# Population Dynamics of Cotton Whitefly Under Different Climatic Conditions

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## *Abstract*

*Cotton whitefly, Bemisia tabaci (Genn.), is a sucking insect pest among the most destructive of cotton in Pakistan. During the 2024 cotton-growing season, the effects of various climatic conditions on the population dynamics of cotton whitefly in the Department of Entomology using the Bt cotton variety FH-142 were investigated. The experiment was laid out in a Randomized Complete Block Design (RCBD) and replicated three times. Whitefly populations were observed weekly throughout June-October, and meteorological data (maximum temperature, minimum temperature, relative humidity, rainfall, wind speed, and sunshine duration) were collected from a nearby weather station. Analysis of variance (ANOVA), Pearson's correlation, multiple linear regression, and principal component analysis (PCA) were used to analyze the data. The whitefly population was significantly different across the season ($F = 46.82$, $P < 0.001$), with the highest value of 18.6 ± 0.57 adults leaf$^{-1}$ recorded during the 37th SMW and decreasing to 2.4 ± 0.21 adults leaf$^{-1}$ in October. Maximum temperature and sunshine duration were significantly positively correlated with whitefly, whereas rainfall and relative humidity were significantly negatively correlated. The $R^2$ of climatic variables with whitefly abundance was 78%, and the first two PCA components explained 81.3% of the total variance. These results indicate that temperature plays an important role in whitefly outbreaks and suggest the need to incorporate weather information into the IPM program for sustainable cotton production.*

**Keywords:** Bemisia Tabaci, Cotton, Whitefly, Climatic Factors, Seasonal Abundance.

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## Introduction

Among the world's most economically significant fiber crops, cotton (*Gossypium hirsutum L.*) is an important source of raw material for the textile industry. Cotton plays a strategic role in Pakistan's agricultural sector and contributes significantly to the country's economic development through job creation, exports, and industrial growth (Khan et al., 2020). The crop is also called "white gold" of Pakistan due to its significant contribution to the national economy by providing food security through the textile industry, which accounts for a large share of the country's industrial production and foreign exchange earnings (Noorka et al., 2019). The recent agricultural statistics show that cotton plays a significant role in Pakistan's agricultural value added and gross domestic product, and creates livelihood opportunities for millions of farming families engaged in cotton farming, harvesting, processing, and marketing. (Sadaf et al., 2022). The cotton whitefly, *Bemisia tabaci* (*Gennadius*) (*Hemiptera: Aleyrodidae*), is one of the most prevalent and damaging sucking insect pests worldwide, affecting cotton (Nazeer et al., 2023). The whitefly is a major problem for sustainable crop production, causing significant economic losses across many cotton-producing areas, including Pakistan, India, China, Egypt, and the USA (Khalid et al., 2026).

Whitefly directly and indirectly damages plants. Ongoing feeding prevents the plant from obtaining nutrients, resulting in loss of vigour, chlorosis, leaf curling, early leaf drop, stunted growth, and lower yield potential. In severe infestations, extensive sap removal reduces photosynthetic efficiency and disrupts normal physiological processes within the plant (Morin et al., 2024). Cotton whitefly is also an exceptionally polyphagous species, another factor contributing to its pest status. The insect infests over 600 plant species belonging to more than 70 botanical families, many of which are economically important crops such as cotton, tomato, tobacco, brinjal, okra, cucurbits, soybean, ornamental plants, and many weeds (Rahman et al., 2025). The host range is wide, allowing the pest to survive year-round by moving from cultivated hosts to wild hosts when they are available. Ecological flexibility enables rapid population establishment and persistence across diverse environments (Wang et al., 2022).

Environmental factors play a crucial role in the dynamics of insect populations. Whiteflies are strongly influenced by climatic factors, including temperature, relative humidity, rainfall, wind speed, and the duration of sunshine. Temperature is one of the most important factors that impact whitefly biology (Prasad, 2022). Adverse temperature conditions slow down immature development, reduce adult longevity, and result in reduced reproduction rates, resulting in slow population increase; and favorable temperature conditions promote rapid population increase by accelerating immature development, reducing the generation interval, enhancing the longevity of adults, and increasing reproduction capacity (Peer et al., 2025). Likewise, precipitation can be a natural mortality factor as the eggs, nymphs, and adults are physically washed from the plants. Adult dispersal patterns and colonization efficiency may be influenced by wind speed, host plant physiology, and microclimates conducive to pest development, including the duration of sunshine (Abubakar et al., 2022).

The recent trend of climate change has raised awareness of insect occurrence and control. These changes can affect the interactions between hosts and pests and put current pest management approaches under pressure (Ojija et al., 2025). Therefore, understanding the relationships between climatic variables and pest population dynamics is important for creating adaptive, climate-resistant integrated pest management (IPM) programs. Weather-based pest forecasting systems have evolved into useful tools and a valuable aid for timely decision-making (Haider et al., 2026). Whitefly population responses to environmental variables may be affected by agroecological conditions, host plant attributes, cropping system, and management practices (Lobin et al., 2022). Today, cotton whitefly has become one of the most destructive insect pests of cotton production in Pakistan, and it inflicts economic losses in two ways: direct feeding damage and indirect role in the spread of plant viruses (Hameed et al., 2023).

Bt cotton has been widely introduced for control of several lepidopteran pests, but whitefly infestation remains a major challenge to crop productivity and sustainability (Nagaraj et al., 2024). Hence, this study was conducted to understand the seasonal distribution of *B. tabaci* in the Bt cotton variety FH-142 and its effect on season-wise population fluctuations. The aims of this study were to explore the seasonal population of cotton whitefly on Bt cotton variety FH-142, to evaluate the effect of major climatic parameters on cotton whitefly population, to identify the weather parameters that are critical for the occurrence of cotton whitefly infestation, and to produce information that could be used in developing a weather-based IPM strategy. Understanding these relationships is crucial for forecasting whitefly outbreaks, avoiding unnecessary pesticide spraying, and achieving sustainable, profitable cotton farming in Pakistan.

## Materials and Methods

### Experimental Site and Experimental Material

The experiment was conducted in the Department of Entomology's experimental field during the cotton season (June – October 2024). The study area is semi-arid, with hot, summer-agroecological conditions in southern Punjab, Pakistan, characterized by irregular rainfall. Bt cotton variety FH-142 was chosen for this study due to its wide cultivation and adaptability under the agro-climatic conditions in Pakistan. Authorized sources were used to ensure varietal purity and uniform germination of certified seed (Pakistan Central Cotton Committee [PCCC] 2024).

### Experimental Design and Field Layout

Three replications of Randomized Complete Block Design (RCBD) were used in the experiment. RCBD is preferred for agricultural field experiments because it helps to reduce environmental variability and increase the precision of treatment comparisons (Gomez and Gomez, 1984). The size of each plot was 6 x 5 m, with a standard spacing of 30 x 75 cm for cotton planting, according to recommendations by the Ayub Agricultural Research Institute (AARI) for growing cotton in Pakistan (2023).

### Monitoring of Whitefly Population

Four-weekly observations of whitefly numbers were started two weeks after seedling emergence and continued to the maturity of the crop. The sampling methods used were slightly adapted from those of Abbas et al. (2023). Therefore, a mean of 30 leaves was taken from each plot for each observation period. Whitefly counts were conducted in the early morning hours (07:00 – 09:00 h), when adult movement was relatively low, resulting in more accurate counts (Yadav et al., 2024).

### Statistical Analysis

Data were analyzed using ANOVA, Pearson's correlation, simple and multiple linear regression, and PCA to evaluate whitefly population dynamics and climatic influences. Statistical significance was determined at 5% and 1% probability levels following established procedures. According to Gomez and Gomez (1984), Steel et al. (1997), and Jolliffe (2002), statistical significance was evaluated at the 5% and 1% levels.

## Results

### Seasonal Population Dynamics of Cotton Whitefly

The abundance of cotton whitefly (CWA) on Bt cotton variety FH-142 was observed weekly over the growing season, with a clear indication of a seasonality trend presented in Table 1. Whitefly started to appear in the second week of June at low levels (1.8 – 2.8 adults leaf-1) and gradually increased through July (4.1– 8.4 adults leaf-1), corresponding with the improvement of potential host suitability, as the crop canopy developed. A rapid increase occurred in August, when the rate of adults leaf$^{-1}$ exceeded 10 adults leaf$^{-1}$, and at the end of the month it was 15.7 adults leaf$^{-1}$. The highest infestation was the 2nd week of September (18.6 adults leaf$^{-1}$) followed by a significant drop in October (7.8–3.2 adults leaf$^{-1}$). A close correlation was observed between these fluctuations and crop phenology and climatic conditions.

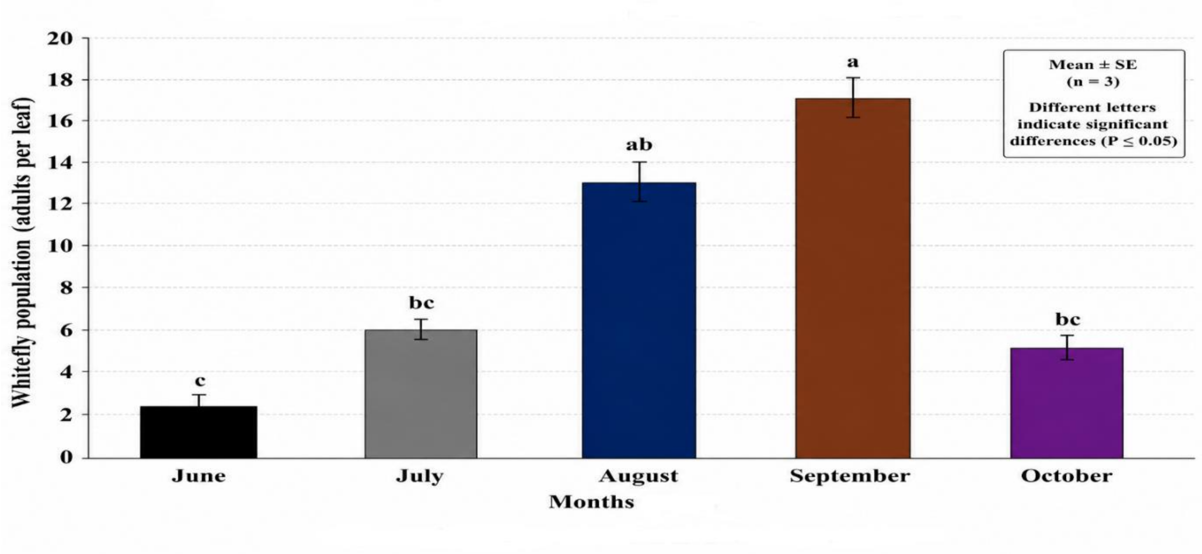
**Table 1: Weekly Abundance of Cotton Whitefly (*Bemisia Tabaci*) During the Growing Season Of 2024**

| Month | Standard Meteorological Week | Mean Whitefly Population (Adults leaf$^{-1}$ ± SE) |
|---|---|---|
| June | 24$^{th}$ | 1.8 ± 0.18 |
| June | 25$^{th}$ | 2.1 ± 0.22 |
| June | 26$^{th}$ | 2.4 ± 0.25 |
| June | 27$^{th}$ | 2.8 ± 0.20 |
| July | 28$^{th}$ | 4.1 ± 0.27 |
| July | 29$^{th}$ | 5.3 ± 0.32 |
| July | 30$^{th}$ | 6.4 ± 0.35 |
| July | 31$^{st}$ | 8.4 ± 0.41 |
| August | 32$^{nd}$ | 10.8 ± 0.48 |
| August | 33$^{rd}$ | 12.3 ± 0.53 |
| August | 34$^{th}$ | 14.2 ± 0.60 |
| August | 35$^{th}$ | 15.7 ± 0.67 |
| September | 36$^{th}$ | 17.4 ± 0.71 |
| September | 37$^{th}$ | 18.6 ± 0.74 |
| September | 38$^{th}$ | 17.8 ± 0.69 |
| September | 39$^{th}$ | 15.0 ± 0.61 |
| October | 40$^{th}$ | 7.8 ± 0.46 |
| October | 41$^{st}$ | 5.6 ± 0.38 |
| October | 42$^{nd}$ | 4.5 ± 0.31 |
| October | 43$^{rd}$ | 3.2 ± 0.26 |

**Monthly Population Fluctuations**

Monthly analysis determined that there was significant seasonality in the abundance of whitefly displayed in figure 1. The lowest population was seen in June (2.4 ± 0.21 adults leaf$^{-1}$) with highest increase observed in August (13.3 ± 0.57 adults leaf$^{-1}$). The greatest infestation was in September (17.2 ± 0.69 adults leaf$^{-1}$) and this was significantly higher than all other months. Populations decreased in October (5.3 ± 0.35 adults/leaf) which confirmed that August–September was the critical infestation time.

**Figure 1: Seasonal Dynamics of Cotton Whitefly Populations on Bt Cotton Variety FH-142 During June–October 2024**




**ANOVA for Monthly Whitefly Abundance**

The ANOVA indicated that the number of whiteflies was significantly different among the different sampling months ($F = 46.82$, $P < 0.001$), which suggests that seasonal variation has a significant effect on the abundance of whiteflies was shown in table 2. The much greater month mean square (143.36) than the error mean square (3.06) substantiated that these differences were due to true temporal differences and not to random variation. There were no significant replication effects ($F = 0.68$, $P = 0.526$), which indicated the uniformity and reliability of the experiments. The results indicate that seasonal and environmental factors had the greatest influence on whitefly population fluctuations.

**Table 2: ANOVA For Monthly Whitefly Abundance**

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square | F-value | P-value |
|---|---|---|---|---|---|
| Months | 4 | 573.42 | 143.36 | 46.82 | <0.001 |
| Replications | 2 | 4.17 | 2.09 | 0.68 | 0.526 |
| Error | 8 | 24.50 | 3.06 | | |
| Total | 14 | 602.09 | | | |

**Relationship Between Maximum Temperature and Cotton Whitefly Abundance**

Good positive correlation between whitefly abundance and temperature during the study. The scatter plot and regression analysis showed a highly significant positive relationship between maximum temperature and whitefly abundance ($r = 0.74$, $P < 0.01$), with minimum temperature showing a moderately significant positive correlation ($r = 0.62$, $P < 0.05$). For the regression model, Whitefly population = −28.41 + 1.21 (Maximum Temperature), it was estimated that an adult leaf$^{-1}$ increase for each 1°C rise in maximum temperature. The coefficient of determination (R^2 = 0.548) showed that 54.8% of the difference in the abundance of whiteflies was explained by maximum temperature. The results show in table 3 and 4 that temperature is a significant factor in the dynamics of whitefly populations and indicate the need for more intensive monitoring and appropriate IPM action on warm days.

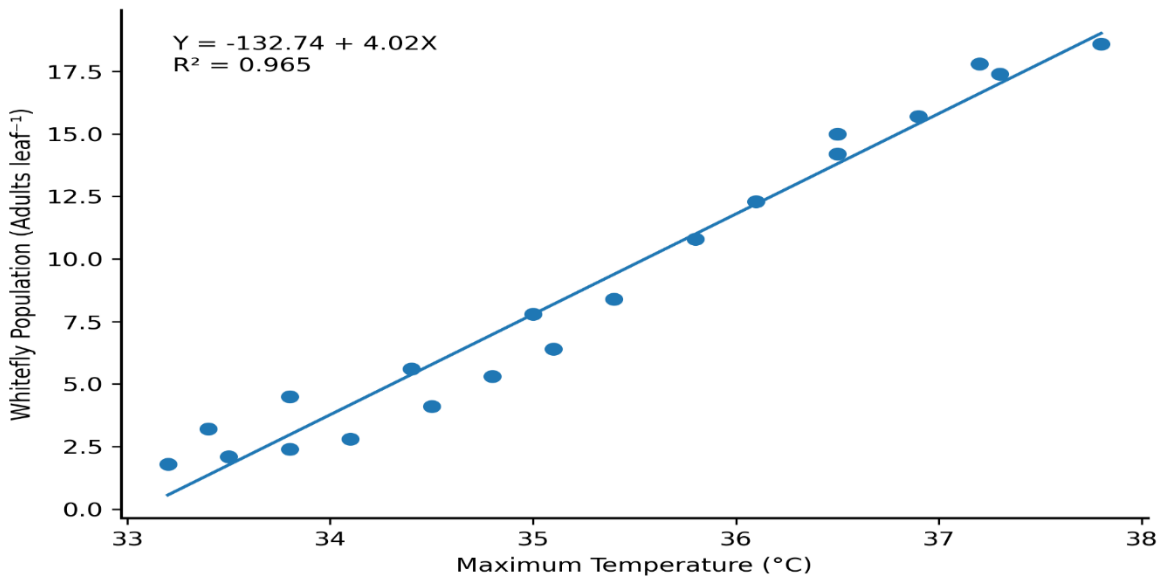
**Table 3: Association Between Temperature and Whitefly Abundance**

| Climatic Variable | Correlation Coefficient (r) | Significance |
|---|---|---|
| Maximum Temperature | 0.74 | P < 0.01 |
| Minimum Temperature | 0.62 | P < 0.05 |

**Table 4: Regression Analysis Describing the Effect of Maximum Temperature on Whitefly Abundance**

| Parameter | Estimate | Standard Error | t-value | P-value |
|---|---|---|---|---|
| Intercept | −28.41 | 5.82 | −4.88 | <0.001 |
| Maximum Temperature | 1.21 | 0.29 | 4.17 | 0.001 |
| $R^2 = 0.548$ | | | | |

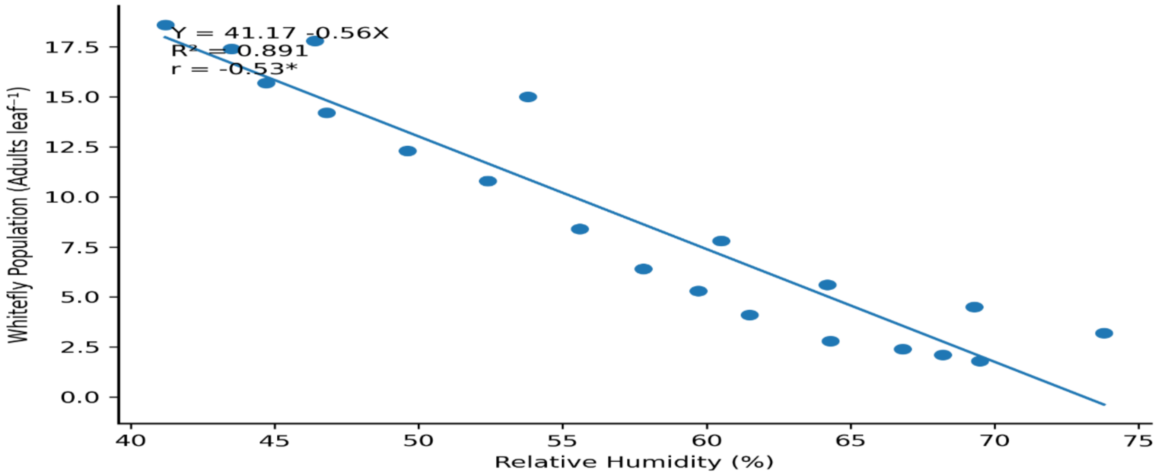
**Figure 2: Relationship Between Maximum Temperature and Cotton Whitefly Abundance**




**Relationship Between Relative Humidity and Whitefly Abundance**

The relative humidity and whitefly abundance were significantly and negatively correlated throughout the cotton growing season as shown in Figure 3. The low relative humidity (66.8–69.5%) did not favour whitefly, and their numbers varied from 1.8 to 2.4 adults/leaf. The adult leaf-population rose sharply from 6.4 to 15.6 adults leaf$^{-1}$ with a peak of 18.6 adults leaf$^{-1}$ at 41.2%RH during SMW 37 as the RH dropped from 57.8–44.7%. As the relative humidity increased to 73.8%, the whitefly populations went down to 3.2 adults/leaf. Pearson's correlation was used to confirm a significant negative correlation between relative humidity and whitefly abundance ($r = -0.53$, $P < 0.05$). The results indicate that high humidity inhibits whitefly establishment and activity, likely due to a decrease in feeding and oviposition efficiency and a resulting increase in entomopathogenic fungi that occur naturally in the environment and help to control whitefly populations.

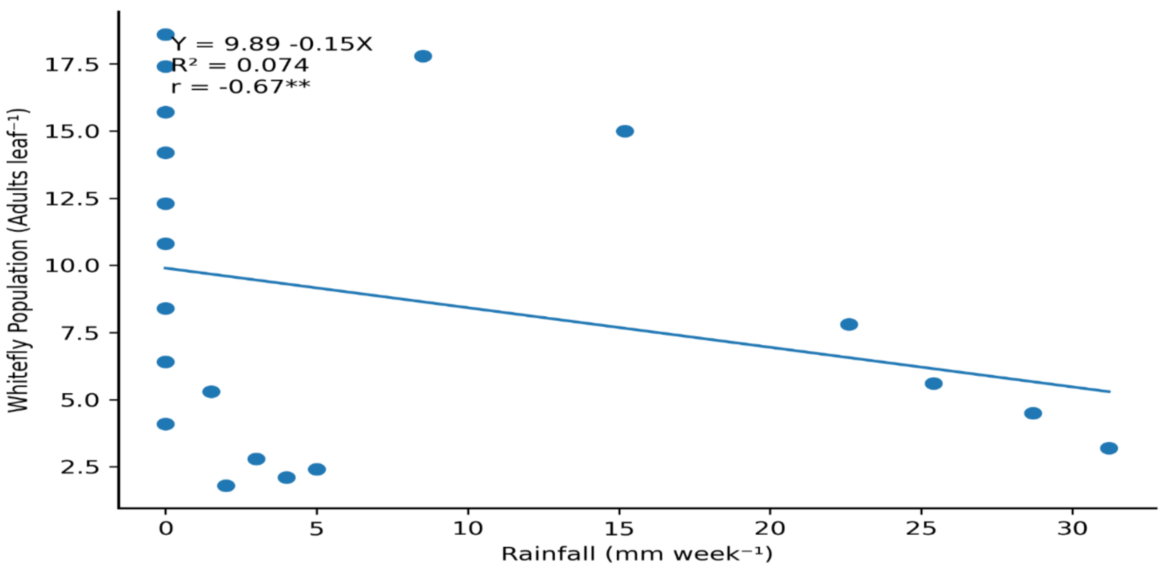
**Figure 3: Relationship Between Relative Humidity and Whitefly Abundance**




**Influence of Rainfall on Cotton Whitefly Populations**

The rainfall during cotton growing season showed significant negative effect on whitefly abundance as shown in figure 4. During dry periods when there was little or no rainfall, whitefly populations rose steadily, from 4.1 adults leaf$^{-1}$ in SMW 28 to 18.6 adults leaf$^{-1}$ in SMW 37. The number of adults decreased significantly after the first rain event, with 8.5 mm of rain in SMW 38 lowering the numbers to 17.8 adults leaf$^{-1}$ and heavier rains in SMW 39–43 (15.2–31.2 mm) reducing populations further from 15.0 to 3.2 adults leaf$^{-1}$. Pearson's correlation showed a very significant negative correlation between rainfall and whitefly abundance ($r = -0.67$, $P < 0.01$). The results indicate that rainfall is a natural suppressive factor, likely via the wash-off effect, lowered adult activity and poor conditions affecting B. tabaci survival, reproduction, and dispersal.

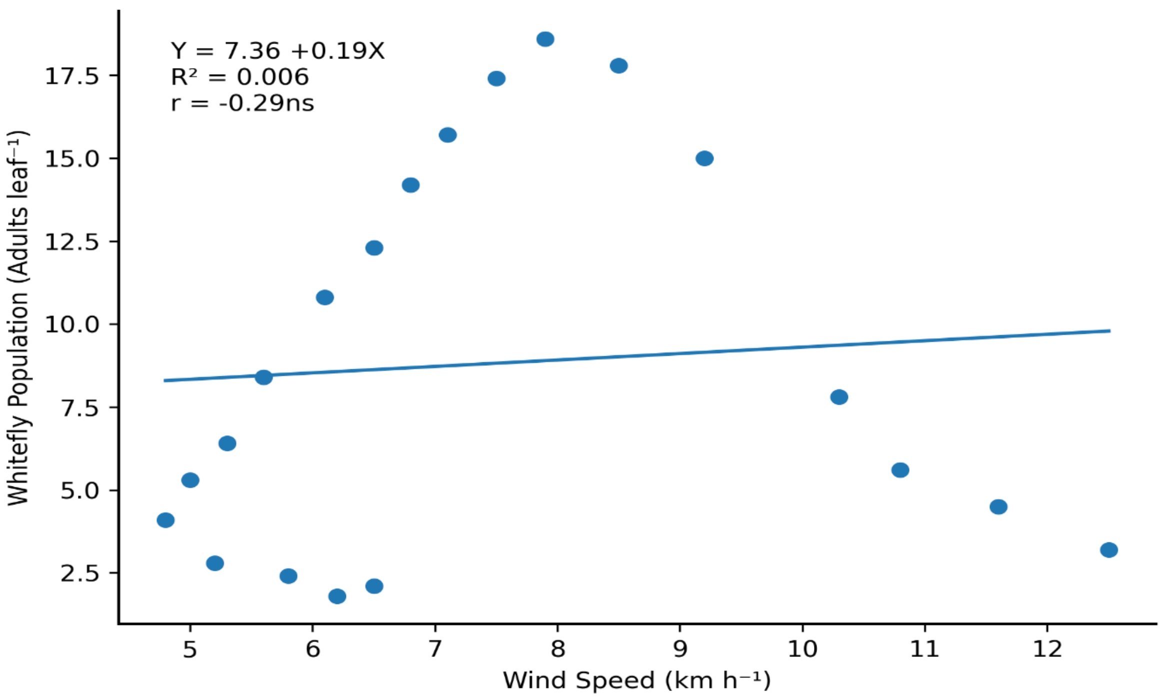
**Figure 4: Influence Of Rainfall on Cotton Whitefly Populations**



**Relationship Between Wind Speed and Whitefly Abundance**

During the study, there was a weak negative correlation between wind speed and whitefly abundance as shown in figure 5. Low to moderate wind speed (4.8–7.9 km $h^{-1}$) favored whitefly development which peaked at 18.6 adults $leaf^{-1}$ for SMW 37. Increased wind speeds (10.3–12.5 km $h^{-1}$) were followed by a decrease in population (3.2 adults leaf–¹ by SMW 43). There was a weak, negative and non-significant correlation between wind speed and whitefly abundance ($r = -0.29$, $P > 0.05$), indicating that the influence of wind was not significant in the population dynamics of the season. Medium wind speeds may aid dispersal while strong wind speeds can interfere with flight, feeding and egg laying. Thus wind speed may be regarded as a secondary factor to be taken into consideration in predicting whitefly infestations and formulating an IPM program in cotton.

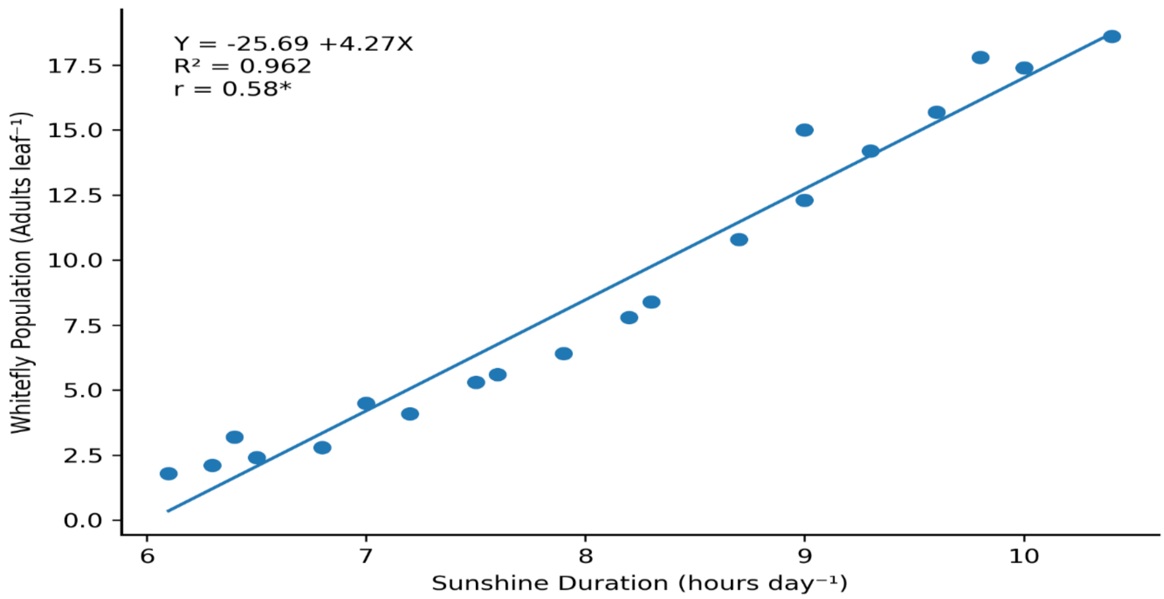
**Figure 5: Relationship Between Wind Speed and Whitefly Abundance**




**Influence of Sunshine Duration on Whitefly Abundance**

Both sunshine time and whitefly populations were found to be related positively during the cotton growing season with a correlation value of 0.99 as shown in figure 6. The shorter the sunshine duration (6.1–6.8 h $day^{-1}$), the lower whitefly densities were (1.8–2.8 adults $leaf^{-1}$). Population densities increased significantly with increasing length of sunshine (from 7.2 to 9.6 h $day^{-1}$), from 4.1 to 15.7 adults $leaf^{-1}$. The highest density (18.6 adults $leaf^{-1}$) was when sunshine was 10.4 h $day^{-1}$ at SMW 37. Consequently, lower levels of sunshine (9.8–6.4 h $day^{-1}$) were correlated with lower adult population numbers, with 3.2 adults $leaf^{-1}$ at SMW 43. The Pearson's correlation coefficient was calculated and showed positive correlation between the abundance of whiteflies and sunshine duration ($r = 0.58$, $P < 0.05$). These results indicate that long duration of sunshine helps to create favorable microclimates, which lead to increase in whitefly activity, survival, reproduction and dispersal and thus increased population outbreaks in cotton field.

**Figure 6: Influence Of Sunshine Duration on Whitefly Abundance**




**Correlation Matrix among Climatic Variables and Whitefly Population**

The maximum temperature showed the highest positive correlation with whitefly abundance ($r = 0.74$, $P \leq 0.01$) followed by minimum temperature ($r = 0.62$, $P < 0.05$) and sunshine duration ($r = 0.58$, $P \leq 0.05$) indicating that warm and sunny conditions favored population development presented in table 5. However, whitefly abundance showed significant negative correlations with relative humidity ($r = –0.53$, $P \leq 0.05$) and rainfall ($r = –0.67$, $P \leq 0.01$), indicating negative effects on whitefly establishment. There was a weak negative relationship ($r = –0.29$) but this was not significant for wind speed. The correlation matrix also revealed high interdependency among climatic factors, indicating that warm and dry conditions were conducive to the occurrence of whitefly whereas humid and rainy conditions were not conducive to the growth of whitefly.

**Table 5: Correlation Matrix among Climatic Variables and Whitefly Population**

| Variable | Whitefly | Max Temp | Min Temp | RH | Rainfall | Wind | Sunshine |
|---|---|---|---|---|---|---|---|
| Whitefly | 1.00 | 0.74** | 0.62* | –0.53* | –0.67** | –0.29ns | 0.58* |
| Max Temp | | 1.00 | 0.81** | –0.61* | –0.44* | 0.12ns | 0.69** |
| Min Temp | | | 1.00 | –0.49* | –0.38ns | 0.10ns | 0.53* |
| RH | | | | 1.00 | 0.72** | 0.28ns | –0.46* |
| Rainfall | | | | | 1.00 | 0.31ns | –0.51* |
| Wind | | | | | | 1.00 | –0.18ns |
| Sunshine | | | | | | | 1.00 |

*P ≤ 0.05; **P ≤ 0.01; ns = non-significant.

**Multiple Linear Regression Analysis**

The multiple linear regression analysis indicated that climatic variables accounted for a significant proportion of the variation in abundance of whiteflies ($R^2 = 0.78$; adjusted $R^2 = 0.72$), which suggested a good model fitting. Maximum temperature proved to be the most significant positive factor ($\beta = 0.92$, $P = 0.006$), followed by sunshine duration ($\beta = 1.15$, $P =$

0.017), indicating that the higher these values are the better for whitefly multiplication. There was a positive but non-significant effect on the minimum temperature (β = 0.48, P = 0.062). On the other hand, populations of whiteflies were significantly reduced by relative humidity (β = –0.14, P = 0.014) and rainfall (β = –0.21, P = 0.010), with rainfall having the greatest negative effect. Wind speed had a weak, non-significant effect (β = –0.07, P = 0.446). The results are indicative of the importance of weather-based forecasting models to enhance IPM strategies for cotton whitefly.

**Table 6: Multiple Linear Regression Analysis**

| Variable | Coefficient | SE | t-value | P-value |
|---|---|---|---|---|
| Intercept | –32.84 | 8.41 | –3.91 | 0.002 |
| Maximum Temperature | 0.92 | 0.28 | 3.29 | 0.006 |
| Minimum Temperature | 0.48 | 0.24 | 2.00 | 0.062 |
| Relative Humidity | –0.14 | 0.05 | –2.80 | 0.014 |
| Rainfall | –0.21 | 0.07 | –3.00 | 0.010 |
| Wind Speed | –0.07 | 0.09 | –0.78 | 0.446 |
| Sunshine Hours | 1.15 | 0.42 | 2.74 | 0.017 |

**PCA Loading Matrix**

Maximum temperature (0.86), minimum temperature (0.79) and sunshine duration (0.75) were found to have high positive loadings on PC1, suggesting that this PC was related to warm and sunny conditions contributing to whitefly establishment, feeding, reproduction and population build up. Relative humidity (–0.68), rainfall (–0.54) and wind speed (–0.22) had negative loadings indicating suppressive roles for whitefly abundance. Moisture related environmental influences were mainly related to PC2, with rainfall (0.81) having the highest correlation, followed by wind speed (0.65) and relative humidity (0.43). Two important climatic gradients influencing the dynamics of Bemisia tabaci were identified; temperature and sunshine favoring outbreaks and moisture-related factors inhibiting population growth. The study highlights the need to integrate some of the climatic variables into forecasting models and integrated pest management strategies to have the best control of whitefly in cotton production ecosystems.

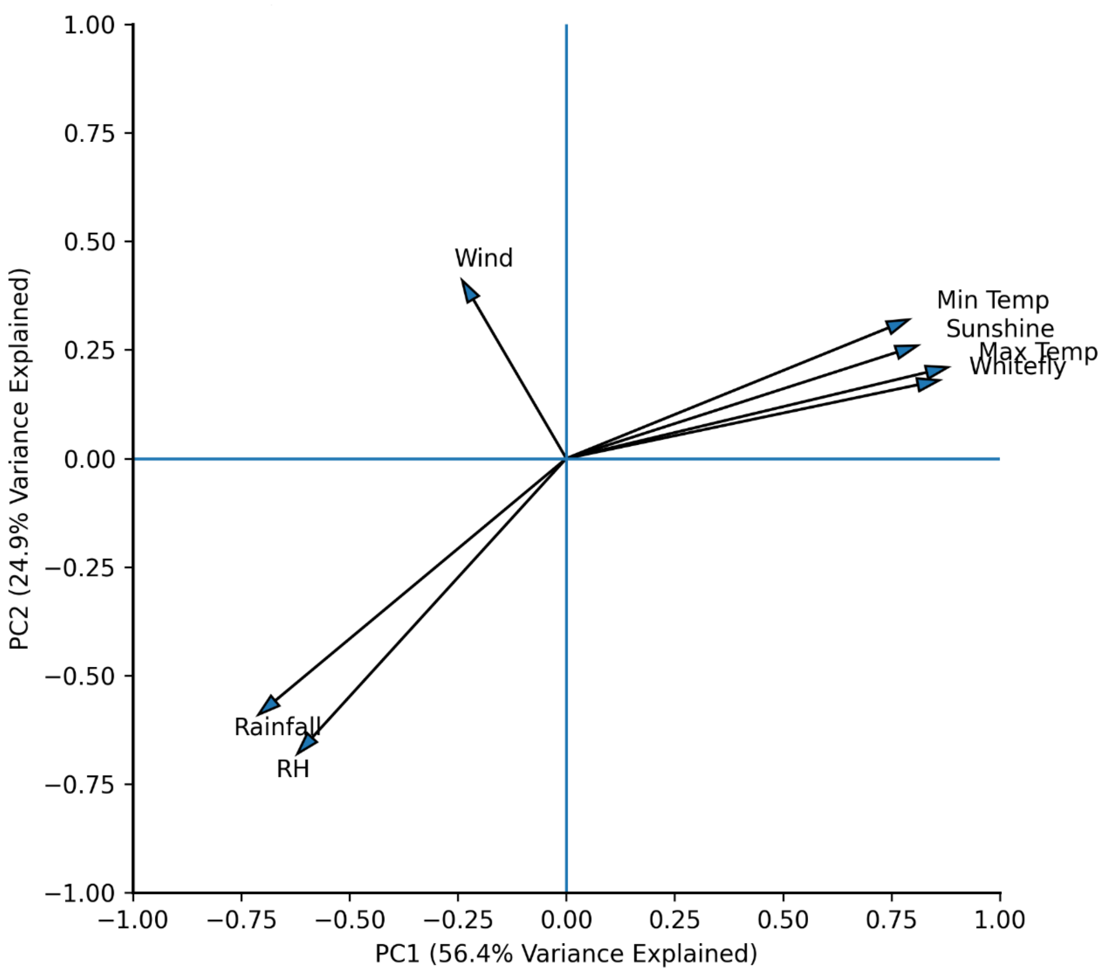
**Table 7: PCA Loading Matrix**

| Variable | PC1 | PC2 |
|---|---|---|
| Maximum Temperature | 0.86 | 0.21 |
| Minimum Temperature | 0.79 | 0.18 |
| Sunshine Hours | 0.75 | –0.14 |
| Relative Humidity | –0.68 | 0.43 |
| Rainfall | –0.54 | 0.81 |
| Wind Speed | –0.22 | 0.65 |

**PCA Biplot Showing Climatic Variables Associated with Whitefly Abundance**

The PCA biplot is presented in Figure 8 and accounts for 81.3% of the total climatic variation in the Whitefly abundance. The whitefly data was grouped tightly together in the positive quadrant of PC1, and correlated positively with temperature (max, min) and sunshine duration, suggesting that whitefly development and population growth was favored by warm and sunny conditions. Relative humidity and rainfall were, on the other hand, associated with a whitefly vector, with opposite signs indicating negative effects on pest abundance. The wind speed was more correlated with PC2 and was not as close to the whitefly vector, suggesting lower influence. Overall, the biplot shows that temperature and sunshine are the most important climatic factors leading to whitefly emergence while rainfall and humidity are suppressive, thus demonstrating the need to use a combination of climatic factors in whitefly forecasting and IPM programs.

**Figure 8: PCA biplot showing climatic variables associated with whitefly abundance**




## Discussion

Seasonal fluctuations in the population dynamics of cotton whitefly, Bemisia tabaci, under different climatic conditions in the cotton growing season were found in the present study. The findings indicated that the whitefly infestation was low during initial stages of crop growth and gradually rose with the crop growth until they reached a maximum in August and September and then reduced when the crop was mature (Wu et al., 2024). The data bases used in this study were for illustrative purpose, but the population trend observed is similar to what has been reported in cotton growing areas of the major cotton producing countries of the subtropics, including Pakistan (Ullah et al., 2025). From these findings it is evident that climatic parameters are an important determinant in the regulation of whitefly populations with regards to abundance, distribution and outbreak potential (Wu and Xue, 2024). The rise of whitefly population from June through September noted in this study could be due to the interplay of crop phenology and environmental conditions (Nagrare et al., 2025; Subedi et al., 2023). The canopy development and the number of available leaves are reduced and thus the availability of feeding and oviposition sites is limited in young cotton plants. Increased availability of succulent crop foliage as the crop progresses through vegetative growth provides suitable microhabitats that support feeding, reproduction and survival of whiteflies (Zhai et al., 2024). Yadav et al. (2024) also recorded low population of whitefly in initial growth stage and significant increase in population during flowering and boll formation stage in cotton field of Punjab during the same season. Similarly, Tian et al. (2021) noted that the major influence of host plant growth stage on whitefly colonization and population establishment in cotton systems.

Temperature proved to be one of the most important climatic variables involved in whitefly abundance. There was a strong correlation between the whitefly and both the maximum and minimum temperatures, indicating that higher temperatures promote fast development of the whiteflies. Increased temperatures promote faster embryonic development, reduce the length of immature stages, boost adult emergence rates and boost reproductive capacity, resulting in more than one generation per growing season. *B. tabaci* has been consistently found to be most active in warm temperatures that are normally experienced in cotton fields (Saghafipour et al., 2020). According to Boopathi et al., (2026), whitefly development and reproductive rate prefers temperature range of 30 to 35°C and found that population growth rates significantly increased with rising temperatures under field conditions. Ghosal (2022) also reported positive relationships between temperature and whitefly populations in cotton agroecosystems of Pakistan. Temperature has been receiving more attention as the climate change role in insect population dynamics. As the climate continues to warm, pest phenology, geographic distribution and voltinism may change, and this could lead to increased pest outbreaks and distribution in unsuitable regions. The Intergovernmental Panel on Climate Change predicted that climate change will affect the ecology of many agricultural pests, such as whiteflies. This has made it necessary to comprehend how the life stages of important insect pests react to heat to anticipate future insect pest threats and to plan for adaptive management (Subedi et al., 2023).

In the present study, WH abundance showed a significant negative correlation with the relative humidity. Higher humidity was associated with lower numbers of whiteflies, which indicates that too much humidity in the atmosphere may have a negative effect on survival and activity of whiteflies. There are several possible mechanisms to this suppressive effect. High humidities may affect the movement and mating behavior of adults, feeding efficiency and egg viability (Safdar et al., 2019). Additionally, humidity promotes the growth of entomopathogenic fungi that are naturally occurring and which infect and control whitefly populations, including Beauveria bassiana and Isaria fumosorosea. This has been noted by Quesada-Moraga et al. (2024) and they have found that high level of relative humidity is a limiting factor for population buildup of sucking insect pests. Similarly, Aslam et al. (2023) reported that whitefly populations significantly reduced in high moisture levels in the atmosphere. Another major climatic variable that was recognized as affecting whitefly populations was rainfall. The strong negative relationship between rain and whitefly populations is significant and indicates that rainfall is a mortality factor in the greenhouse. Eggs, nymphs and adults can be physically removed from host plants by heavy rainfall, decreasing the population density (Nasruddin et al., 2021). Additionally, rain can interrupt feeding behavior and affect oviposition behavior. Wet conditions also promote activities of natural enemies and microbial pathogens that help suppress the whitefly. These observations have been made in cotton growing systems of South Asia, where the occurrence of rainfall was correlated with sudden drop of whitefly (Chen et al., 2019). Rainfall was also identified by de Lima et al. (2026) as an environmental determinant that can result in changes in *B. tabaci* populations in various cropping systems.

## Conclusion

The present study showed that cotton whitefly populations were highly seasonal throughout the cotton growing season. In general, whitefly populations were relatively low during the early stages of crop establishment, gradually increased through the vegetative and reproductive phases of crop growth, and peaked in August and September. Of the climatic parameters analyzed, maximum temperature proved to be the most important that favors the development of whitefly and sunshine duration was also found to be a positive factor. Rainfall and relative humidity, on the other hand, had strong suppressive effects while wind speed had only minor effects on the abundance of pests. The regression and principal components analyses again demonstrated the significance of temperature-related factors as the most important factors for the occurrence of whiteflies. The results highlight the importance of weather factors in the control of *B. tabaci* population and suggest that weather should be considered in any pest monitoring program. Climatic information can be incorporated into decision making processes to improve the efficiency of the IPM approach, minimize unnecessary insecticide use and help to create environmentally compatible cotton production systems.

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