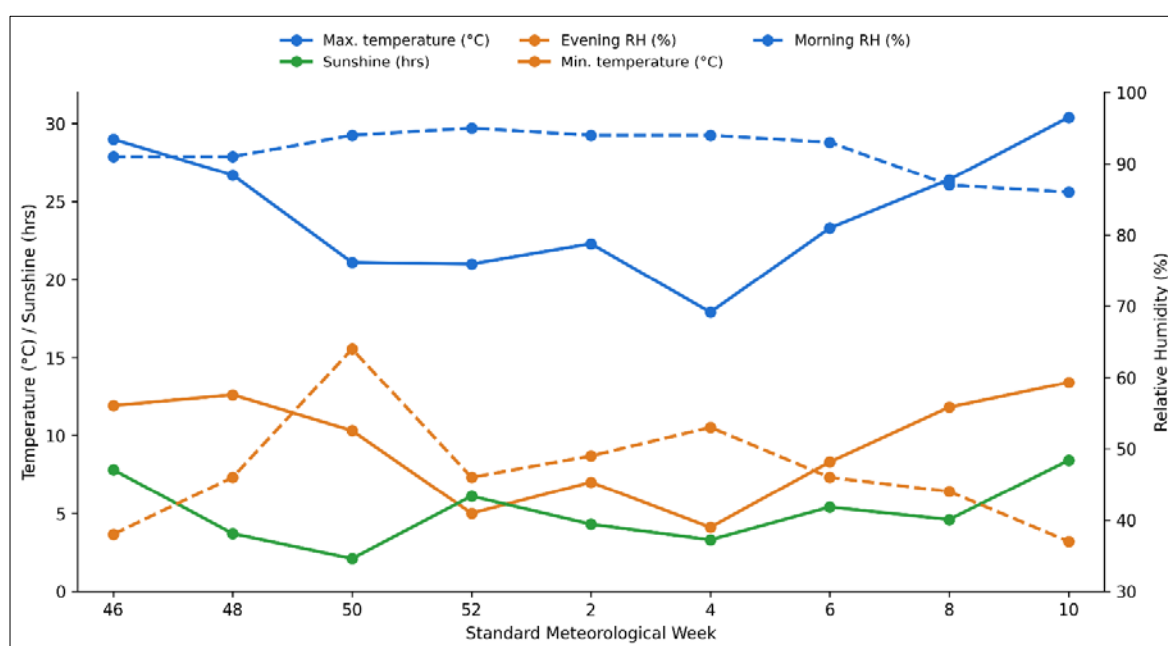


Fig 1: Weekly variation in weather parameters during the study period in chilli (*Capsicum annum* L.) cv. Commando under open-field conditions.

Relationship between weather parameters and pest populations

Pearson's correlation analysis

Pearson's correlation analysis resulted varying relationships between major sucking insect pest populations and the prevailing weather parameters (Fig. 2). The aphid population demonstrated a significant negative correlation with maximum ($r=-0.72$, $P<0.05$) and minimum temperature ($r=-0.69$, $P<0.05$), whereas showing a significant positive correlation with morning relative humidity ($r=0.67$, $P<0.05$). Simultaneously evening relative humidity had a positively influence on aphid abundance ($r=0.56$), but the relationship was not statistically significant. However, thrips population exhibited marginally significant negative correlations with maximum ($r=-0.62$, $P=0.075$) and minimum temperature ($r=-0.60$, $P=0.085$), while a significant positive correlation was found with morning relative humidity ($r=0.69$, $P<0.05$). In contrast,

whitefly population had a weak negative correlation with maximum ($r=-0.30$) and minimum temperature ($r=-0.32$), along with weak positive correlations with morning ($r=0.54$) and evening relative humidity ($r=0.28$); however, none of these associations were statistically significant. Moreover, Rainfall, sunshine hours, and wind velocity had negative influence on the populations of aphids, thrips, and whiteflies, although none of these correlations were statistically significant (Fig. 2).

Overall, aphid and thrips populations had a significant negative influence of temperature and positively relationship with morning relative humidity, however whitefly population showed comparatively weaker and non-significant relationship with these weather parameters. Rainfall, sunshine hours, and wind velocity demonstrated negligible, non-significant relationship with on the populations of all three sucking insect pests (Fig. 2).

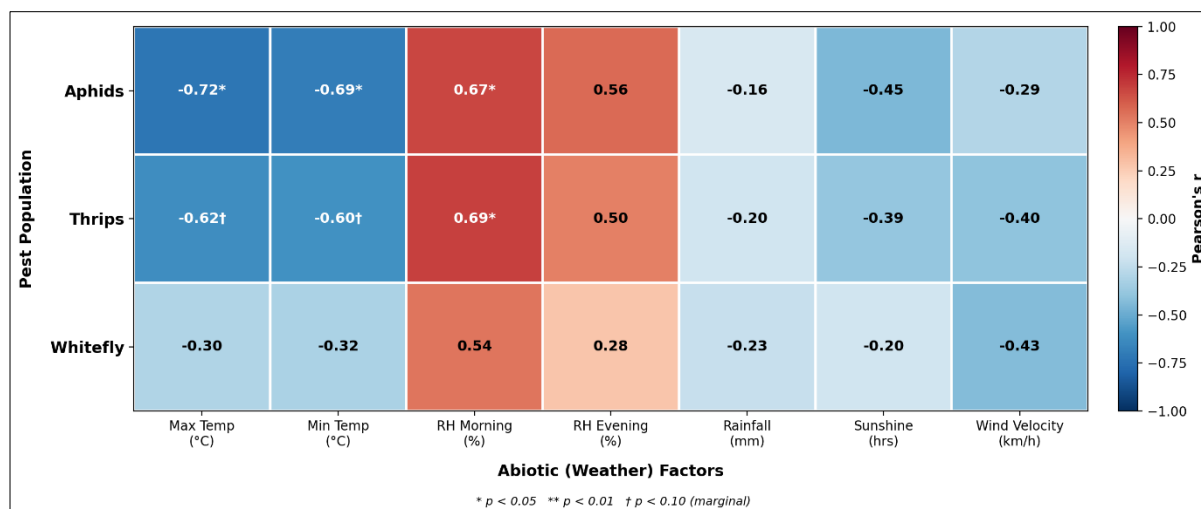


Fig 2: Pearson's correlation matrix (r) between abiotic weather parameters and major sucking insect pest populations on chilli (*Capsicum annuum* L.) cv. Commando under open-field conditions

Simple Linear regression analysis

Simple linear regression analysis revealed that maximum temperature was the strongest predictor of aphid population, explaining 52.1% of the observed variation ($R^2=0.521$, $P=0.028$). The negative regression coefficient ($Y=-0.090x+3.157$) suggested a decline in aphid population with increasing maximum temperature. Significant

regression models were also obtained for minimum temperature ($R^2=0.482$, $P=0.038$) and morning relative humidity ($R^2=0.448$, $P=0.049$), representing negative and positive relationships with aphid population, respectively. In contrast, evening relative humidity, rainfall, sunshine hours, and wind velocity did not yield significant regression models ($P>0.05$).

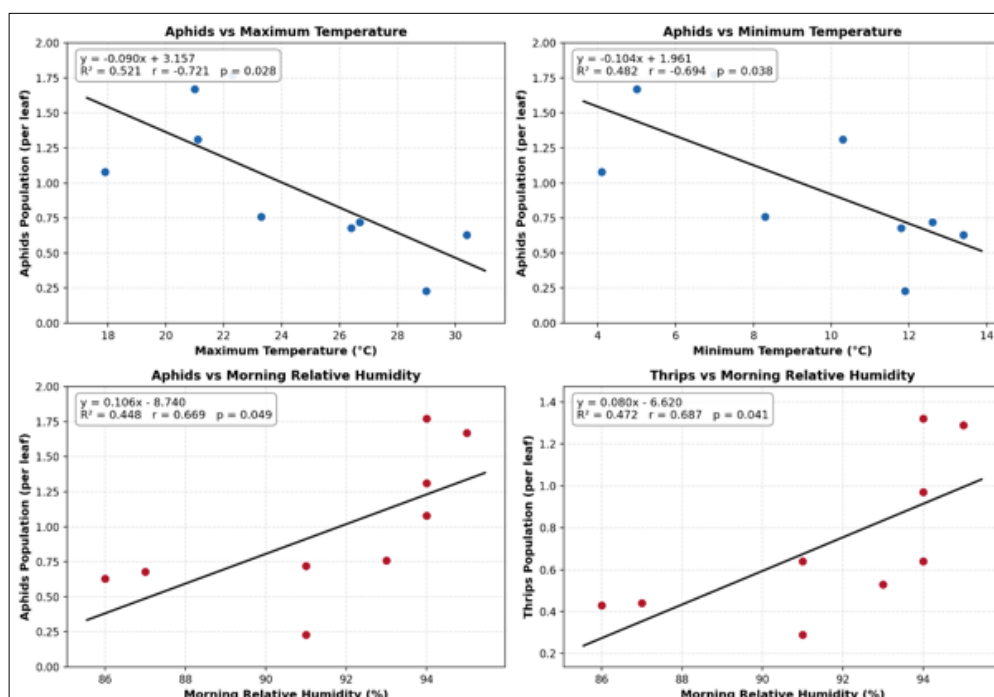


Fig 3: Significant simple linear regression models depicting the associations between weather parameters and populations of aphids and thrips on chilli (*Capsicum annuum* L.) cv. Commando under open-field conditions

In case of thrips, morning relative humidity was the only key predictor, explaining 47.2% of the variation in thrips population ($R^2=0.472$, $P=0.041$). The positive regression coefficient ($Y= 0.080x-6.620$) suggested a rise in thrips population with increasing morning relative humidity. Regression models for maximum temperature ($R^2=0.384$, $P=0.075$) and minimum temperature ($R^2=0.366$, $P=0.085$) displayed marginally significant negative associations, however evening relative humidity, rainfall, sunshine hours, and wind velocity were not significantly associated with thrips population ($P>0.05$). In contrast, none of the assessed

weather parameters significantly predicted whitefly population ($P>0.05$). However, positive relationships were noted with morning and evening relative humidity and a negative relationships with maximum and minimum temperature, rainfall, sunshine hours, and wind velocity, the ability of the regression models to explain variation was low ($R^2=0.039$ to 0.286), suggesting that these variables explained only a small proportion of the variation in whitefly population.

Overall, the regression analysis revealed that maximum temperature was the strongest predictor of aphid population,

however morning relative humidity best explained variation in thrips population. In contrast, none of the individual weather parameters significantly predicted whitefly population during the study period.

Discussion

The population dynamics presented in this study are broadly consistent with the general pattern documented for sucking pests of chilli and other related crops, in which aphids and thrips, and to a lesser extent whiteflies increase under the cool, humid environments of the winter (*Rabi*) season and decrease as temperatures rise toward crop maturity. A comparable pattern was recorded in Bangladesh for sucking insect vectors on chilli, the vectors were active during the cropping period and generally displayed positive relationship with both temperature and relative humidity (Khatun *et al.*, 2023) [3]. In particular, whitefly populations had a negative relationship with temperature and rainfall, which is in accordance with the weak and non-significant relationships between weather parameters and whitefly population documented in the present study.

The strong negative correlation between aphid population and both maximum and minimum temperature, along with a positive correlation with morning relative humidity, aligns with the previously reported sensitivity of aphids to temperature and moisture conditions. A controlled environment study demonstrated that low relative humidity generally enhances heat tolerance in several aphid species, where high relative humidity intensifies mortality under high temperature conditions, and that responses vary between species (Yuan *et al.*, 2026) [6]. These results provide a probable physiological justification for the higher aphid population recorded during the relatively cooler, more humid weeks (50th to 2nd SMW) and the following gradual reduction in population throughout the later weeks of the study. The positive association among thrips population and morning relative humidity, coupled with the negative relationship with maximum and minimum temperatures documented in the present study, is in agreement with the findings of Saini *et al.* (2023) [11], who also reported negative relationships of thrips population with both maximum and minimum temperatures and a positive correlation with morning relative humidity in chilli, although their associations were comparatively weaker and non-significant. Similarly, Chauhan *et al.* (2024) [12] revealed a significant negative association between thrips population and maximum temperature and a significant positive relationship with morning relative humidity in non-*Bt* cotton, suggesting that relatively cooler and more humid weather may favour thrips population across different cropping systems. However, the scale and significance of these associations have been reported to vary among crops, cultivars and agro-climatic circumstances, suggesting that thrips responses to meteorological conditions are influenced by local climate.

The whitefly population exhibited weak negative relationships with maximum and minimum temperatures and weak positive associations with morning and evening relative humidity; none of these relationships were statistically significant. A similar pattern was reported in *BT* cotton (Kataria *et al.*, 2019) [13] and mung bean (Manish *et al.*, 2026) [14], although the magnitude of the relationship varied among studies. Similar trends have also been reported in bhendi, where incidence of sucking pest was in

negative relationship with temperature and in a positive relationship with relative humidity, although again, the magnitude of these relationships varied (Prasad *et al.*, 2026) [15]. However, contrasting associations have also been reported in chilli and other vegetable crops, indicating that crop, season and agro-climatic conditions may differentially influence whitefly population. Therefore, the absence of significant correlations in the present study suggests that abiotic factors alone were insufficient to explain whitefly population dynamics and that additional factors, such as crop phenology, host plant attributes and other biotic factors, may also contribute to its seasonal abundance.

Taken together, the current results indicate that the major sucking insect pests of chilli vary in their reaction to prevailing weather parameters. The temperature and morning relative humidity exhibited the strongest influence on aphids, while thrips population had major influence by morning relative humidity. In contrast, whitefly population displayed relatively weak and non-significant associations with the measured abiotic factors, indicating that its population dynamics is likely controlled by additional crop phenology and biotic factors. These results have significant implications for the development of pest forecasting models using weather variables, suggesting that temperature and relative humidity may serve as valuable indicators for forecasting aphid and thrips outbreaks, however, weather variables alone may be insufficient for predicting whitefly incidence. Given the estimated effects of climate change on insect pest dynamics (Deutsch *et al.*, 2018) [2] and the considerable yield losses caused by insect pests worldwide (Oerke, 2006) [5], long-term field studies will be vital for developing forecasting models and reinforcing integrated pest management approaches in chilli cultivation under open field conditions.

Conclusion

The present study revealed that populations of major sucking insect pests of chilli exhibited distinct seasonal fluctuations under open field conditions. Aphids exhibited significant negative associations with maximum and minimum temperatures and a positive correlation with morning relative humidity, while thrips were primarily associated with morning relative humidity. In contrast, whiteflies showed weak and non-significant relationships with the measured weather parameters, indicating that influences beyond abiotic factors may also influence its seasonal abundance. These results suggest that temperature and relative humidity are valuable predictors for aphid and thrips incidence and may facilitate the developing weather-based pest forecasting models. Nonetheless, forecasting whitefly incidence may require the integration of additional crop and biotic factors. Further long-term investigations will be effective for validating these associations and reinforcing integrated pest management strategies for chilli cultivation under open field conditions.

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