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Occurrence of the whitefly *Bemisia Tabaci* and its potential damage to vegetative growth parameters, essential nutrients, and productivity of pepper plants

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Abstract
The purpose of this study is to offer fundamental information for assessing the negative effects of the whitefly *Bemisia tabaci* on pepper plant traits (growth parameters, yield, and nutrients). During the 2023–2024 and 2024–2025 seasons, sweet pepper (Top Star F1 hybrid) field trials were carried out in a greenhouse in Mansoura, Dakhlia Governorate, Egypt. According to the data, *B. tabaci* infestations on sweet pepper plants in both sprayed and unsprayed main plots started four weeks after planting, in the first week of October, and lasted until the fourth week of January in each season.

According to the data, the sprayed pepper plants outperformed *B. tabaci* in terms of vegetative development parameters, such as average plant height, stem diameter, number of leaves/plants, and number of branches per plant. In comparison to plants sprayed with pesticides (treated with insecticides), the unsprayed plant leaves (free of pesticide treatments, control treatment) had lower plant fresh weight and lower percentages of moisture, nitrogen, phosphate, and protein. In this case, the sprayed plants had lower dry weight per plant, dry matter percentages, and K and Ca levels than the untreated plants.

As for the resulting pepper yield {number of fruits per plant, average fresh fruit weight (g), early yield/m² (kg), and total fruit yield/m² (kg)}, the treated plants outperformed the untreated plants. Untreated pepper plants infested with *B. tabaci* showed the highest reductions in all growth, nutrient, and productivity traits studied, with the exception of plant dry weight, dry matter percentages, and potassium and calcium contents.

Simple correlation estimates showed a highly significant negative relationship between variations in a specific preferred attribute and changes in *B. tabaci* counts and percentages of damaged leaves in all evaluated parameters, with the exception of fresh plant weight, moisture, nitrogen, and phosphorus percentages (all of which showed positive relationships).

Based on the efficient planning of associated control measures that should be established in place to control this pest and lessen damage to the pepper crop, we can infer that this information might assist farmers and decision-makers in managing *B. tabaci* populations.

Keywords: *Bemisia tabaci*, pepper, yield, reduction, population density

Introduction

The color, flavor, pungency, scent, and taste of pepper (Capsicum spp.) make it a significant vegetable and spice crop in many parts of the world (Rohini and Lakshmanan, 2017) [43]. The sweet pepper, or *Capsicum annum* L., belongs to the genus Capsicum and the family Solanaceae (Amaechi *et al*., 2021) [6]. One of the most well-liked and widely grown vegetables in Egypt is grown in plastic houses for both local and export markets (Ibrahim *et al*., 2019) [27]. It ranks second in terms of the acreage planted to vegetable crops under plastic homes (Omar *et al*., 2018) [40]. Pepper is one of the greatest vegetable sources of components that are good for human health (Block *et al*., 1992) [13]. Fresh marketplaces throughout Asia, Southeast Asia, South and Central America, and Africa sell pepper leaves (Specialty Produce, 2020) [48]. When cooked as greens, they are said to have a little bitterness (Abilgos-Ramos *et al*., 2012) [1]. According to Specialty Produce (2020), pepper leaves are an excellent source of antioxidants and vitamins A and B. Certain phytochemicals that are released as secondary metabolites of the plant contribute to its nutritional advantages, including its antioxidant qualities. The leaves are eaten as another edible plant portion after cooking; however, the fruits of the capsicum species are devoured first (Stephens, 2002) [50]. According to Rhodes (2009) [42], the nightshade family Solanaceae includes the genera *Capsicum* spp.

The fruit of the red sweet pepper is rich in bioactive substances that promote health, such as carotenoids, phenolics, and antioxidants including β-carotene, which functions as provitamin A (Jamiołkowska *et al*., 2016) [30]. Weight, pericarp thickness, color, and nutritional value are the factors that consumers consider when evaluating the quality of sweet pepper fruit; they often choose fruit that is more nutrient-denser, heavier, thicker, and more colorful when fully mature (Buczkowska and Najda 2022). According to Hameed *et al*. (2023) [22], sweet peppers are susceptible to infestation by many insect pests. The scientific name for the whitefly, *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae), is one of these pests. It is an economically significant insect pest that attacks agricultural hosts worldwide (Bakry *et al*., 2023) [8, 9, 10]. The global, polyphagous, and dangerous pest is *B. tabaci*. The undersides of leaves are usually home to these tiny, white, moth-like insects (Shehata *et al*., 2024) [45]. According to Ibrahim (2017) [28], whiteflies are polyphagous insects that may be raised and colonized on a variety of floral and vegetable crops in greenhouses and open fields. Sweet pepper plants may suffer wilting, yellowing, and stunted development as a result of it draining the sap from the leaves (Lima *et al*. 2000) [37]. Additionally, they release a sticky material known as honeydew, which can encourage the formation of sooty mold (Bakry *et al*., 2023) [8, 9, 10].

According to Al-Saidi and Al-Obaidy (2022) [5], a severe infestation can weaken and destroy pepper plants, lowering production and slowing plant development. It can also spread several viral infections. Significant infestations of adult whiteflies and their larvae can kill seedlings or cause older plants to become less vigorous and productive (Horowitz *et al*., 2020) [26]. According to Havanoor and Rafee (2018) [24], *B. tabaci*, one of the most destructive insects that destroys several profitable vegetable crops globally, poses a major danger to pepper plants. Since this pest has become resistant to several traditional pesticides, it needs to be controlled right now (Zayed *et al*., 2022) [51]. The chemical composition of pepper leaves determines how different pepper plants respond to an insect infestation. According to Leite (2000) [35], the concentration of insect species inside a plant host may be a sign or explanation of the species' affinity for the plant because of its chemical and behavioral characteristics. N and K levels, weather, plant vigor and age, trichome type and density, and natural enemies are some of the variables that might impact the whitefly population density in host plants. Insects that pierce and suck the mouthparts of plants are linked to potassium levels, which can lead to plant resistance. As an antifeedant that counteracts insect presence, potassium helps make the host less suitable for insect pests (Facknath and Lalljee, 2005) [19]. Increasing the phosphorus and nitrogen applications lowered the number of Hemiptera pests. The population reduced dramatically as the treatment rate increased, while the phosphorus content was increased to enhance the reaction of other insect pests such as *Empoasca* sp. and *Frankliniella occidentalis* (Bala *et al*., 2018) [11]. Thus, biochemical factors, together with genetic changes that prevent hazardous insects from feeding or laying their eggs, may provide hosts with a form of defense to keep out certain pests (Rani and Jyothsna, 2010) [41]. According to Smith (2009) [46], *B. tabaci* nymphs have the ability to inject enzymes that alter plant physiology, resulting in uneven fruit ripening and delayed interior pigmentation. Due to the honeydew that *B. tabaci* excretes, sooty mold can form on the leaves and fruits, lowering photosynthetic activity and potentially lowering the quality of agricultural produce (Solanki and Jha, 2018) [47]. According to Kunjwal and Srivastava (2018) [34], feeding *B. tabaci* can result in large financial losses for crops because it damages the host plants by secreting honeydew and spreading plant viruses. So, the purpose of the current study was to evaluate the impact of B. tabaci on plant development metrics, nutrients, and the sweet pepper (Top Star F1 hybrid) production that results.

Materials and Methods

During the 2023–2024 and 2024–2025 seasons, sweet pepper (Top Star F1 hybrid) experiments were carried out in a plastic greenhouse in Mansoura, Dakhlia Governorate, Egypt. During both research seasons, pepper seeds were planted in seedling trays on September 1st. The 22-day-old seedlings were then moved into the plastic homes on September 23 of both seasons, spaced 30 cm apart, with a ridge that was 1 m wide. Using a drip irrigation system, the experimental plot was made out of a single ridge that was 3 meters long and 1 meter broad, totaling 3 meters². One week following transplantation, all lost transplants were replaced with new ones of the same age. The plastic house had a total surface of 150 m², measuring 25 m in length and 6 m in width. Thirty centimeters from the entrance and the end exit (of the plastic home, as well as fifty centimeters from each side of the arch near the plastic) were left bare of vegetation in both seasons. Thus, there are around 400 plants in all, including plastic housing. In every plot, the standard agricultural procedures of fertilization, irrigation, and planting were carried out on schedule.

In order to allow for a natural whitefly infestation, the first four plots were kept free of chemical control measures and insecticides throughout the study period. The population density of the aforementioned pest was thought to be a key indicator of the presence of *B. tabaci* from the time peppers were planted until they were harvested. The remaining four duplicates were regarded as uninfested plots after receiving pesticide treatments. Given its short life cycle and potential to attack and repeat its infestation multiple times during pepper growing seasons, the replicates were directly sprayed with pesticides three times during the season in response to the first invasion of *B. tabaci* on pepper plants. This was done in accordance with the Egyptian Ministry of Agriculture's preventative schedule. The first spray of Espinoza 1.8% EC (Abamectin) at a rate of 40 ml/100 ml of water at the first appearance of small numbers of whiteflies on pepper plants. This technique is always performed on October 5 for two consecutive years (i.e., four weeks after planting). By the third week of November, the population of individual tobacco aphids (*B. tabaci* individuals) had increased during both seasons. Pepper plants were sprayed with Challenger 24% SC (Chlorfenapyr) at a rate of 60 ml/100 ml water. Another pesticide treatment was done the third week of December over the two seasons and was sprayed with a Keribs 35% SC (Imidacloprid) pesticide at the rate of 75 ml/100 ml of water. A backpack-powered sprayer with a 20-liter capacity was used to apply all pesticide treatments prior to dusk. In addition to spraying the insecticide on both leaf surfaces, the plants were also coated from the outside. After 1, 2, 3, and 4 weeks of treatment, 30 randomly selected leaves from each pesticide treatment were used to analyze the pepper plants. Data on both living and dead whiteflies were documented.

Based on the advice of Sadek *et al*. (2024) [44], which recommended that pesticide control treatments against *B. tabaci* be used within the first few days following the commencement of infestation, the aforementioned control treatments were put into place.

1. Population studies of *B. tabaci* on the pepper plants

a. Abundance of *B. tabaci*

Ten pepper leaves per duplicate were selected at random each week in the early hours of the day (7–9 a.m.) from different places inside the greenhouse over the two seasons, as well as from different parts of the pepper plant, in order to establish seasonal abundance of *B. tabaci*. The number of whiteflies (adults and nymphs) on each leaf was counted while the leaves were examined through 10x lenses in order to monitor the population's seasonality. We gathered 2240 pepper leaves, or 56 separate observation sessions, over the two cropping seasons. 28 inspection dates × 4 replicates × 10 leaves × 2 seasons were utilized for the sample. There are 1120 leaves in each season.

b. Damaged leaf percentages by *B. tabaci*

According to Bakry and Abdel-Baky (2023a) [8, 9, 10], the proportion of damaged pepper leaves by *B. tabaci* was graded, and the counts of *B. tabaci* on pepper leaves were estimated.

A = (n / N) × 100

Where A is the percentage of damaged leaves, and n is the number of damaged leaves in the sample, N is the total number of analyzed leaves (damaged and undamaged) for each studied date. One-way ANOVA was used to statistically analyze the mean number of *B. tabaci* and the percentage of damaged leaves throughout the two study seasons. The least significant difference (LSD) test applied by SPSS (1999) [49] was used to compare means at the 5% probability level.

Recorded data

From each experimental plot, four plants were chosen at random and labeled to document growth information, early yield, total yield, and fruit quality metrics. Characteristics associated with vegetative growth: Following a 120-day transplant, all of the following traits were measured: Using a meter scale, the height of the tagged plants was measured in centimeters from the base to the terminal growing point. Each plant's number of leaves and branches was counted. Plant fresh weights were obtained as the average fresh weight of plant leaves.

The percentages of moisture, dry matter, nitrogen, phosphorus, potassium, calcium, and protein in leaves were ascertained using plant chemical analysis. 10 plants were taken out of every replication. The samples were gathered from the fifth leaf on the growing top of the pepper plant. To get rid of any dust or other residues, new leaf samples were cleaned with tap water first and then distilled water (Cardoso *et al*., 2024) [15]. After that, these samples were dried for 48 hours at 70ºC in an electric oven (Ni *et al*., 2001).

We noted the leaves' fresh and dried weights. After undergoing treatment in an electric mill, the dried material was placed on paper for further examination. As recommended by Jones (2001) [31], plant materials were broken down using H_2SO_4. A dry weight approach was used for the study.

The following formulas were used to determine the percentages of moisture and dry matter

- $$\text{Moisture (\%)} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Fresh weight}} \times 100$$

- $$\text{Dry matter (\%)} = \frac{\text{Average dry weight (g)}}{\text{Average fresh weight (g)}} \times 100$$

The formula for protein percentage was N% × conversion factor (6.25).

Jones (2001) [31] reported that the total nitrogen (N) in the ground material was measured using micro Kjeldahl techniques, the potassium (K) was tested using a flame photometer, and the phosphorus (P) was colorimetrically measured using ascorbic acid. The calorimetric total carbohydrate content of pepper leaves was measured using the anthrone reagent, and the color intensity at 240 µm was evaluated using the A.O.A.C. (2000) approach.

Mean fruits, number/plant, which was calculated from the total number of fruits collected during the full harvest period (110 days), was used to calculate fruit number and yield characteristics. The fruit gathered during all picking periods was used to compute the fruit weight per plant.

The tagged plants' total fruit weight was noted, and the fruit yield per square meter was calculated by multiplying the average fruit production per plant by the number of plants per square meter. Total fruit output (kg) divided by the total number of fruits produced by each plant was used to get the average fruit weight (g). The weight of all fruits gathered within the first 30 days of harvesting per square meter, given in kilograms, was referred to as the early yield.

The following formula was used to assess the amount of losses and damage brought on by the *B. tabaci* infestation:

% Decrease = [(A-B) / A] × 100 (Bakry and Abdel-Baky, 2023b) [8, 9, 10] Whereas A is the average of a specific evaluation of the sprayed plants, B averages the identical attribute of the unsprayed plants. Statistical analysis: A paired T-test at $P < 0.05$ was used to compare the averages for unsprayed and sprayed plots for each examined parameter. This was done by computer using the MSTATC Program software (Freed, 1991) [21]. To determine the relationship between the two whitefly parameters—the population estimates and the percentage of damaged leaves by *B. tabaci* (the independent variables)—and the tested parameters for pepper plants (the dependent variable) during the 2023–2024 and 2024–2025 seasons. The R program was used to generate and plot the simple correlation values between various variables (Mendiburu, 2015) [38]. A straightforward regression technique was also used to explain the variations among the measured variables that *B. tabaci* might create, and the percentage of explained variance was computed. Additionally, Microsoft Excel 2016 was used to assess the gathered data.

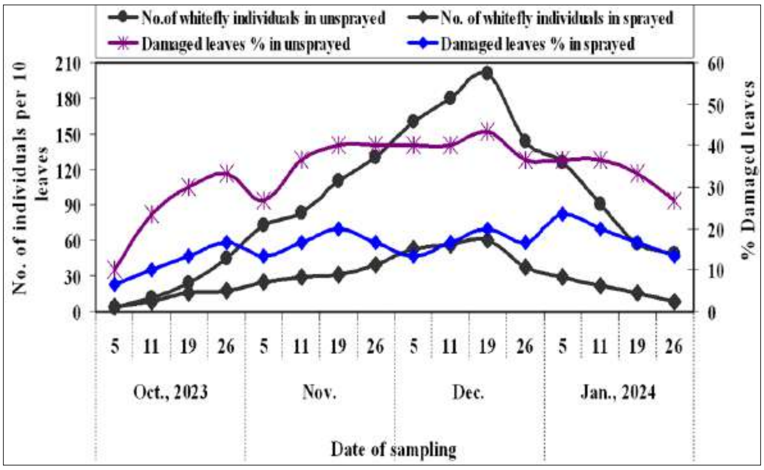
Results and Discussion

Population estimates and damage studies

1.1 Occurrence of *B. tabaci* on pepper plants

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, both in sprayed and unsprayed main plots, according to the results obtained, which are shown in Table (1) and Fig. (1).

There were significant differences between the average number of *B. tabaci* individuals/10 leaves at sprayed and unsprayed plots in our investigation. In this case, during the course of the two seasons, the unsprayed pepper plants averaged 92.90 ± 8.57 and 97.04 ± 9.32 individuals/10 leaves, respectively, whereas the sprayed pepper plants averaged 28.21 ± 2.47 and 22.42 ± 2.09 individuals/10 leaves. According to Table (1) and illustrated in Fig. (1), the number of *B. tabaci* individuals in untreated pepper plants increased by around 3.29 in 2023/2024 and 4.33 times in 2024/2025 when compared to treated plants. Based on the dates of inspection, the analysis of variance revealed very significant differences with regard to *B. tabaci* individuals. The L.S.D. values for the two seasons were 7.28 and 7.22 for the treated plants and 7.34 and 7.28 for the untreated plants, respectively (Table 1). According to statistics, there were extremely significant differences in the numbers of *B. tabaci* in the sprayed and unsprayed plants; the L.S.D. values were 4.72 in 2023/2024 and 4.66 in 2024/2025 (Table 1).



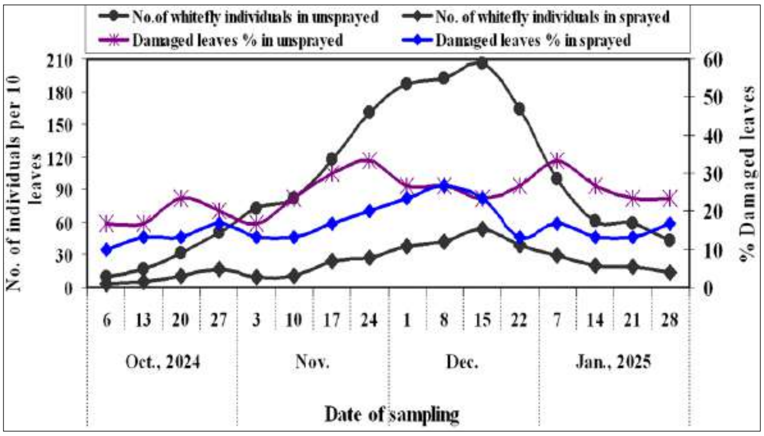


Fig. 1: Weekly mean numbers of *B. tabaci* individuals and damaged leaf percentage of pepper plants at two rates (sprayed and unsprayed) at Mansoura district, Dakhlia Governorate, during the two growing seasons (2023/2024 and 2024/2025).

Table 1: Weekly mean numbers of *B. tabaci* individuals and damaged leaves percentage of pepper plants at two rates (sprayed and unsprayed) at Mansoura district, Dakhlia Governorate, during the two growing seasons (2023/2024 and 2024/2025).

Sampling date		2023/2024 season				2024/2025 season			
		Whiteflies count per 10 leaves ± S.E.		Damaged leaves percentage (%) ± S.E.		Whiteflies count per 10 leaves ± S.E.		Damaged leaves percentage (%) ± S.E.	
		Unsprayed (Untreated leaves)	Sprayed (Treated leaves)	Unsprayed (Untreated leaves)	Sprayed (Treated leaves)	Unsprayed (Untreated leaves)	Sprayed (Treated leaves)	Unsprayed (Untreated leaves)	Sprayed (Treated leaves)
Oct.	5	3.33 ± 0.33	3.67 ± 0.33	10.00 ± 5.77	6.67 ± 3.33	9.67 ± 0.88	2.67 ± 0.33	16.67 ± 3.33	10.00 ± 5.77
	11	11.67 ± 0.33	8.33 ± 0.33	23.33 ± 3.33	10.00 ± 5.77	17.00 ± 1.53	5.00 ± 0.58	16.67 ± 3.33	13.33 ± 3.33
	19	24.00 ± 1.15	16.00 ± 2.31	30.00 ± 5.77	13.33 ± 3.33	32.00 ± 2.00	10.67 ± 0.67	23.33 ± 3.33	13.33 ± 6.67
	26	45.00 ± 2.89	17.33 ± 1.76	33.33 ± 3.33	16.67 ± 3.33	50.00 ± 1.15	16.33 ± 0.33	20.00 ± 5.77	16.67 ± 3.33
Nov.	5	72.67 ± 1.20	25.00 ± 0.58	26.67 ± 8.82	13.33 ± 3.33	72.33 ± 2.33	9.00 ± 0.58	16.67 ± 6.67	13.33 ± 3.33
	11	83.67 ± 3.76	29.00 ± 1.53	36.67 ± 3.33	16.67 ± 3.33	82.33 ± 3.18	10.00 ± 0.58	23.33 ± 3.33	13.33 ± 3.33
	19	110.00 ± 4.62	31.33 ± 0.67	40.00 ± 5.77	20.00 ± 5.77	117.33 ± 2.91	23.67 ± 0.88	30.00 ± 10.00	16.67 ±8.82
	26	130.00 ± 5.77	39.33 ± 0.67	40.00 ± 5.77	16.67 ± 3.33	160.67 ± 6.36	27.67 ± 1.45	33.33 ± 6.67	20.00 ± 11.55
Dec.	5	160.00 ± 7.64	53.00 ± 1.53	40.00 ± 5.77	13.33 ± 6.67	187.00 ± 1.53	37.67 ± 1.45	26.67 ± 8.82	23.33 ± 3.33
	11	180.00 ± 5.77	56.33 ± 0.88	40.00 ± 5.77	16.67 ± 3.33	192.00 ± 4.62	42.00 ± 1.15	26.67 ± 8.82	26.67 ± 3.33
	19	200.67 ± 5.21	60.00 ± 1.15	43.33 ± 3.33	20.00 ± 5.77	205.33 ± 3.53	53.33 ± 2.40	23.33 ± 8.82	23.33 ± 3.33
	26	143.33 ± 12.02	37.33 ± 2.91	36.67 ± 3.33	16.67 ± 3.33	164.00 ± 2.31	38.33 ± 2.73	26.67 ± 12.02	13.33 ± 3.33
Jan.	5	126.00 ± 6.00	29.33 ± 1.76	36.67 ± 3.33	23.33 ± 3.33	100.00 ± 3.71	29.33 ± 1.76	33.33 ± 13.33	16.67 ± 3.33
	11	90.00 ± 5.77	21.33 ± 2.40	36.67 ± 3.33	20.00 ± 5.77	61.00 ± 9.71	20.00 ± 3.06	26.67 ± 3.33	16.67 ± 3.33
	19	57.33 ± 2.67	15.67 ± 1.20	33.33 ± 3.33	16.67 ± 3.33	58.67 ± 2.67	19.00 ± 1.00	23.33 ± 3.33	13.33 ± 3.33
	26	48.67 ± 3.67	8.33 ± 2.33	26.67 ± 3.33	13.33 ± 3.33	43.33 ± 5.46	14.00 ± 2.00	23.33 ± 3.33	13.33 ± 3.33
General average		92.90 ± 8.57	28.21 ± 2.47	33.33 ± 1.61	15.83 ± 0.98	97.04 ± 9.32	22.42 ± 2.09	24.38 ± 1.68	16.46 ± 1.21
L.S.D. at 0.05 level		7.34**	7.28**	6.99**	6.96**	7.28**	7.22**	6.94**	6.91**
L.S.D. at 0.05 level between the two treatments		4.72 **		4.44**		4.66**		4.38**	

1.2 Damaged leaves percentage by *B. tabaci*

As the inspection times for the various pepper growth stages in the unsprayed plots throughout the two seasons grew, so did the proportion of damaged leaves cause by *B. tabaci*. This might be because of the presence of a *B. tabaci* nymphal population, the accessibility of food, the short life cycle of the insect, and its spread, which causes more serious harm to pepper plants (Table 1 and Fig. 1).

Nevertheless, during the pepper growth in the two research seasons, the percentage of afflicted plants in the treated plots varied between increasing and decreasing over the various evaluation times. The untreated plots had an average of 33.33 ± 1.61 and 24.38 ± 1.68 percent pepper-damaged leaves, whereas the treated plots had 15.83 ± 0.98 and 16.46 ± 1.21 percent pepper-damaged leaves during the two seasons, respectively. In 2023–2024 and 2024–2025, the proportion of pepper-damaged plots in the untreated plots rose by approximately 2.11 and 1.48 times, respectively, compared to the treated plots (Table 1 and Fig. 1). The proportion of pepper-damaged leaves differed statistically substantially depending on the inspection dates (Table 1), showing that the L.S.D. values for the sprayed plants were 6.96 and 6.91, whereas the L.S.D. values for the unsprayed plants were 6.99 and 6.94. The percentages of damaged pepper leaves in this situation differed greatly based on the treatments (sprayed and unsprayed plants), as the L.S.D. values for the two seasons were 4.44 and 4.38, respectively.

These results are consistent with Our results supported Hegab's (2017) prediction that during the third week of July, there would be a single peak of *B. tabaci* infesting cucumber leaves. According to Kamel *et al*. (2000) [32], the *B. tabaci* infestation gradually increased from mid-June to the end of July 1996. However, Ahmed (1994) [3] discovered that *B. tabaci* produced three peaks on summer cucumber harvests in each season. Accordingly, the steady increase in *B. tabaci* populations on tomatoes during various time periods implies that pest control should start during the vegetative and seedling stages, before the insect achieves its maximum population. These findings align with those of El-Shazly *et al*. (2019) [18]. El-Damer *et al*. (2024) [17] reported that *B. tabaci* on pepper had one to three peaks.

Influence of *B. tabaci* infestation on vegetative growth, necessary nutrients, resulting yield, and its contents of the pepper plants

1.1 On the pepper vegetative growth measurements:

There are several ways to describe the growth of pepper plants, including length, leaf breadth, and area. Therefore, four growth characteristics—plant height, stem diameter, number of leaves/plants, and number of branches/plants—were utilized in this experiment to gauge the growth of pepper plants under *B. tabaci* infestation (Omar *et al*., 2018) [40].

a. Plant height

During the two growing seasons, the heights of pepper plants in the sprayed plots were 58.98 ± 0.43 and 58.83 ± 0.48 cm, respectively, whereas those in the untreated plots were 52.98 ± 0.49 and 52.90 ± 0.42 cm (Tables 2 and 3). Consequently, in 2023–2024 and 2024–2025, the height of pepper plants decreased by 10.17% and 10.07%, respectively, in unsprayed plants compared to sprayed ones. Over the course of two consecutive seasons, there was a very significant difference in plant height between treated and untreated pepper plants (paired T-test values were 26.40 and 53.44, respectively).

Table 2: Measurements of vegetative growth, necessary nutrients, and resulting yield of the pepper plants as affected by *B. tabaci* individuals' numbers at two blocks (sprayed and unsprayed) during the first season (2023/2024). Each value is the mean of the four different replicates ± S.E.

Parameters	Sprayed plants (Treated)	Unsprayed plants (Untreated)	Average	Effect resulted	Paired T -test
Plant height (cm)	58.98 ± 0.43	52.98 ± 0.49 (10.17%)	55.98 ± 0.17	Reduction	26.40 **
Stem diameter (cm)	0.81 ± 0.01	0.72 ± 0.01 (10.80%)	0.77 ± 0.02	Reduction	11.67**
NO. of leaves/ plant	139.75 ± 0.85	125.50 ± 1.89 (10.20%)	132.63 ± 2.86	Reduction	10.84**
NO. of branches/ plant	9.45 ± 0.33	8.48 ± 0.09 (10.32%)	8.96 ± 0.24	Reduction	3.91**
Plant fresh weight (g):	880.00 ± 17.80	762.50 ± 4.79 (13.35%)	821.25 ± 23.79	Reduction	8.18**
Dry weight/ plant (g):	112.50 ± 4.79	140.00 ± 4.08 (24.44%)	126.25 ± 5.96	Increase	11.00**
Moisture %	87.23 ± 0.39	81.65 ± 0.44 (6.40%)	84.44 ± 1.09	Reduction	13.39**
Dry matter %	12.77 ± 0.36	18.35 ± 0.38 (43.69%)	15.56 ± 1.02	Increase	13.39**
N (%)	2.40 ± 0.04	2.00 ± 0.09 (16.67%)	2.20 ± 0.09	Reduction	6.93**
P (%)	0.20 ± 0.01	0.17 ± 0.01 (12.66%)	0.19 ± 0.01	Reduction	8.66**
K (%)	2.53 ± 0.02	2.78 ± 0.05 (9.68%)	2.65 ± 0.05	Increase	7.36**
Ca (%)	2.34 ± 0.02	2.60 ± 0.04 (11.23%)	2.47 ± 0.05	Increase	4.20**
Protein	15.00 ± 0.26	12.50 ± 0.57 (16.67%)	13.75 ± 0.55	Reduction	6.93**
No. of fruits per plant	20.73 ± 0.67	16.33 ± 0.62 (21.23%)	18.53 ± 0.93	Reduction	5.04**
Average fruit fresh weight (g)	40.53 ± 0.49	37.23 ± 0.29 (8.14%)	38.88 ± 0.68	Reduction	12.62**
Early yield/ m^2 (kg)	1.75 ± 0.06	1.35 ± 0.06 (22.86%)	1.55 ± 0.09	Reduction	6.02**
Total fruit yield/m^2 (kg)	2.43 ± 0.18	1.75 ± 0.05 (27.84%)	2.13 ± 0.14	Reduction	4.26**

Table 3: Measurements of vegetative growth, necessary nutrients, resulting yield of the pepper plants as affected by *B. tabaci* individuals' numbers at two blocks (sprayed and unsprayed) during the second season (2024/2025). Each value is the mean of the four different replicates ± S.E.

Parameters	Sprayed plants (Treated)	Unsprayed plants (Untreated)	Average	Reduction	Paired T-test
Plant height (cm)	58.83 ± 0.48	52.90 ± 0.42 (10.07%)	55.86 ± 1.16	Reduction	53.44**
Stem diameter (cm)	0.81 ± 0.01	0.71 ± 0.01 (11.49%)	0.76 ± 0.01	Reduction	12.33**
No. of leaves/ plant	139.00 ± 1.29	124.50 ± 1.71 (10.43%)	131.75 ± 2.91	Reduction	29.00**
No. of branches/ plant	9.45 ± 0.32	8.45 ± 0.06 (10.58%)	8.95 ± 0.24	Reduction	3.74**
Plant fresh weight	870.00 ± 13.54	757.50 ± 4.79 (12.93%)	813.75 ± 22.28	Reduction	11.89**
Dry weight / plant	112.50 ± 4.33	138.75 ± 4.27 (23.33%)	125.63 ± 5.70	Increase	10.97**
Moisture %	87.08 ± 0.39	81.69 ± 0.45 (6.18%)	84.38 ± 1.05	Reduction	15.05**
Dry matter %	12.92 ± 0.39	18.31 ± 0.45 (41.67%)	15.62 ± 1.05	Increase	15.05**
N (%)	2.38 ± 0.05	1.88 ± 0.07 (21.05%)	2.13 ± 0.10	Reduction	12.25**
P (%)	0.20 ± 0.01	0.17 ± 0.01 (12.82%)	0.18 ± 0.01	Reduction	8.66**
K (%)	2.51 ± 0.04	2.76 ± 0.06 (10.28%)	2.63 ± 0.06	Increase	11.84**
Ca (%)	2.33 ± 0.03	2.58 ± 0.05 (10.75%)	2.45 ± 0.05	Increase	3.87**
Protein	14.84 ± 0.30	11.72 ± 0.47 (21.05%)	13.28 ± 0.64	Reduction	12.26**
No. of fruits per plant	20.60 ± 0.64	16.25 ± 0.63 (21.12%)	18.43 ± 0.92	Reduction	4.88**
Average fruit fresh weight (g)	40.65 ± 0.47	37.28 ± 0.29 (8.30%)	38.96 ± 0.69	Reduction	14.53**
Early yield/ m^2 (kg)	1.74 ± 0.07	1.34 ± 0.07 (23.02%)	1.54 ± 0.09	Reduction	6.24**
Total fruit yield/m^2 (kg)	2.45 ± 0.16	1.74 ± 0.05 (29.08%)	2.14 ± 0.14	Reduction	5.62

b. Stem diameter

According to the aforementioned, during the 2023–2024 and 2024–2025 seasons, the diameter of the pepper plant stems in sprayed plants was greater, measuring 0.81 ± 0.01 and 0.81 ± 0.01 cm, respectively, than in unsprayed plants (0.72 ± 0.01 and 0.71 ± 0.01 cm). Consequently, over the two seasons, the stem diameter of untreated pepper plants dropped by 10.80 and 11.49%, respectively, in comparison to sprayed plants. According to the statistical study, the untreated and treated pepper plants' stem diameters varied significantly throughout the course of the two seasons (paired T-test values were 11.67 and 12.33, respectively).

c. Number of leaves plant

The findings indicated that over the two seasons, treated pepper plants recorded 139.75 ± 0.85 and 139.00 ± 1.29 leaves/plant, respectively, while untreated pepper plants recorded fewer leaves/plant, averaging 125.50 ± 1.89 and 124.50 ± 1.71 leaves/plant (Tables 2 and 3). Over the course of the two seasons, the number of leaves on untreated pepper plants dropped by around 10.20 and 10.43%, respectively, in comparison to treated plants. Additionally, there was a highly statistically significant difference in the number of leaves per plant between pepper plants that were treated and those that were not (paired t-test values were 10.84 in the 2023/2024 season and 29.00 in the 2024/2025 season).

d. Number of branches plants

In contrast to untreated plants (8.48 ± 0.09, 8.45 ± 0.06, and 8.45 ± 0.06 branches/plant), sprayed pepper plants grew bigger branches, with an average of 9.45 ± 0.33 and 9.45 ± 0.32 branches/plant, according to data in Tables 2 and 3. Comparing untreated plants to sprayed plants, the number of branches per plant dropped by 10.32% and 10.58%, respectively (Tables 2 and 3). Additionally, there was a highly statistically significant difference in the number of branches per plant between pepper plants that were sprayed and those that were not (paired t-test values: 3.91 in the 2023/2024 season and 3.74 in the 2024/2025 season).

1.2 Effect on the chemical properties of pepper plants

a. On the plant fresh weight

The results in Tables 2 and 3 showed that the fresh weight of pepper-treated plants was substantially greater, with an average of 880.00 ± 17.80 and 870.00 ± 13.54, than that of untreated plants (762.50 ± 4.79 and 757.50 ± 4.79 g) during the two consecutive seasons, respectively. In both seasons, there were highly statistically significant differences in fresh weight between untreated and treated plants (paired T-tests were 8.18 and 11.89), respectively. During the two growth seasons, the fresh weight of the untreated pepper plants decreased by around 13.35% and 12.93%, respectively, in comparison to the treated plants (Tables 2 and 3).

b. On the dry weight plant

During the two seasons, the dry weight of unsprayed pepper plants was substantially greater, with an average of 140.00 ± 4.08 and 138.75 ± 4.27 g, than that of sprayed plants (112.50 ± 4.79 and 112.50 ± 4.33 g, respectively). The dry weight differences between the treated and untreated plants in both seasons were highly statistically significant (paired t-tests were 10.97 and 11.00, respectively). Throughout the two growth seasons, the dry weight of the untreated pepper plants increased by around 24.44% and 23.33%, respectively, in comparison to the treated plants (Tables 2 and 3).

c. On the percentage of moisture

The level of water in leaves is reflected in the moisture content. According to the findings in Tables 2 and 3, over the two seasons, the sprayed pepper plants had the maximum moisture content (87.23 ± 0.39 and 87.08 ± 0.39%), while the sprayed plants had the lowest moisture content (81.65 ± 0.44 and 81.69 ± 0.45%). The data's statistical analysis revealed that the moisture content of sprayed and unsprayed plants differed significantly (paired t-test p-values were 13.39 and 15.05, respectively). During the two growth seasons, the unsprayed pepper plants' moisture content dropped by around 6.40% and 6.18% of their weight, respectively, in comparison to the sprayed plants (Tables 2 and 3).

d. On the percentage of dry matter

Material that remains after water has been removed is referred to as dry matter. According to Tables 2 and 3, the percentage of dry matter in the untreated pepper plants was greater over the two seasons (18.35 ± 0.38 and 18.31 ± 0.45%) than in the treated plants (12.77 ± 0.36 and 12.92 ± 0.39%), respectively. The dry matter content of sprayed and unsprayed plants differed significantly, according to statistical analysis of the data (paired T-test p-values were 13.39 and 15.05, respectively). During the two growth seasons, the dry matter content of unsprayed pepper plants raised by about 43.69% and 41.67% of their weight, respectively, in comparison to sprayed plants (Tables 2 and 3).

1.3 Effect on the necessary nutrients of leaves

a. On the percentage of N in leaves

The most vital mineral for plant growth and development, nitrogen also plays a major role in the evolution of herbivore populations. High yield, photosynthesis, and vegetative development can all be enhanced by sufficient nitrogen absorption. According to data in Tables 2 and 3, over the two seasons, the sprayed pepper leaves had the greatest percentages of N content (2.40 ± 0.04 and 2.38 ± 0.05%), whereas the unsprayed leaves had the lowest percentages (2.00 ± 0.09 and 1.88 ± 0.07%). The data's statistical analysis revealed that the N content of sprayed and unsprayed leaves differed significantly (paired T-test p-values were 6.93 and 12.25, respectively). Throughout the two growth seasons, the N content of unsprayed pepper leaves dropped by around 16.67% and 21.05%, respectively, in comparison to sprayed leaves (Tables 2 and 3).

b. On the percentage of P in leaves

According to the data in Tables 2 and 3, over the two seasons, the unsprayed pepper leaves had the lowest percentages of P content (0.17 ± 0.01 and 0.17 ± 0.01 %) in comparison to the sprayed leaves (0.20 ± 0.01 and 0.20 ± 0.01%). The P content of treated and untreated leaves differed significantly, according to statistical analysis of the data (paired T-test p-values were 8.66 and 8.66, respectively). Throughout the two seasons, the P content of untreated pepper leaves dropped by around 12.66% and 12.82%, respectively, in comparison to treated leaves (Tables 2 and 3).

c. On the percentage of K in leaves

An essential solute for growing cells is potassium. Additionally, expanded development is highly susceptible to a lack of K. Furthermore, potassium has a significant function in regulating the water content of cells as well as the production and mobilization of carbohydrates in plant tissues. As indicated in Tables 2 and 3, the findings verified that across the two seasons, the sprayed pepper leaves had the lowest estimated K content (2.53 ± 0.02 and 2.51 ± 0.04%) in comparison to the unsprayed leaves (2.78 ± 0.05 and 2.76 ± 0.06%). The K content of treated and untreated leaves differed significantly, according to statistical analysis of the data (paired T-test p-values were 7.36 and 11.84, respectively). Throughout the two seasons, the K content of unsprayed pepper leaves increased by around 9.68 and 10.28%, respectively, in comparison to sprayed leaves (Tables 2 and 3).

d. On the percentage of Ca in leaves

As indicated in Tables 2 and 3, the findings verified that over the two seasons, the unsprayed pepper leaves had the highest Ca content (2.60 ± 0.04 and 2.58 ± 0.05%), while the sprayed leaves had the lowest Ca content (2.34 ± 0.02 and 2.33 ± 0.03%). The data's statistical analysis revealed that the Ca content of treated and untreated leaves differed significantly (paired T-test p-values were 4.20 and 3.87, respectively). During the two seasons, the untreated pepper leaves' calcium levels increased by around 11.23% and 10.75%, respectively, in comparison to the treated leaves (Tables 2 and 3).

e. On the percentage of protein in leaves

As can be seen in Tables 2 and 3, the results showed that over the two seasons, the unsprayed pepper leaves had the lowest percentages of protein content (12.50 ± 0.57 and

11.72 ± 0.47 %) in comparison to the sprayed leaves (15.00 ± 0.26 and 14.84 ± 0.30%). The protein content of treated and untreated leaves differed significantly, according to the statistical examination of the data (paired T-test p-values were 6.93 and 12.26, respectively). Throughout the two seasons, the protein content of untreated pepper leaves dropped by around 16.67% and 21.05%, respectively, in comparison to treated leaves (Tables 2 and 3).

1.4 Effect on the pepper yield characteristics

a. On the number of fruits per plant

According to the data in Tables 2 and 3, the treated pepper plants produced more fruits per plant on average during the two seasons (20.73 ± 0.67 and 20.60 ± 0.64 fruits per plant) than the untreated plants (16.33 ± 0.62 and 16.25 ± 0.63 fruits per plant, respectively). As a result, it decreased by 21.23 and 21.12% for the two seasons, respectively, in comparison to the untreated pepper plants. Additionally, over the two consecutive seasons, there was a very significant difference in the quantity of fruits produced per plant between treated and untreated pepper plants (paired T-test values were 5.04 and 4.88, respectively).

b. On the average fruit fresh weight (g)

In comparison to the treated plants (40.53 ± 0.49 and 40.65 ± 0.47 g) across the two seasons, the average fresh fruit weight of the untreated pepper plants was substantially lower, averaging 37.23 ± 0.29 and 37.28 ± 0.29 g, as seen in Tables 2 and 3. The mean fresh fruit weight of the treated and untreated plants varied significantly over both seasons (paired T-tests were 14.53 and 12.62, respectively). Additionally, during the two growing seasons, the average fresh fruit weight of untreated pepper plants was approximately 8.14% and 8.30% lower than that of treated plants, respectively.

c. On the early yield/m^2 (kg)

It was clear from Tables 2 and 3 that the untreated pepper plants produced less than the treated ones (1.75 ± 0.06 and 1.74 ± 0.07 kg/m², respectively; average weights were 1.35 ± 0.06 and 1.34 ± 0.07 kg/m²). The paired T-test scores for the two seasons were 6.02 and 6.24, respectively, indicating a very significant difference in pepper yield weight (kg/m²) between untreated and treated plants. Additionally, during the two seasons, the untreated plants' pepper yield weight (kg/m²) decreased by 22.86% and 23.02%, respectively, compared to the treated plants.

d. On the total fruit yield (kg /m^2)

The findings shown in Tables 2 and 3 demonstrated that throughout the two growing seasons, the average total fruit yield weight of the treated pepper plants was 2.43 ± 0.18 and 2.45 ± 0.16 kg/m², while the untreated plants' average was 1.75 ± 0.05 and 1.74 ± 0.05 kg/m². Throughout the two seasons, the differences between the untreated and treated pepper plants were statistically significant (paired t-test p-values were 4.26 and 5.62, respectively). Additionally, throughout the two growing seasons, untreated pepper plants' average total fruit production weight (kg/m²) dropped by 27.84% and 29.08%, respectively, in comparison to treated plants.

The relationship between changes in *B. tabaci* populations, the percentage of damaged leaves, differences in desired vegetative growth parameters, essential nutrients, and the yield of pepper plants

1.1 Number of *B. tabaci* individuals

According to the data in Tables (4) and Figure (3), there was a highly significant negative correlation between the vegetative growth characteristics—such as plant height, stem diameter, number of leaves/plants, and number of branches/plants—and the average estimates of *B. tabaci*. The corresponding r values were -0.97, -0.93, -0.94, and -0.76 for the 2023/2024 season and -0.97, -0.95, -0.94, and -0.79 for the 2024/2025 season. A decrease in vegetative growth properties, such as plant height (0.09 and 0.08 cm), stem diameter (0.01 and 0.01 cm), number of leaves/plant (0.22 and 0.18 leaves), and number of branches/plant (0.02 and 0.01 branches) for two seasons, respectively, would result from an increase of one individual per ten pepper leaves, according to the computed regression coefficient (Table 4). Additionally, Tables (4) and Figure (3) exhibit highly significant negative relationships between the *B. tabaci* estimates and the dry weight/plant and dry matter, which are (-0.87 and -0.88) and (-0.97 and -0.97), respectively, during the two seasons. In contrast, the calculated r values between the average of *B. tabaci* individuals and the chemical properties, i.e., plant fresh weight and the percentage of moisture, were highly significant positive, being (+0.93 and +0.95) and (+0.97 and +0.97). According to this context, the computed regression coefficient showed that during the two seasons, an increase of one pest per ten leaves would result in a decrease in plant dry weight (0.43 and 0.34 g) and dry matter content (0.09 and 0.07%), but an increase in plant fresh weight (1.81 and 1.46 g) and moisture content (0.09 and 0.07%) (Table 4).

Additionally, as shown in Tables (4) and Figure (3), the estimated simple correlation values between the average of *B. tabaci* individuals and the necessary nutrients, i.e., the percentages of N and P, were highly significant positive; they were (+0.85 and +0.92) and (+0.89 and +0.90), with the exception of highly significant negative relationships between the B. tabaci estimates and the percentages of K & Ca and protein, which were (-0.87, -0.92, and -0.85) and (-0.82, -0.88, and -0.91), respectively, during the two seasons. According to the computed regression coefficient, for two seasons, an increase of one pest per ten leaves would result in a decreased percentage of K (0.01 and 0.01%), Ca content (0.01 and 0.01%), and protein content (0.04 and 0.04%), but an increase in the percentage of N (0.01 and 0.01%) and the percentage of P (0.01 and 0.01%) (Table 4).

Estimates of *B. tabaci* showed highly significant negative correlations with crop characteristics, including number of fruits per plant, mean fresh fruit weight (g), early yield/m² (kg), and total fruit yield/m² (kg). For the two seasons, these correlations were (-0.89, -0.92, -0.87, and -0.80) and (-0.90, -0.93, -0.86, and -0.85), respectively. The mean fresh fruit weight (0.05 and 0.04 g), early yield/m² (0.01 and 0.01 kg), total fruit yield/m² (0.01 and 0.01 kg) for the two seasons, and the number of fruits (0.07 and 0.06 fruits) per plant would all decrease with an increase of one pest per 10 leaves, according to the estimated regression coefficient (Table 4).

Table 4: Simple correlation, regression coefficients, and explained variance estimates between the mean numbers of *B. tabaci* individuals and the measurements of the vegetative growth, necessary nutrients, and resulting yield of the pepper plants over the two growing seasons (2023/2024 and 2024/2025).

Parameters \ Season		First season (2023/2024)				Second season (2024/2025)			
		r	b	E.V.%	P	r	b	E.V.%	P
Vegetative growth	Plant height	-0.97	-0.09	93.59	0.000	-0.97	-0.08	93.58	0.000
	Stem diameter	-0.93	-0.01	86.37	0.001	-0.95	-0.01	89.67	0.000
	No. of leaves/ plant	-0.94	-0.22	88.93	0.000	-0.94	-0.19	89.67	0.000
	No. of branches/ plant	-0.76	-0.02	57.86	0.028	-0.79	-0.01	61.89	0.021
Chemical properties	Plant fresh weight	0.93	1.81	86.82	0.001	0.95	1.46	90.09	0.000
	Dry weight / plant	-0.87	-0.43	76.42	0.005	-0.88	-0.34	77.22	0.004
	Moisture %	0.97	0.09	93.91	0.000	0.97	0.07	93.96	0.000
	Dry matter %	-0.97	-0.09	93.91	0.000	-0.97	-0.07	93.96	0.000
Necessary nutrients	N (%)	0.85	0.01	73.00	0.007	0.92	0.01	85.11	0.001
	P (%)	0.89	0.01	78.38	0.003	0.90	0.01	81.78	0.002
	K (%)	-0.87	-0.01	75.61	0.005	-0.82	0.01	67.95	0.012
	Ca (%)	-0.92	-0.01	83.75	0.001	-0.88	0.01	78.12	0.004
	Protein	-0.85	-0.04	72.33	0.007	-0.91	-0.04	82.72	0.002
Yield characteristics	No. of fruits per plant	-0.89	-0.07	79.70	0.003	-0.90	-0.06	80.68	0.003
	Average fruit fresh weight (g)	-0.92	-0.05	84.99	0.001	-0.93	-0.04	87.05	0.001
	Early yield/ m^2 (kg)	-0.87	-0.01	76.54	0.004	-0.86	-0.01	75.27	0.006
	Total fruit yield/m^2 (kg)	-0.80	-0.01	63.68	0.018	-0.85	-0.01	72.65	0.007

1.1 The damaged leaves' percentage

The percentage of damaged leaves by *B. tabaci* was negatively correlated with vegetative growth characteristics, such as plant height, stem diameter, number of leaves/plants, and number of branches/plants, as indicated in Table (5) and Figure (3). The r values for the 2023/2024 season were -0.98, -0.95, -0.96, and -0.81, while for the 2024/2025 season they were -0.99, -0.97, -0.99, and -0.90. A 1% increase in the percentage of damaged plants would, however, result in a decrease in vegetative growth characteristics, such as plant height (0.35 and 0.65 cm), stem diameter (0.01 and 0.01 cm), number of leaves/plant (0.83 and 1.62 leaves), and number of branches/plant (0.06 and 0.12 branches) for two seasons, respectively, according to the computed regression coefficient (Table 5). In this case, the estimated r values between the percentage of damaged leaves by *B. tabaci* and the chemical properties, such as plant fresh weight and the percentage of moisture, were highly significant positive; they were (+0.91 and +0.98) and (+0.82 and +0.97) during the two seasons, respectively. However, there were also highly significant negative relationships between the percentage of damaged leaves by *B. tabaci* and the dry weight/plant and dry matter, which were (-0.91 and -0.99) and (-0.96 and -0.97), respectively. According to the calculated regression coefficient, in this case, a 1% increase in the percentage of damaged plants would result in a higher fresh weight (6.50 and 10.27 g) and moisture content (0.32 and 0.58%) for the plants, but a lower dry weight (1.63 and 3.08 g) and dry matter content (0.32 and 0.58%) for the plants over the course of the two seasons (Table 5).

Table 5: Simple correlation, regression coefficients, and explained variance estimates between the damaged leaves percentage by *B. tabaci* and the measurements of the vegetative growth, necessary nutrients, and resulting yield of the pepper plants over the two growing seasons (2023/2024 and 2024/2025).

Parameters	Season	First season (2023/2024)				Second season (2024/2025)			
		r	b	E.V.%	P	r	b	E.V.%	P
Vegetative growth	Plant height	-0.98	-0.35	96.82	0.00	-0.99	-0.65	98.66	0.00
	Stem diameter	-0.95	-0.01	89.83	0.00	-0.97	-0.01	94.54	0.00
	No. of leaves/ plant	-0.96	-0.83	92.87	0.00	-0.99	-1.62	97.55	0.00
	No. of branches/ plant	-0.81	-0.06	65.53	0.01	-0.90	-0.12	80.12	0.00
Chemical properties	Plant fresh weight	0.91	6.50	82.34	0.00	0.82	10.27	66.99	0.01
	Dry weight / plant	-0.91	-1.63	82.82	0.00	-0.96	-3.08	92.06	0.00
	Moisture %	0.98	0.32	96.86	0.00	0.97	0.58	94.79	0.00
	Dry matter %	-0.98	-0.32	96.86	0.00	-0.97	-0.58	94.79	0.00
Necessary nutrients	N (%)	0.89	0.02	79.82	0.00	0.97	0.06	94.37	0.00
	P (%)	0.92	0.01	84.25	0.00	0.97	0.01	94.54	0.00
	K (%)	-0.91	-0.01	82.02	0.00	-0.92	-0.03	85.20	0.00
	Ca (%)	-0.90	-0.01	80.18	0.00	-0.83	-0.02	68.69	0.01
	Protein	-0.81	-0.14	65.61	0.01	-0.75	-0.27	56.55	0.03
Yield characteristics	No. of fruits per plant	-0.90	-0.25	81.80	0.00	-0.90	-0.47	80.48	0.00
	Average fruit fresh weight (g)	-0.95	-0.19	90.29	0.00	-0.99	-0.38	97.59	0.00
	Early yield/ m^2 (kg)	-0.91	-0.02	83.15	0.00	-0.97	-0.05	93.19	0.00
	Total fruit yield/m^2 (kg)	-0.84	-0.04	70.83	0.01	-0.92	-0.07	84.17	0.00

Additionally, as shown in Table (5) and Figure (3), the estimated simple correlation values between the percentage of damaged leaves by *B. tabaci* and the necessary nutrients, i.e., the percentages of N and P, were highly significant positive, being (+0.89 and +0.92) and (+0.97 and +0.97) during the two seasons, respectively. However, there were also highly significant negative relationships between the percentage of damaged leaves by *B. tabaci* and the percentages of K & Ca and protein, which were (-0.91, -0.90, and -0.81). According to the computed regression coefficient, for two seasons, a 1% increase in the percentage of damaged plants would result in higher percentages of N (0.02 and 0.06%) and P (0.01 and 0.01%), but lower percentages of K (0.01 and 0.03%), Ca content (0.01 and 0.02%), and protein content (0.14 and 0.27%) (Table 5).

The percentage of damaged leaves by *B. tabaci* also showed highly significant negative correlations with crop characteristics, such as the number of fruits per plant, mean fresh fruit weight (g), early yield/m² (kg), and total fruit yield/m² (kg). These were -0.90, -0.99, -0.97, and -0.92 for the two seasons, respectively. Additionally, according to the estimated regression coefficient, a 1% increase in the percentage of damaged plants would result in a decrease in the mean fresh fruit weight (0.19 and 0.38 g), early yield/m² (0.02 and 0.05 kg), total fruit yield/m² (0.04 and 0.07 kg), and number of fruits (0.25 and 0.47 fruits) per plant for the two seasons, respectively (Table 5). Regression coefficient estimates and simple correlation showed a highly substantial negative association between changes in a particular desired variable and changes in the number of *B. tabaci* individuals and the proportion of damaged plants. A 1% increase in the percentage of injured plants or an increase of one pest per ten pepper leaves would lower all evaluated metrics of pepper plant production, vital nutrients, and vegetative development factors. However, the investigation of the range of physiological and morphological alterations produced by the *B. tabaci* in afflicted pepper plants remains weak. The available data about the response of the investigated vegetative development indices, yield, and their constituents in pepper plants are mostly consistent with Farina *et al*. (2022) [20], who reported that the plant height, stem dry weight, leaf area, and chlorophyll content were significantly reduced in infected tomato plants *by B. tabaci* compared with uninfected control plants by 39.36%, 32.37%, 61.01%, and 37.85%, respectively. Although the percentages of plant height, dry root weight, and chlorophyll content reduction were less pronounced (16.15%, 31.65%, and 11.39%, respectively), the similar outcome was seen for eggplant. According to Li *et al*. (2014), *B. tabaci* really had a variety of effects on a number of commercially significant crops. Along with altering phenological, chemical, growth, and photosynthetic processes (Bhupathi *et al*., 2015). According to Islam *et al*. (2010) [29], *B. tabaci* had a detrimental effect on eggplant development characteristics, reducing plant height by up to 20.6%. According to Abubakar *et al*. (2022) [2], *B. tabaci* immature and mature stages both suck sap and release honeydew, or sugary secretions, while feeding, which encourages the formation of sooty mold on leaves and fruits and reduces crop yields. According to Khan *et al*. (2018) [33], infected plants exhibit yellowing, stunted leaves, slowed growth, and distorted fruits. During feeding, *B. tabaci* nymphs inject enzymes that change crop physiology, resulting in aberrant fruit ripening and reduced internal pigmentation (Smith, 2009) [46]. According to Hasanuzzaman *et al*. (2016) [23], the *B. tabaci* caused four nymphs per leaf and one adult per tray of economic damage to tomatoes. By decreasing the plant's resilience, herbivorous insects are more likely to infest and harm crops when there is a higher nitrogen level in the plant (Horgan *et al*., 2021) [25]. Through nitrogen fertilization, herbivorous insects can distinguish between plants receiving varying amounts of nitrogen, and herbivorous insects are directly impacted by the nutritional content and defenses of plants (Chen *et al*., 2008) [16]. Bi *et al*. (2003) found that the number of adult and juvenile whiteflies that appeared at their peak population positively correlated with nitrogen application rates. According to Ahmed *et al*. (2007) [4], the average number of whiteflies per leaf increased with the greatest nitrogen rates.

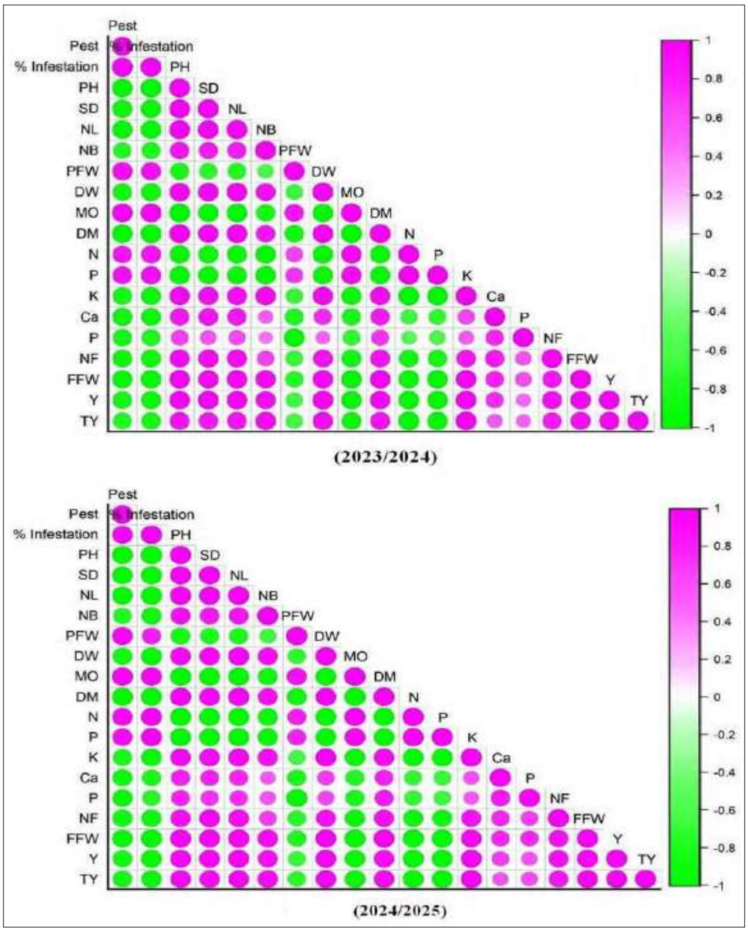


Fig. 2: The correlation estimates between the mean numbers of *B. tabaci* individuals & damaged plant percentage and the measurements of vegetative growth, necessary nutrients, and resulting yield of the pepper plants over the two growing seasons (2023/2024 and 2024/2025).



Conclusion

In order to offer fundamental data for a research framework intended to forecast the growth and development of pepper plants under pest pressure, the impact of *B. tabaci* on vegetative growth features, critical nutrients, and productivity was assessed in this study. In order to build a practical pest control strategy, research along these lines might assist in clarifying the causes of the two-season variation in the effect of the necessary nutrients in pepper leaves on the populations of *B. tabaci*.

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