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Population Ecology of the Whitefly *Bemisia tabaci* (Gennadius) Infesting Pepper Plants and Its Control

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ABSTRACT

Bemisia tabaci (Gennadius), known commonly as the whitefly, is of global economic importance as it can cause damage to agricultural hosts on a global scale. The objective of this paper will be to understand the population abundance of *B. tabaci* on pepper plants (*Capsicum annuum*) throughout the two seasons (2023/2024 and 2024/2025) under Mansoura district, Dakhlia Governorate, Egypt. We also assessed the weather factors and plant age on *B. tabaci* abundance using the simple correlation coefficient, multiple regression, and principal components models. The data revealed that *B. tabaci* were found on the pepper plants 30 days after planting, which is from the first week of October, and continued to be found on the pepper plants until the fourth week of January during both seasons. For both seasons, the cumulative whitefly-days were 10234.00 and 10717.00 *B. tabaci* individuals each season. The variability of *B. tabaci* counts to predict using a multiple regression model was 94.50% and 88.81% for each season, respectively. After evaluating the effect of the insecticide viability after 72 hours, the activity of the tested insecticide, imidacloprid, exhibited it to be the most susceptible insecticide compared to the other tested pesticides on *B. tabaci* nymphs and adult females, and the mineral oil was the least toxic. These results will improve the ability to control the whitefly population on pepper plants and reduce the damage of each of the insecticides.

INTRODUCTION

Due to its color, flavor, pungency, scent, and taste, pepper (*Capsicum* spp.) is a significant vegetable and spice crop in many countries (Rohini and Lakshmanan, 2017). A member of the genus Capsicum and family Solanaceae is the sweet pepper (*Capsicum annum* L.) (Amaechi *et al.,* 2021). According to Ibrahim *et al.* (2019), it is one of the most well-liked and popular vegetables grown in plastic homes in Egypt and Saudi Arabia for both local and export markets. Among vegetable crops cultivated in plastic homes, it ranks second (Omar *et al.,* 2018). According to Block *et al.* (1992), pepper is regarded as one of the top vegetable sources for components that are favorable to human health. Certain regions, including Asia, Southeast Asia, South and Central America, and Africa, sell pepper leaves in their fresh marketplaces (Specialty Produce, 2020). They are described as having a somewhat bitter taste when cooked as greens (Abilgos-Ramos *et al.,* 2012). Vitamins A, B, and antioxidants are said to be abundant in pepper leaves (Specialty Produce, 2020). The existence of certain phytochemicals released as the plant's secondary metabolites contributes to the nutritional advantages, including its antioxidant qualities. The fruits of the capsicum species are the main food source, while the leaves are used as a secondary edible plant portion after cooking (Stephens, 2002). The Solanaceae family of nightshades includes the genus Capsicum spp. as blooming plants (Rhodes, 2009).

Red sweet pepper fruit is rich in antioxidants like β-carotene, which functions as provitamin A, and health-promoting bioactive components such as phenolics and carotenoids (Jamiołkowska *et al.,* 2016). Customers often favor fruit that is heavier, thicker, and more colorful at full maturity and more nutritious. They base their evaluation of sweet pepper fruit quality on factors such as weight, pericarp thickness, color, and nutritional content (Buczkowska and Najda 2002). It is possible for several insect pests to infest sweet peppers (Hameed *et al.,* 2023). The whitefly, scientifically known as *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae), is one of these pests. It is an economically significant insect pest that poses a danger to agricultural hosts worldwide (Bakry *et al.,* 2023a).

B. tabaci is a polyphagous, global, and dangerous bug. Moth-like, tiny, white insects that are usually found on the undersides of plants (Shehata *et al.,* 2024). As polyphagous insects, whiteflies may grow and colonize a variety of floral and vegetable crops in greenhouses and open fields (Ibrahim, 2017). By drawing sap from the leaves, it can harm sweet pepper plants, causing wilting, yellowing, and reduced development (Lima *et al.* 2000). Additionally, they release honeydew, a sticky material that can encourage the formation of sooty mold (Bakry *et al.,* 2023a). In addition to causing various viral infections, severe infestation can weaken and harm pepper plants, limiting their development and output (Al-Saidi and Al-Obaidy 2022). An excessive number of whitefly adults and their young can kill seedlings or cause older plants to become less vigorous and productive (Horowitz *et al.,* 2020). Havanoor and Rafee (2018) stated that *B. tabaci*, one of the most destructive insects that destroys many profitable vegetable crops globally, poses a major danger to pepper plants. Many conventional pesticides are no longer effective against this pest, which needs to be controlled right now (Zayed *et al.,* 2022).

There are variations in the number of insects and the harm they do due to the year-round variations in climate (Pareek *et al.,* 2017). Furthermore, the amount of infestation is influenced by a wide variety of equally significant known and unknown variables (Janu and Dahiya, 2017). The weather, season, plant growth, and physical characteristics of the plant all affect the occurrence of pests on the host plant. Understanding an insect pest's ecology requires knowledge of its phenology. It's critical to understand that a variety of factors, including location, climate, and management techniques, can affect the severity and frequency of pests (Johnson *et al.,* 2016). There are variations in the number of insects and the harm they do due to the year-round variations in climate (Pareek *et al.,* 2017). Furthermore, the amount of infestation is influenced by a wide variety of equally significant known and unknown variables (Janu and Dahiya, 2017). The weather, season, plant growth, and physical characteristics of the plant all affect the occurrence of pests on the host plant. Understanding an insect pest's ecology requires knowledge of its phenology. It's critical to understand that various factors, including location, climate, and management techniques, can affect the severity and frequency of pests (Johnson *et al.,* 2016).

A multivariate analytical technique called Principal Component Analysis (PCA) lowers the dimensionality of data by establishing connections between variables and offering a more lucid visual depiction (Grane & Jach 2014). Data are represented using axes in PCA, where the first principal component explains the greatest amount of variability (Mishra *et al.* 2017). Covariance or correlation can be used for this; however, for data on multiple scales, correlation-based PCA is recommended. According to Johnson (1998), eigenvalues are also useful in determining the optimal number of main components.

The present investigation aims to investigate estimates of the abundance of whiteflies on pepper plants throughout the two seasons. Additionally, the correlation between the two seasons' whitefly populations and climatic conditions is estimated. To determine which pesticides are most successful in controlling whitefly nymphs and adults, we also test several chemical compounds.

MATERIALS AND METHODS

1- Population Studies of the Whitefly, *Bemisia tabaci on* Pepper Plants:

1.1- Seasonal Fluctuation of *B. tabaci on* Pepper Plants:

This research study was conducted in a plastic greenhouse in Mansoura region, Dakhlia Governorate, Egypt, during the 2023/2024 and 2024/2025 seasons. Sweet pepper seeds of the "Top Star F1 hybrid" type were sown in the second week of September, and the 25-day-old seedlings were transported to the greenhouse (approximately 600 cm^2). The seedlings were spread in a fully random block, and those that were lost were replaced with others of similar age one week following planting. Except for chemical management, all field techniques were followed. Leaf sampling commenced at weekly intervals shortly after the pest infestation began in the first week of October and lasted until the harvest of the crop. To determine population counts, 10 pepper leaves from each replicate were chosen at random every week in the morning (7–9 a.m.) from various locations within the greenhouse during the two seasons, as well as from the top, middle, and bottom levels of the pepper plant. Using 10x lenses, these leaves were inspected, and in order to track the population's seasonality, the total number of whiteflies adults and nymphs—was tallied and calculated per leaf.

Over the two cropping seasons, we collected 2240 pepper leaves, representing 56 individual observation times. The sample consisted of twenty-eight times × four replicates × 10 leaves × two seasons. Each season has 1120 leaves.

1.2- The Percentage of Leaves Attacked by *B. tabaci*:

Bakry and Abdel-Baky (2023b) ranked the percentage of attacked pepper leaves due to *B. tabaci*. **A = (n / N) × 100**

Where:

A is the percentage of attacked leaves, n is the number of attacked leaves in the sample, and **N** is the total number of leaves (attacked and uninfested) analyzed on each study date.

During the two seasons under investigation, the mean number of *B. tabaci* and the percentage of damaged leaves were statistically analyzed using one-way ANOVA. In order to compare means at the 5% probability level, the SPSS (1999) least significant difference (LSD) test was employed.

1.3- Whitefly-Days and Cumulative Whitefly-Days:

Here, the cumulative values of whitefly days are calculated using data on whitefly counts gathered over two consecutive growth seasons.

The following formula was used to tabulate this approach using the equation provided by many writers (Bakry and Fathipour, 2023; Mohamed *et al.,* 2021).

$$\textbf{Days of a whitefly} = [7 \times [(P_1 + P_2) / 2]$$

Where:

P1 is the average number of whiteflies per 10 leaves on the day of the last inspection.

P2 is the average number of whiteflies per 10 leaves on the day of the examination.

For each sample period, the running cumulative total is calculated by adding the total number of whitefly days from the earlier inspection date to the total number of whitefly days from the present examination date.

2- Impacts of the Climatic Variables and Plant Age on Whitefly Estimates on Pepper Plants:

Whitefly populations of *B. tabaci* were correlated with climatic parameters such as temperature (maximum and minimum) and relative humidity percentage and the age of the plant in both growing seasons (2023/2024 and 2024/2025). The daily values of these variables were re-tabulated to derive average daily temperature and humidity values within a seven-day window of the date of the whitefly estimate. We were required to go back and take all the numbers for the climatic variables each day of the sampling process, which meant a full two weeks of record keeping prior to each date of sampling for the correct averages. The age of the plant was calculated as the date of the whitefly estimate at each date of inspection. This was calculated by a third-order nonlinear equation. Bakry and Abdel-Baky (2023a) used this approach, which consisted of data collected that was subsequently evaluated for differences among multiple mathematical models (correlation and regression) in order to measure the relationships between weather variables, plant age, and the rate of whitefly infestation. They followed Fisher's (1950**)** formula and used SPSS to conduct the analyses. As well, the simple correlation models were calculated, and variables were plotted using R software.

3- Principal Component Analysis:

Principal component analysis (PCA was also utilized in order to visualize the weather variables effect on seasonal patterns of *B.* tabaci **.** PCA provides a multivariate analysis, which reduces dimensionality of data by identifying relationships between variables with better visuals (Grane & Jach 2014 and Asiri & Bakry, 2025). PCA was used in this work to investigate the multidimensionality of meteorological factors associated with *B. tabaci* estimations on pepper plants, and R software-generated scatterplots were used to show the findings (R Core Team 2019).

4- Toxicological Study:

The toxicological efficacy of the all-target synthetic compounds was assessed using pepper leaf dipping techniques in a laboratory setting at the Plant Protection Research Institute, Mansoura Branch, Dakhlia Governorate, Egypt. The compounds' derivatives at 5 concentrations (Bakry and Gad, 2023) and were combined with 0.11% tween-80, which is utilized as a surfactant. Just fifty *B. tabaci* adults and fifty nymphs were immersed for ten seconds in each of the produced component concentrations (three repetitions) (Bakry *et al.,* 2023 b).

The test insects were allowed to stand at 25ºC for approximately 30 minutes, during which time the control group of insects which were submerged in water and tween-80 alone was also used (El-Gaby *et al.,* 2023). Following their withering, the employed pests were moved to glass jars filled with distilled water (Bakhite *et al.,* 2025). After one, two, and three days of exposure, the deceased and living were examined, measured, and registered using a new binocular microscope (Gad *et al.,* 2023). The *B. tabaci* that unable to move were considered dead. Mortality was equalized using the Abbott formula (Abbott 1925), and probability analysis was used to objectively review the mortality setback line estimates (Mohamed *et al.,* 2025). The Harmfulness Index was taken extremely seriously by using sun formulas (Finny 1952). Using probit analysis and a statistical (LDP-line) equation, the death rate of adult insects and nymphs was determined. Using 95% confidence intervals, the LDP-line equation estimates the LC_{50} values' slope, upper and lower confidence limits (Sun, 1950).

Imidacloprid, Sulfoxaflor, Cyantraniliprole, pyriproxyfen and mineral oil were purchased from the Central Agricultural Pesticides Laboratory (CAPL) in Dokki, Giza, Egypt.

RESULTS AND DISCUSSION

1- Population Ecology and Percentages of Attacked Leaf Studies:

1.1- Abundance of *B. tabaci* on Pepper Plants:

The weekly estimations of *B. tabaci* were registered on pepper plants cultivated in the field (Top Star F1 hybrid) in the Mansoura region, Dakhlia Governorate, throughout the growing seasons (2023/2024 and 2024/2025). Also, during both growing seasons of the study season, the mean weekly records of age and climatic condition of pepper plants were provided in Tables (1& 2) and Figures (1& 2).

The effect of climate and pepper plant age on the population abundance of *B. tabaci* was established based on the average number of individuals (adults and nymphs) per leaf in the successive investigation periods. From the results, *B. tabaci* individuals on pepper plants occurred from October 5th to January 26th, or simply, insect outbreaks began on pepper plants 30 days post-planting per season.

Significant differences occurred between the abundance of *B. tabaci* individuals/10 leaves averages of this research. The overall estimations of *B. tabaci* during the first growth season (2023/2024) were smaller than those during the second growing season (2024/2025). The two growth seasons had an average of 92.90 ± 8.57 and 97.04 ± 9.32 individuals/10 leaves, respectively. *B. tabaci* on the pepper plants peaked at a single peak of population on December 19 of each season. The average percentage of damaged plants in the region by the *B. tabaci* was 33.33% and 24.38% for each season, respectively. Lastly, the date for infestation and activity for each season was 30 days post-planting. The infestations of *B. tabaci* on sweet pepper plants started four weeks after planting in the first week of October and lasted until the fourth week of January in each season as shown in Tables (1 & 2) and Figures (1 & 2).

There were significant differences between the average number of *B. tabaci* individuals/10 leaves in our investigation. In this case, during the two seasons, the pepper plants averaged 92.90 ± 8.57 and 97.04 ± 9.32 individuals/10 leaves, respectively.

In comparison to 2023/2024, the total count of *B. tabaci* individuals on pepper plants increased by approximately 1.45 in 2024/2025, as shown in Tables (1 & 2).

Regarding *B. tabaci* individuals, the analysis of variance showed extremely significant variations based on the times of examination. According to Tables (1 & 2), the LSD values for the two seasons were 7.34 and 7.28, respectively.

1.2- Attacked Leaves Percentage by *B. tabaci*:

As the evaluation timings of the various pepper stages of growth throughout both seasons increased, so did the percentage of damaged leaves. The increase may be attributed to the presence of a *B. tabaci* nymphal population, the abundance of food, the insect's short life cycle, and its dispersal and cause more significant damage to the pepper plants (Tables 1 & 2 and Figs. 1 & 2).

Despite the damaging of the pepper plants during the two growth seasons, the proportion of attacked plants varied between increasing and decreasing through the various evaluation timings. The proportion of pepper-damaged leaves was 33.33 ± 1.61 and 24.38 ± 1.68% during the two seasons, respectively.

Table 1: Weekly mean numbers of *B. tabaci* individuals and damaged leaves percentage of pepper plants at Mansoura district, Dakhlia Governorate, during the first growing season (2023/2024).

Inspection date		Plant age	No. of individuals per 10 leaves	% No. whiteflies of total counts	Cumulative numbers	% Cumulative No.	Whitefl y-Days	Cumulative whitefly-days	% Attacked leaves	Weather factors		
										Max. temp.	Min temp.	% R.H.
Oct., 2023	5	30	3.33 ± 0.33	0.22	3.33	0.22	11.67	11.67	10.00	33.39	26.61	73.33
	11	37	11.67 ± 0.33	0.78	15.00	1.01	52.50	64.17	23.33	32.87	26.22	73.16
	19	44	24.00 ± 1.15	1.61	39.00	2.62	124.83	189.00	30.00	32.34	25.84	72.99
	26	51	45.00 ± 2.89	3.03	84.00	5.65	241.50	430.50	33.33	32.06	25.96	72.26
Nov.	5	58	72.67 ± 1.20	4.89	156.67	10.54	411.83	842.33	26.67	31.78	26.08	71.53
	11	65	83.67 ± 3.76	5.63	240.33	16.17	547.17	1389.50	36.67	26.89	24.71	77.81
	19	72	110.00 ± 4.62	7.40	350.33	23.57	677.83	2067.33	40.00	27.15	23.35	70.33
	26	79	130.00 ± 5.77	8.75	480.33	32.32	840.00	2907.33	40.00	27.41	21.89	73.95
Dec.	5	86	160.00 ± 7.64	10.76	640.33	43.08	1015.00	3922.33	40.00	27.14	20.43	77.15
	11	93	180.00 ± 5.77	12.11	820.33	55.19	1190.00	5112.33	40.00	20.82	20.49	72.01
	19	100	200.67 ± 5.21	13.50	1021.00	68.69	1332.33	6444.67	43.33	22.88	20.55	74.85
	26	107	143.33 ± 12.02	9.64	1164.33	78.34	1204.00	7648.67	36.67	24.94	20.51	77.69
Jan., 2024	5	114	126.00 ± 6.00	8.48	1290.33	86.81	942.67	8591.33	36.67	24.28	20.48	85.11
	11	121	90.00 ± 5.77	6.06	1380.33	92.87	756.00	9347.33	36.67	23.83	13.21	76.77
	19	128	57.33 ± 2.67	3.86	1437.67	96.73	515.67	9863.00	33.33	22.52	11.10	78.30
	26	135	48.67 ± 3.67	3.27	1486.33	100.00	371.00	10234.00	26.67	21.21	8.88	79.83
Total			1486.33	100.00			10234.00					
General average			92.90 ± 8.57						33.33	26.97	21.02	75.44
L.S.D. at 0.05 level			7.34**						6.99**			

Table 2: Weekly mean numbers of *B. tabaci* individuals and damaged leaves percentage of pepper plants at Mansoura district, Dakhlia Governorate, during the second growing season (2024/2025).

Inspection date		Plant age	No. of individuals per 10 leaves	% No. whiteflies of total counts	Cumulative numbers	% Cumulative No.	Whitefly-Days	Cumulative whitefly-days	% Attacked leaves	Weather factors		
										Max. temp.	Min temp.	% R.H.
Oct., 2024	5	30	9.67 ± 0.88	0.62	9.67	0.62	33.83	33.83	16.67	32.94	24.21	73.82
	11	37	17.00 ± 1.53	1.09	26.67	1.72	93.33	127.17	16.67	32.40	23.86	73.65
	19	44	32.00 ± 2.00	2.06	58.67	3.78	171.50	298.67	23.33	31.87	22.40	73.48
	26	51	50.00 ± 1.15	3.22	108.67	7.00	287.00	585.67	20.00	31.58	24.56	72.73
Nov.	5	58	72.33 ± 2.33	4.66	181.00	11.66	428.17	1013.83	16.67	31.30	23.73	71.99
	11	65	82.33 ± 3.18	5.30	263.33	16.96	541.33	1555.17	23.33	26.31	21.02	78.40
	19	72	117.33 ± 2.91	7.56	380.67	24.52	698.83	2254.00	30.00	26.57	18.87	70.77
	26	79	160.67 ± 6.36	10.35	541.33	34.86	973.00	3227.00	33.33	26.83	21.25	74.46
Dec.	5	86	187.00 ± 1.53	12.04	728.33	46.91	1216.83	4443.83	26.67	26.56	18.58	77.73
	11	93	192.00 ± 4.62	12.37	920.33	59.27	1326.50	5770.33	26.67	20.11	5.34	72.48
	19	100	205.33 ± 3.53	13.22	1125.67	72.50	1390.67	7161.00	23.33	22.21	12.02	75.38
	26	107	164.00 ± 2.31	10.56	1289.67	83.06	1292.67	8453.67	26.67	24.32	18.70	78.27
Jan., 2025	5	114	100.00 ± 3.71	6.44	1389.67	89.50	924.00	9377.67	33.33	23.65	15.54	85.85
	11	121	61.00 ± 9.71	3.93	1450.67	93.43	563.50	9941.17	26.67	23.18	11.10	77.34
	19	128	58.67 ± 2.67	3.78	1509.33	97.21	418.83	10360.00	23.33	21.85	9.92	78.90
	26	135	43.33 ± 5.46	2.79	1552.67	100.00	357.00	10717.00	23.33	20.51	5.55	80.45
Total			1552.67	100.00			10717.00					
General average			97.04 ± 9.32						24.38 ± 1.68	26.39	17.29	75.98
L.S.D. at 0.05 level			7.28**						6.94**	26.39	17.29	75.98

The proportion of pepper-damaged leaves increased, which increased approximately 1.37 times during 2023/2024 and 2024/2025 (Tables 1 and 2). The proportion of pepper-damaged leaves differed statistically significantly among the inspection grading dates (Tables 1 & 2), as indicated by the LSD values, which were 6.99 and 6.94 during the two seasons, respectively.

These findings align with Our findings confirmed Hegab's (2017) hypothesis that there would be a single peak of B. tabaci infesting cucumber leaves during the third week of July. The B. tabaci infestation grew steadily between mid-June and the end of July 1996, according to Kamel *et al.* (2000). Ahmed (1994), however, found that *B. tabaci* generated three peaks in each season's summer cucumber yields. In light of this, the consistent rise in

B. tabaci numbers on tomatoes throughout time suggests that pest management should begin in the vegetative and seedling phases, before the pest reaches its peak population. These results are consistent with those of El-Shazly *et al.* (2019). One to three peaks were seen in *B. tabaci* on pepper, according to El-Damer *et al.* (2024).

1.3- Cumulative Whitefly -Days:

B. tabaci whitefly-days and cumulative whitefly-days on pepper plants were displayed using data from Tables 1 and 2 and Figures 1and 2 to illustrate the total impact of a continuously varying individual over time. These results demonstrate that the *B. tabaci* population had a bigger impact on pepper plants in the second season (10717.00 cumulative whitefly-days) than in the first season (10234.00 cumulative whitefly-days).

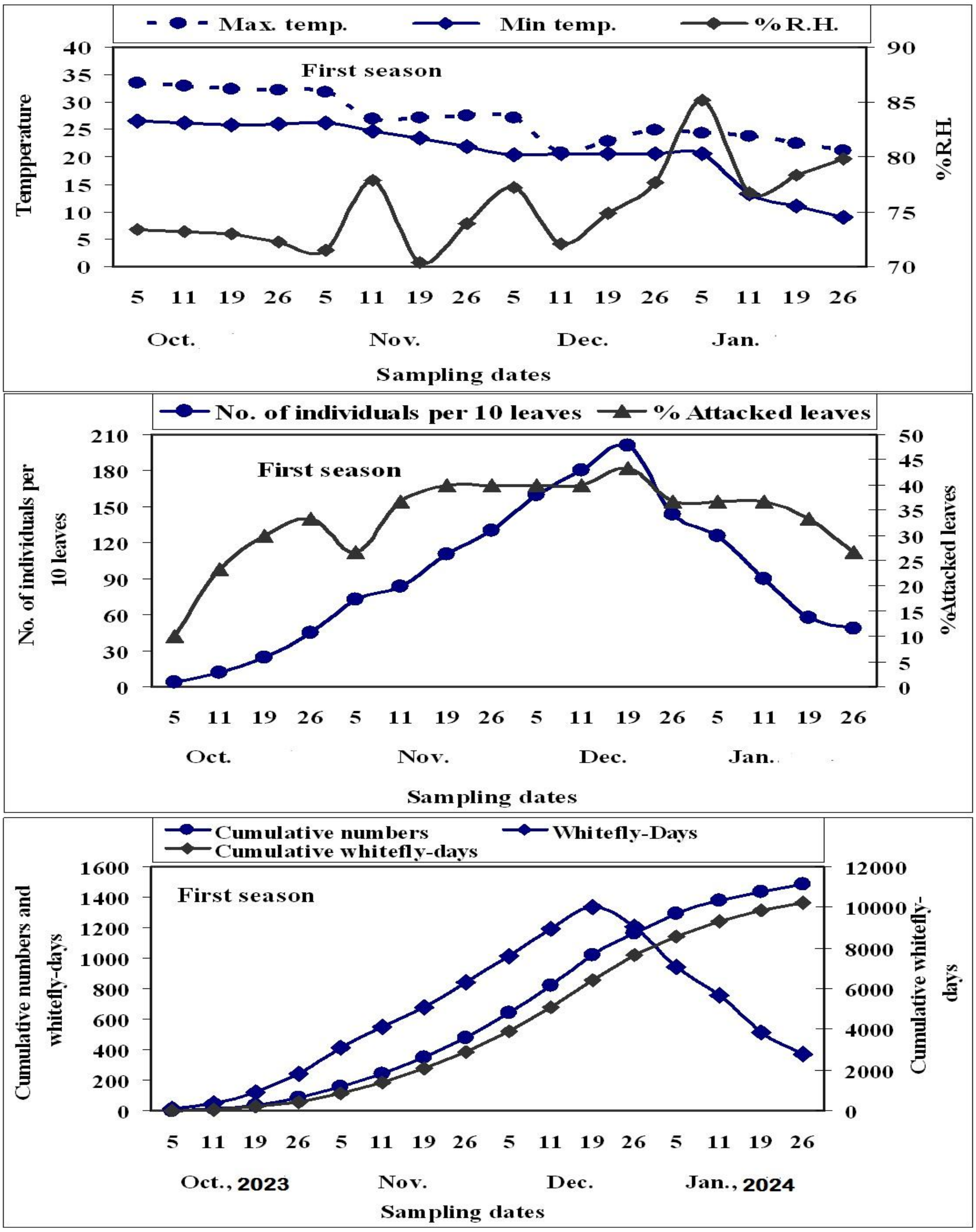

Fig. 1. Weekly mean numbers of *B. tabaci* individuals and damaged leaves percentage of pepper plants at Mansoura district, Dakhlia Governorate, during the first growing season (2023/2024).

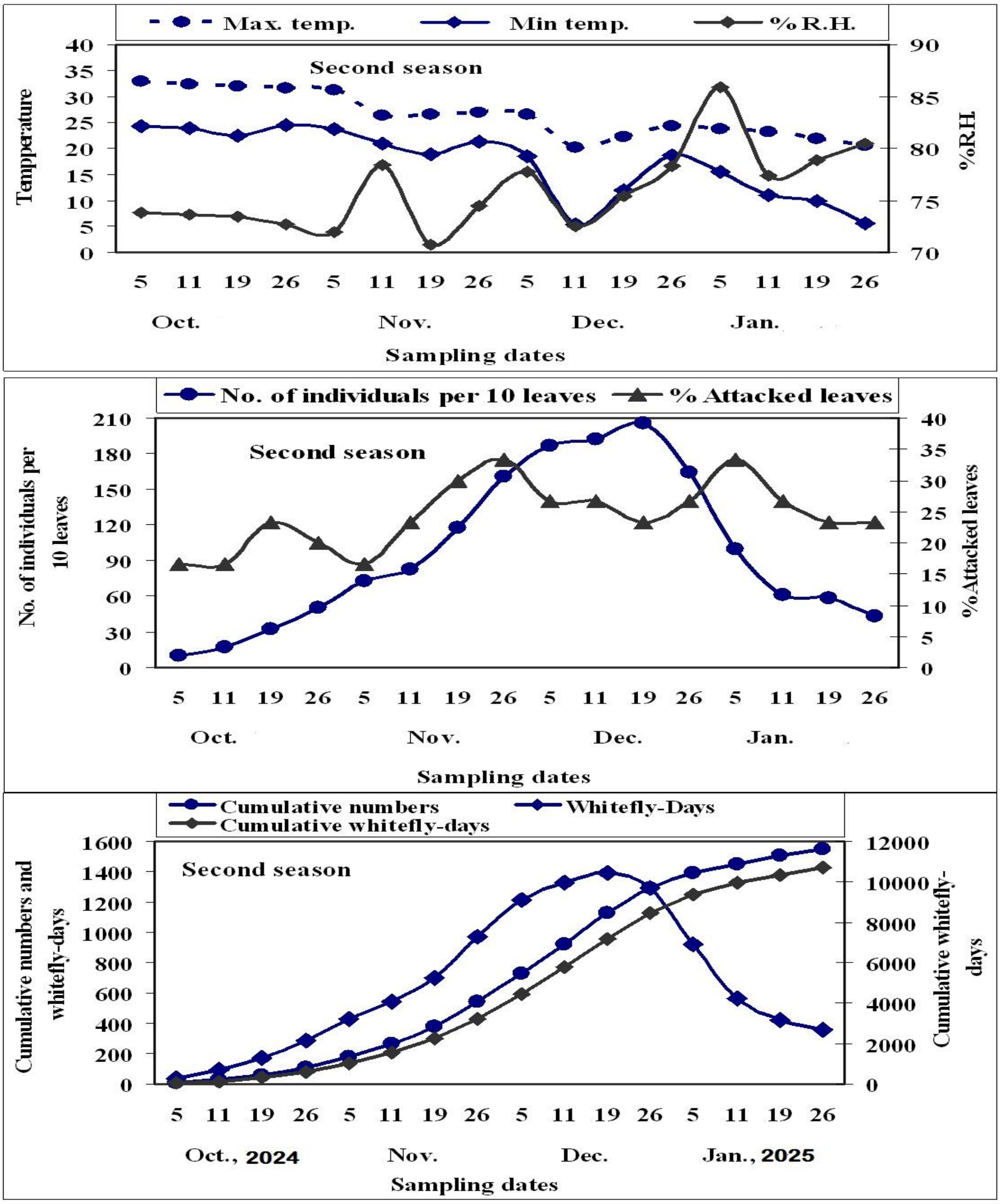

Fig. 2. Weekly means numbers of *B. tabaci* individuals and damaged leaves percentage of pepper plants at Mansoura district, Dakhlia Governorate, during the second growing season (2024/2025).

1.4- The Correlation Between the Percentages of Damaged Leaves and *B. tabaci* Estimates:

A third-order nonlinear regression model was used to assess the correlations between *B. tabaci* estimations and the percentages of damaged leaves, as shown in Figure 4. This model was utilized by Bakry and Fathipour (2023).

The following are the nonlinear formulas:

First season (2023/2024):

$Y = 1E\text{-}05\ X^3 - 0.0037\ X^2 + 0.4977\ X + 14.262$ $R^2 = 0.8190$ Equation (1)

Second season (2024/2025):

$Y = -7E\text{-}06\ X^3 + 0.0013\ X^2 + 0.0477\ X + 16.967$ $R^2 = 0.6183$ Equation (2)

The estimations for *B. tabaci* and the percentages of damaged leaves for the two research years were found to be highly statistically significant. According to equations (1 & 2) and Figure 3, the coefficient of determination percentages (R^2) for the two seasons were 81.90 and 61.83%, respectively.

2- Effect of the Climatic Factors and Plant Age on *B. tabaci* Estimates on Pepper Plants:

2.1- Effect on Tested Climatic Factors and Plant Age on *B. tabaci* Estimates:

A- Effect of Daily Mean Maximum Temperature:

According to the data in Table 3, there was a highly considerable negative simple correlation (r value of -0.63) in the first season and a significant negative correlation (r value of -0.53) in the second season between this element and the *B. tabaci* counts (Fig. 4). Furthermore, simple regression analysis shows that a 1°C rise in this component would result in a reduction of 8.77 and 7.87 persons per 10 leaves for the two seasons, respectively (Table 4). The *B. tabaci* counts were negatively impacted by this factor in the first season in an insignificant way (P. reg. value: -10.28) and in the second season in a highly significant way (P. reg. value: -36.18), according to the partial regression estimations.

B- Effect of daily mean minimum temperature:

This component and the estimates of *B. tabaci* for both seasons (Fig. 4) had non-significant negative relationships (r values: -0.16 and -0.32), according to the data gathered in Table 3. However, the regression coefficient (b) shows that for every 1°C rise in this variable, the number of people per 10 leaves decreases by 1.79 and 3.22 throughout the course of the two seasons. As indicated in Table 4, this variable had a very significant positive impact (P. reg. value; +16.43) on the total number of *B. tabaci* throughout the first season and a substantial positive effect (P. reg. value; +14.28) during the second season.

C- Effect of the Mean Relative Humidity:

According to the data in Table 3, there was an insignificantly positive (+0.14 and +0.02) connection between the mean relative humidity and the *B. tabaci* estimations for each of the two seasons (Fig. 4). Additionally, simple regression revealed that for two seasons, an increase of 2.28 and 0.41 insects per 10 leaves, respectively, results from increasing this component by 1°C (Table 3). Non-significant negative effects (P. reg. values; -4.90 and -6.56) between this component and *B. tabaci* population for both seasons were also shown by partial regression, as shown in Table 3.

D- Effect of the Plant Age:

The effect of plant age on *B. tabaci* individuals was demonstrated in Table 3. According to Table (3) and Figure (4), the correlation coefficient (r) was positive and highly significant (r value of 0.47 in the first season) and positive and non-significant (r value of 0.5) in the second. Simultaneously, the computed simple regression coefficient for the impact of this component showed that throughout the two research seasons, the total number of *B. tabaci* would increase by 0.85 and 4.89 individuals per 10 leaves, respectively, for every day increase in pepper plant age.

Partial regression findings (Table 3) showed that the actual association between pepper plant ages and *B. tabaci* counts was substantially positive (P. reg. value was 2.48) over the first season and non-significantly negative (P. reg. value was -5.84) during the second season.

E- The Combined Effect of Certain Weather Factors and Plant Age on *B. tabaci* Numbers:

The combined effect of plant age and climate on *B. tabaci* populations during the two growing seasons was very significant, as shown by the data in Table 3, where the «F» values were 12.61 and 5.66, respectively. The variance ratios explained for the two seasons were 82.10 and 66.31%, respectively.

2.2- Effect of Plant Ages:

This relationship was evaluated using the third-degree nonlinear equation, $Y= a+ b_1X+ b_2X^2+ b_3X^3$. There was shown to be a very significant association between the changes in *B. tabaci* populations. The corresponding explained difference rates during the two seasons were 85.70% and 92.14%, respectively (Table 4). The regression equation was shown in Figure 5.

First season (2023/2024):

$$Y = -0.0007 X^3 + 0.1253 X^2 - 4.1396 X + 27.773 \qquad R^2= 0.9214$$

Second season (2024/2025):

$$Y = -0.0007 X^3 + 0.1203 X^2 - 3.3392 X + 9.7676 \qquad R^2 = 0.857$$

With corresponding «F» values of 46.90 and 23.97 for the two seasons, these variables also had a significant combined impact on *B. tabaci* estimates (Table 3).

2.3- Effects of All Tested Variables on *B. tabaci* Counts:

The combined effects of the three weather variables and plant age studied in this research were shown to affect the numbers of *B. tabaci*. The combined effects of all these factors affecting the numbers of *B. tabaci* exhibited a highly significant effect; for both seasons, the "F" value was 25.79 and 11.90 (Table 3). In addition, Table 3 indicated that the percentages of clarified differences between the two seasons were 94.50% and 88.81%, respectively.

In recent years, current research plans on pest management have focused more on the ecological needs of various vegetable crop pests (Bakry *et al.,* 2023a). However, to the knowledge of Abou-Zaid (2003), there had been some related research looking at the effect of climatic conditions on population fluctuation within the damage, losses, and pest control of vegetable crops. Adam *et al.* (1997) measured that there was a strong positive correlation with *B. tabaci* populations on cucumber plants grown in greenhouses with temperature and relative humidity. Bharadia and Patel (2005) also found that Flora had the most whiteflies during the fourth week in October and that there was a substantial negative relation to relative humidity on *B. tabaci* populations, but the weather parameters (max, min, and mean temperature) and the age of the okra plant had a substantial positive effect in the 2009 and 2020 seasons (Abdel-Hamed *et al.,* 2011). The proportion of variation explained by these covariates in the two seasons was 94.60% and 91.50%, respectively.

Kumar and Gupta (2016) determined that *B. tabaci* incidence in potato plants decreased progressively as the high and low temperatures decreased. According to Hegab (2017), during the two seasons (2016 & 2017), weather variables played a role in *B. tabaci* fluctuation at 21.5% and 67.2% of explained variance, respectively. Moanaro and Choudhary (2018) established a significant association of whitefly population with capsicum's minimum and maximum temperatures.

El-Shazly *et al.* (2019) reported that mean counts of *B. tabaci* increased when relative humidity decreased and counts of *B. tabaci* increased with higher temperatures in-season. *B. tabaci* benefits from temperature, humidity, and temperature interactions. According to Kataria *et al.* (2019), whitefly counts had a significant relationship with relative humidity and negative relationships with high and low temperatures. Ghongade *et al.* (2021) also reported a significant positive relationship between whitefly populations and low and high-temperature readings, while relative humidity had an insignificant negative effect on cucumber plant performance. Conversely, in their reports, Kumar *et al.* (2023) demonstrated that *B. tabaci* incidence was overall not significantly related to weather conditions.

Numerous researchers have discovered that insect activity and the rates of infestation of different insects may be significantly impacted by the age of the plant. For instance, the fall armyworm *Spodoptera frugiperda* (Lepidoptera: Noctuidae) on maize (Bakry and Abdel-

Baky 2023), the solenopsis mealybug *Phenacoccus solenopsis* (Hemiptera: Pseudococcidae) attacking okra (Bakry and Fathipour 2023), and whiteflies infesting cucumbers (Bakry *et al.,* 2023a).

3- Principal Component Analysis (PCA):

For this study, principal components analysis yielded two components (PC1 and PC2) with eigenvalues exceeding one, which together accounted for 88.03% and 87.02% of the total variance, respectively, for the two years studied (Fig. 6). The daily means maximum and minimum temperatures, relative humidity, and plant ages comprised the environmental variables for PC1 and PC2. PC1 accounted for 68.42% and 66.88% of the variation, respectively, in both years, while PC2 explained 19.61% and 20.14% of the variation, respectively (Fig. 6).

The total numbers of the *B. tabaci* estimates exhibited a negative relationship with the maximum and minimum temperatures in the two seasons of the study in relation to the variable PC1, which had a strong explanatory power. In this regard, there was also a positive correlation between the average counts of *B. tabaci* and the relative humidity and age of the pepper plants in both seasons (Fig. 6).

Table 3. Different models of correlation and regression analyses for describing the relationship between some weather factors and plant age on *B. tabaci* on pepper plants during the two-growing season (2023/2024 and 2024/2025).

Season	Tested Variables	Simple correlation and regression values				Partial correlation and regression values				Analysis variance			
		r	b	S. E	T	P. cor.	P. reg.	S. E	t	F values	MR	R^2	E.V. %
2023/2024	Max. temp (X_1)	-0.63	-8.77	2.87	-3.05**	-0.54	-10.28	4.84	-2.13	12.61	0.91	0.82	82.10
	Min. temp (X_2)	-0.16	-1.79	2.87	-0.63	0.81	16.43	3.57	4.60 **				
	R.H.% (X_3)	0.14	2.28	4.18	0.55	-0.45	-4.90	2.92	-1.68				
	Plant age (X_4)	0.47	0.85	0.43	2.00**	0.59	2.48	1.03	2.41*				
	Plant ages (X_4, X_4^2, X_4^3)									46.90	0.96	0.92	92.14
	Combined effect (X_1 to X_4^3)									25.79	0.97	0.95	94.50
2024/2025	Max. temp (X_1)	-0.53	-7.87	3.36	-2.34 *	-0.77	-36.18	9.15	-3.96 **	5.66	0.82	0.67	67.31
	Min. temp (X_2)	-0.32	-3.22	2.52	-1.28	0.67	14.28	4.75	3.01 *				
	R.H.% (X_3)	0.02	0.41	4.51	0.09	-0.42	-6.56	4.26	-1.54				
	Plant age (X_4)	0.35	4.89	3.45	1.42	-0.24	-5.84	7.20	-0.81				
	Plant ages (X_4, X_4^2, X_4^3)									23.97	0.93	0.86	85.70
	Combined effect (X_1 to X_4^3)									11.90	0.94	0.89	88.81

r = Simple correlation; b = Simple regression; P. cor. = Partial correlation; MR = Multiple correlation; P. reg.= Partial regression R^2= Coefficient of determination; E.V% = Explained variance; S.E = Standard error

* Significant at P ≤ 0.05 ** Highly significant at P ≤ 0.01

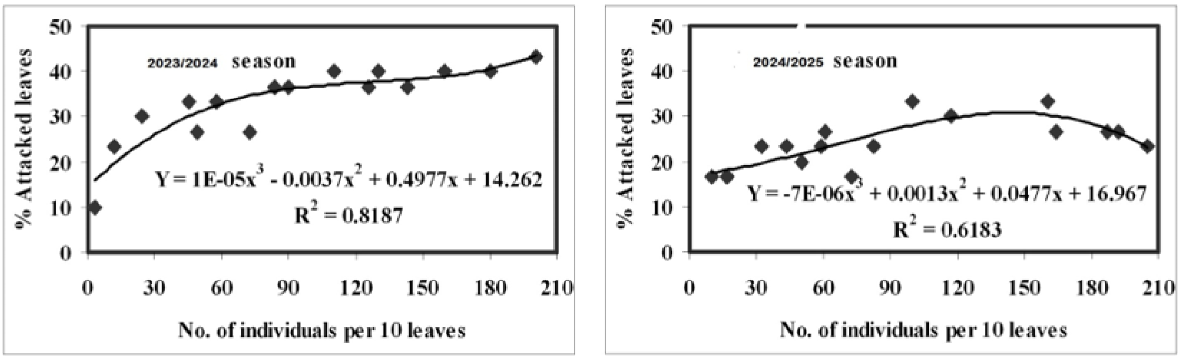

Fig. 3. The polynomial relationship between the numbers of *B. tabaci* individuals per 10 leaves and the attacked leaves in the two growing seasons (2023/2024 and 2024/2025).

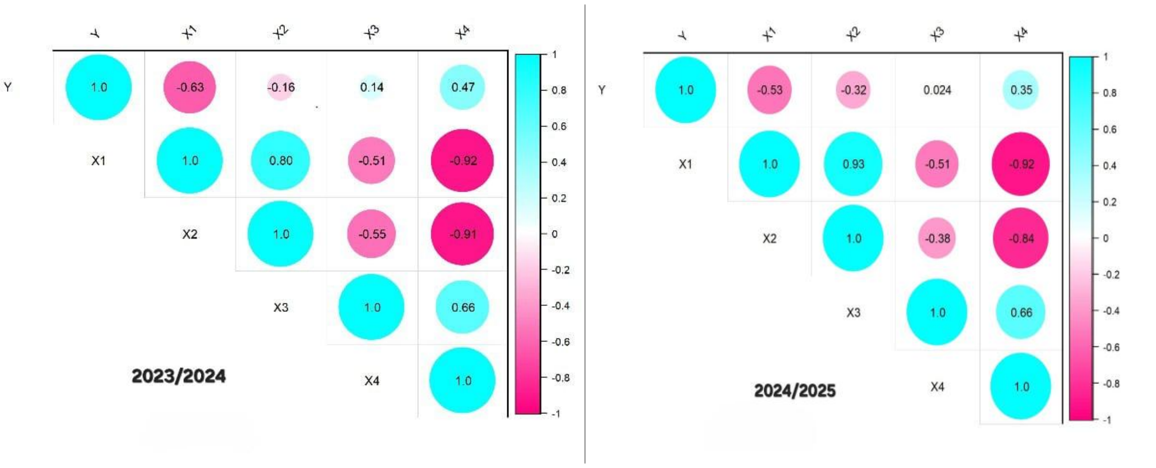

Fig. 4. The correlation analysis between the tested parameters and the *B. tabaci* estimates per 10 pepper leaves throughout the two seasons (2023/2024 and 2024/2025).

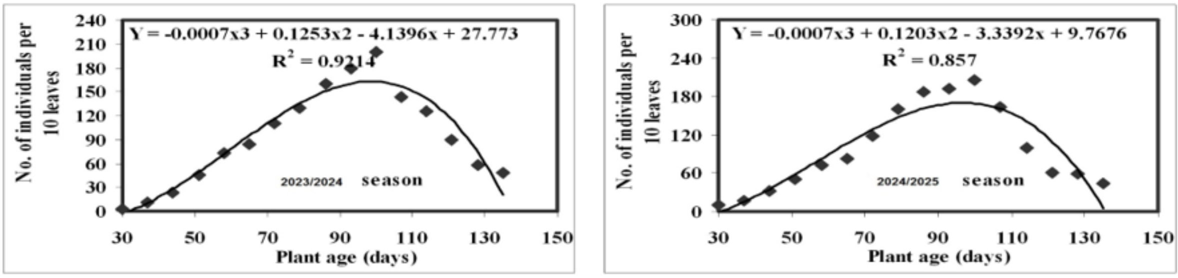

Fig. 5. The polynomial relationship between the pepper plant ages and the numbers of *B. tabaci* individuals per 10 leaves over the two growing seasons (2023/2024 and 2024/2025).

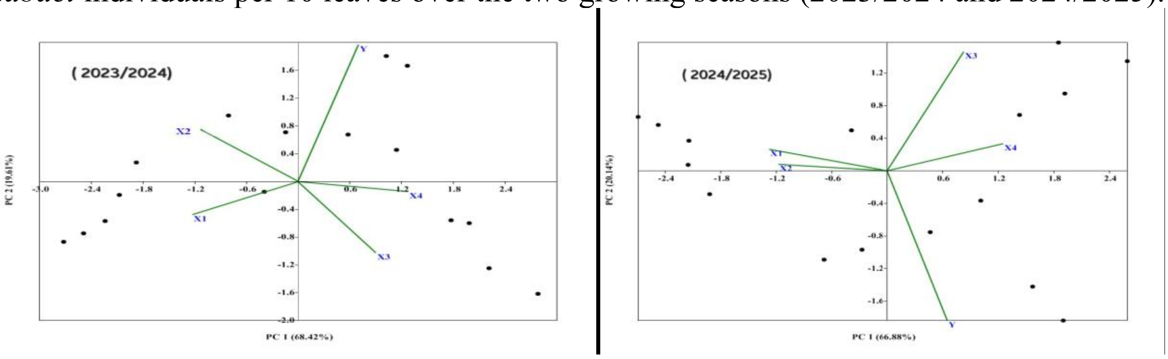

Fig. 6. Principal component analysis correlation-based biplot of climatic variables and *B. tabaci* estimations over the two seasons.

4- Toxicological Screening:

The concentration that eradicates 50% of the *B. tabaci* population is a more statistically significant point for comparison, as shown in Table 4. Using statistics (LDP-line) software, a probit analysis was applied to the aphid mortality data. The results produced LC_{50} values with 95% educible limits for the slope, standard error, chi-square, and correlation coefficient. The following describes the procedures used to evaluate each target synthetic chemical's insecticidal activity, as illustrated in Figure 7.

Table 4: Insecticidal activity of compounds imidacloprid, sulfoxaflor, cyantraniliprole, pyriproxyfen and mineral oil as reference insecticide against nymphs and adult of *B. tabaci* individuals after 72 hr.

Comps.	Nymphs				Adults			
	LC_{50} (mg/L)	Slope	χ^2	Toxic ratio	LC_{50} (mg/L)	slope	χ^2	Toxic ratio
Imidacloprid	2.0 (0.83-3.20)	0.48 ±0.24	0.22	1.00	3.62 (2.66-5.02)	0.47 ± 0.24	0.04	1.00
Sulfoxaflor	4.43 (2.31-5.68)	0.56 ±0.24	0.47	0.45	9.11 (7.27-11.96)	0.63 ± 0.24	0.15	0.39
Cyantraniliprole	5.01 (3.85-8.38)	0.75 ±0.25	0.14	0.39	11.0 (9.12-13.14)	0.63 ± 0.24	0.32	0.32
Pyriproxyfen	6.58 (4.02-7.60)	0.56 ±0.24	0.25	0.30	13.7 (12.5-15.09)	0.72± 0.24	0.28	0.26
Mineral Oil	9.91 (7.36-11.25)	0.48 ±0.24	0.24	0.20	19.6 (17.9-21.8)	0.74 ± 0.24	0.54	0.18

Notes: The Toxicity Ratio is determined by dividing the baseline toxicity of Malathion by the LC_{50} value of the molecule.

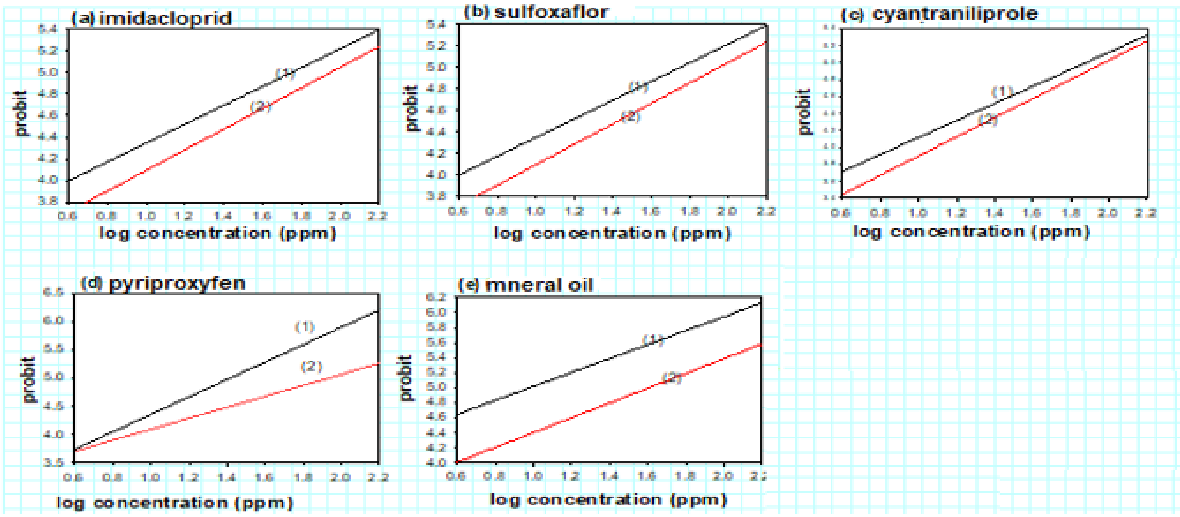

Fig. 7: Insecticidal activity of selective Imidacloprid, Sulfoxaflor, Cyantraniliprole, pyriproxyfen and mineral oil against the nymphs and adult of *B. tabaci* after treatment. (1): nymphs and (2): adult females

Table 4 displays the outcomes of the toxicological testing against *B. tabaci* for our target compounds imidacloprid, sulfoxaflor, cyantraniliprole, pyriproxyfen, and mineral **oil**. After testing, some of the target five compounds produced a range in terms of their toxicological effects on the nymphs of *B. tabici* (LC_{50} values varied from 2.0 to 9.91 mg/L). For example, LC_{50} values of compounds imidacloprid, sulfoxaflor, cyantraniliprole, pyriproxyfen, and mineral oil were 2.0, 4.43, 5.01, 6.58, and 9.91 mg/L, respectively.

Furthermore, the toxicity indices of imidacloprid, sulfoxaflor, cyantraniliprole, pyriproxyfen, and mineral oil were 1, 0.45, 0.39, 0.30, and 0.20, respectively. From the results above, the toxicity of compound imidacloprid against the nymphs of *B. tabaci* was more active than other target compounds after treatment.All target compounds were evaluated for their bioactivity as insecticides against adults of *B. tabaci* based on the studding results of the toxicity index, as shown in Table 4. The outcomes of the toxicological testing against *B. tabaci* for our target compounds imidacloprid, sulfoxaflor, cyantraniliprole, pyriproxyfen, and mineral oil**.** After treatment, some of the target five compounds produced a range in terms of their toxicological effects on the nymphs of *B. tabaci* (LC50 values varied from 3.62 to 19.6 mg/L). For example, LC50 values of compounds imidacloprid, sulfoxaflor, cyantraniliprole, pyriproxyfen, and mineral oil were 3.62, 9.11, 11.0, 13.7, and 19.6 mg/L, respectively. Furthermore, the toxicity indices of the compounds imidacloprid, sulfoxaflor, cyantraniliprole, pyriproxyfen, and mineral oil were 1, 0.339, 0.32, 0.26, and 0.18, respectively. From the results above, the toxicity of compound imidacloprid against the nymphs of *B. tabaci* was more active than other target compounds after treatment.

The findings align with Tomizawa and Casida (2001), who indicated that sulfoxaflor treatment was more effective and toxic in decreasing *B. tabaci*. Al-Kherb (2011) demonstrated that thiamethoxam (10 g a.i./ha) was the most toxic against *B. tabaci* individuals, followed by imidacloprid (10 g a.i./ha) and acetamiprid (10 ml a.i./ha). Meena and Ranju (2014) stated that profenophos was the most effective insecticide for controlling whiteflies, followed by indoxacarb. Das and Islam (2014) demonstrated that imidacloprid had a very rapid action against whiteflies and decreased their population. Gorri *et al.* (2015) showed that chlorpyrifos and thiamethoxam were both effective at reducing adult whiteflies in tomatoes. Jahel *et al.* (2017) observed that sulfoxaflor was the most toxic against nymphs and adult whiteflies, while azadirachtin had the least effect. Jha and Kumar (2017) noted that imidacloprid was the most effective and active option for reducing whiteflies. Eweis *et al.* (2022) indicated that the use of cyantraniliprole and sulfoxaflor significantly reduced *B. tabaci* on tomatoes. Mahendra and Singh (2022) indicated that acetamiprid 20 SP (0.20 ml/litre) and imidacloprid 17.8 SL (0.22 ml/litre) were considered toxic in reducing *B. tabaci* on tomatoes.

Conclusions and Recommendations:

The collected data may be employed to assess insect populations, perform scouting, and analyze the influence of weather on the efficacy of successful IPM strategies. Successful IPM strategies can lead to healthier ecosystems and more sustainable agricultural practices. By regularly analyzing this data, farmers can utilize the afor ementioned results to formulate strategies for managing and controlling *B. tabaci*, thereby mitigating damage to pepper plants

Declarations

Ethical Approval: Not applicable

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ARABIC SUMMARY

بيئة تعداد حشرة الذبابة البيضاء التي تصيب نباتات الفلفل ومكافحتها.

إيمان عوض شحاتة[1]،ايناس مصطفي يحيي[2] و نيره سمير المصري[3]
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تتمتع حشرة بيميسيا تاباسي (جيناديوس)، المعروفة باسم الذبابة البيضاء، بأهمية اقتصادية عالمية، إذ يمكنها أن تسبب الضرر بالعوائل النباتية على نطاق عالمي. والهدف من هذه الدراسة هو دراسة وفرة الموسمية لحشرة الذبابة البيضاء التى تصيب نباتات الفلفل خلال موسمين المتتاليين (2024/2023 و2025/2024) في مركز المنصورة -محافظة الدقهلية – مصر. وأيضا، تم دراسة تأثير بعض عوامل الطقس المناخية وعمر النبات على الكثافة العددية للحشرة باستخدام معامل الارتباط البسيط والانحدار المتعدد ونماذج المكونات الرئيسية. أظهرت النتائج، أن حشرة الذبابة البيضاء ظهرت على نباتات الفلفل بعد 30 يومًا من الزراعة، أي من الأسبوع الأول من شهر أكتوبر، وأستمر وجودها على نباتات الفلفل حتى الأسبوع الرابع من شهر يناير خلال كلا الموسمين. وأوضحت النتائج، أن حساب التراكم اليومي لحشرة الذبابة البيضاء (10234.00 و10717.00 فرداً في الموسمين)، على الترتيب .وتبين من نتائج الدراسة، أن التأثير المشترك لعوامل الطقس المناخية (متوسط اليومي لدرجة الحرارة العظمى ومتوسط اليومي لدرجة الحرارة الدنيا ومتوسط نسبة الرطوبة النسبية) والظواهر الفينولوجية للنبات مقدرة كعمر النبات (باليوم) على التعداد الحشرى خلال الموسمين المتتاليين كان معنويا وواضحا، وأن تأثير هذه العوامل يختلف من موسم إلى أخر،

وأظهر التحليل الإحصائي باستخدام طريقة الأنحدار المتعدد، أن التأثير المشترك لجميع العوامل المختبرة فى مجال الدراسة مجتمعة وكانت عالية المعنوية على التعداد الحشرى خلال موسمى النمو. كما أن نسبة الاختلاف والتي يمكن أعزاؤها إحصائياً إلى التغير فى العوامل المختبرة كانت94.50% و88.81% لكل موسم على التوالي.

كذلك تم تقييم تأثير فعالية المبيدات المختبرة بعد 72 ساعة من المعاملة، وأظهرت النتائج، أن مبيد إيميداكلوبريد هو الأكثر تأثيرًا على حوريات والإناث البالغة لحشرة الذبابة البيضاء، مقارنةً بالمبيدات المختبرة الأخرى، وكان الزيت المعدني الأقل سمية. تفيد هذه النتائج في مكافحة الذبابة البيضاء على نباتات الفلفل، وتُقلل من أضرار المبيدات المستخدمة.