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Research Article

Effect of Whitefly (*Bemisia tabaci* Genn.) Infestation on the Growth Parameters of Eggplant (*Solanum melongena* L.) in Kebbi State, Nigeria

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Abstract

Whiteflies (*Bemisia tabaci* Genn.) are aggressive hemipteran species that depend primarily on leaf tissue for their nourishment, causing substantial damages and yield losses in their hosts. This study was carried out to assess the effect of whitefly infestation on the growth parameters of one of the commercial eggplant cultivars (round green *Solanum melongena* L) under filed conditions. The trial consists of four treatments (T_1= 15, T_2= 30, T_3= 45 and control (T_4) = 0 whiteflies/plot) replicated four times. The result revealed that all the parameters assessed are negatively affected by whitefly infestation with plants in treatment (T_3) being most affected while those in T_1 are least affected. The dry weight recorded least value (1.1 g/leaf) having the highest percentage reduction (69.11%) followed by leaf area with 152.5cm^2 (48.83% reduction) while the number of leaves was least affected recording 50.3 leaves/plant (18.09% reduction) at 90 days after infestation in 2022 experiment. In 2023 experiment, similar results were recorded with plants in T_3 being most affected. Dry weight of the leaves had the lowest value (1.3g/leaf) representing the highest reduction (68.30%) followed by the leaf area with 167.3cm^2 (44.8% reduction) with the number of leaves also being least affected, recording 52.1 leaves/plant representing 9.40% reduction with plants in treatment T_1, at 90 days after infestation. The highest reduction in yield was also recorded with plants in T_3 (92.10, 90.10%) while the least was observed in T_1 (86.8 and 85.70%) for the respective trials (2022 and 2023). The result shows the level of susceptibility of the variety examined to whitefly infestation, demonstrating the urgent needs for the development of eco-friendly and sustainable whitefly management regimes for improved eggplant production in the area.

More Information

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Introduction

Eggplant (*Solanum melongena* L.; family solanaceae) is among the most popularly grown vegetables universally [1-3]. It is a rich source of nutrients and other substances that are beneficial to human health, which explains in part why it has a high variety of species utilized for food or medication. Numerous phytonutrients are found in eggplant, including hydroxycinnamic acid (HCA) conjugates, which have a major role in consumer well-being, fruit flavor, and texture [2,4,5]. Additionally, eggplant has been utilized in traditional medicine to cure a variety of illnesses. For instance, in areas of Asia, the vegetal aerial portions of this plant have historically been used to cure skin conditions and as a purgative, to facilitate urination [4,6,7].

Morphologically, the stem of eggplant is simple, long, and flat with branches while the leaves are coarsely lobed with green color that are placed alternatively on the branches. The leaves may be 10 cm - 20 cm (4– 8 in) long and 5 cm - 10 cm (2–4 in) wide. Purple blooms that are 3–5 cm (1.2–2.0 in) in diameter are produced by the crop [8-10]. The fruits are huge, fleshy ovoid berries having shiny soft skin with many seeds that may grow to a height of 40 cm (15.7 in) long [11,12]. The color of the fruit varies and might be white, green, yellow, purple, or black. Eggplants may grow to a height of 1.5 m (4.9 ft.) [13,14]. Although they are perennial crops, they are most often planted as annuals [9,10,15]. Taxonomically, eggplant is a little-known monophyletic group (the eggplant clade) comprising mostly of andromonoecious species within the vast and varied Leptostemonum clade of the Solanum genus (previously referred to as subgenus Leptostemonum Bitter).

In the species-rich genus Solanum, the Leptostemonum clade (also known as the spiny solanum) consists of more than 500 species that can be found across all continents except Antarctica, making it the most diversified monophyletic group in the genus [16,17].

The production of eggplants is constrained by a number of biotic and abiotic factors, hindering the potential of the crop globally [18,19]. This is due to the fact that most of the cultivated genotypes lacked sufficient tolerance levels to the biotic and abiotic stresses [18,20-23]. Fluctuation in temperature [24,25], salinity [26,27], drought [7,28,29], waterlogging [30,31], and heavy metal concentrations [32] are among the abiotic factors affecting eggplant cultivation worldwide. Similarly, several biotic factors including pathogenic organisms such as fungi [33], bacteria [34,35], viruses [36,37] and insect pests (aphids, colorado potato beetles, shoot and fruit borer, thrips, spotted beetles, leafhoper, stem borer, blister beetles, spider mites and whiteflies also affect the production potential of this vegetable [38].

Whiteflies are polyphagous devastating insect pests with a universal presence on different vegetable crops including tomato, cassava, peppers, sweet potato, squash, melons, lettuce, cucumber, beans, eggplant, okra, and watermelon [39-42]. Both young (nymphs) and adult whiteflies cause direct feeding damage by piercing and sucking sap from the leaves of their host (Gangwar, et al. 2018; Abubakar, et al. 2022). This leads to early wilting and weakening of the plant. It also causes leaf chlorosis, crumbling, withering, drop off of leaves, and death of young seedlings [14,40,42]. Whiteflies feeding also leads to leaf mosaic and wrinkling, which cause stunting and disfigured fruits [40].

They also cause indirect damage to their hosts by the release and accumulation of large amounts of sugary excreta (honeydew) that promote sooty mold development on the foliage and fruits, leading to adverse effects on crop productivity [43,44]. Sooty mold turns the leaves black, decreases the rate of photosynthesis, and affects plant vigor and consequently the quantity and quality of farm produce [43-45]. For instance, the chlorophyll content and photosynthetic activities were reported to be negatively affected and reduced by 9.7% and 65.9% respectively [46]. This will in turn affect the growth parameters such as plant height, leaf size, and weight as well as the quality and quantity of the farm produce [43,44] thereby reducing the market value of the crop or even make them unmarketable Ghosh 2022; Abubakar, et al. 2023 [13,14].

Whitefly was also known to vector more than 350 species of various plants [36,37]. Eggplant, tomato, potato, and soybean have been reported to be susceptible to such viruses (Kedar, et al. 2014). Begomoviruses are the primary cause of crop-reduced productivity, extending from 20% – 100% losses in crop yield worth millions of dollars (Gangwar, et al. 2018). Eggplant mild leaf mottle virus (EMLMV) (lapidot, et al. 2014), Tomato torado virus (ToTV) (Amari, et al. 2017), Tomato chlorosis virus (ToCV) and Tomato yellow leaf curl virus (TYLCV) which are vectored by whiteflies and frequently seen in tomatoes also affect eggplants (Fidan and sarikaya 2020). In a nutshell, whiteflies are among the common destructive agricultural pests, affecting various vegetables and other food crops characterized by both primary and secondary effects causing crop losses of up to 100% (Barkman 2013; Singh and Aggarwal 2023). The significant damage caused by whiteflies in different crop plants has rendered them major pests that lead to an increase in the application of chemical pesticides, which are well-known to be harmful to human health and the ecosystem [47,48].

Understanding the level of damage by these vectors will enhance the development and deployment of different control measures in an attempt to manage their devastating effects on different vegetables. This could also improve our capacity to predict plant growth under whitefly infestation by giving a better understanding of the alterations to the morphological parameters of eggplants due to whitefly infestation. Thus, this study aimed to assess the extent of damage caused by whitefly infestation on eggplant growth parameters on the most cultivated cultivar of eggplant (green round variety) in Kebbi State, North Western Nigeria.

Materials and methods

Study area

The study was conducted in an Agricultural research farm of the Kebbi State University of Science and Technology, Aliero, Kebbi State, Nigeria. The area is on the latitude 12° 13' 19.88" N, longitude of 4° 22' 46.67'E." The area has dry and wet seasons. The wet season begins in May and extends to late September while the dry season lasts from October to May. The mean annual rainfall and temperature are 500 mm and 31 °C respectively. Most of the occupants in the area are farmers cultivating different food and vegetable crops for their sustenance [49,50].

Plant culture and insect collection

The experiment was conducted using one of the commercial eggplant cultivars (green round variety), being the most cultivated variety by the farmers in the area. The seeds were procured from Afrimash Company Limited, Ibadan, Nigeria, and used in raising the seedlings for the experiment. A portable nursery bed (1x3m) was prepared, organic fertilizer was added and seeds were broadcasted, slightly covered with the soil, and organic mulches were added to preserve the bed's moisture and protect the young seedlings from excessive heat and birds. The seedlings were transplanted five weeks after planting when they developed five to six leaves. The insects used for the study (*Bemisia tabaci* Gennundus) were collected from the vegetables (watermelon, eggplants, and tomatoes) at the research farm of Kebbi State University of Science and Technology, Aliero, kebbi State, Nigeria using aspirators. The required number of whiteflies for each plot (15, 30, 45, and 0 whiteflies/plot) were counted as they were being caught from the field and they were released gently by slightly shaking the aspirator at the lower surface of the eggplant leaves.

Experimental design

To determine the level of damage by whiteflies on eggplant, indoor and open field trials were conducted. The field experiment was a randomized block design (RBD) with four treatments replicated four times. Each experimental plot (block) has four rows (covered with mosquito nets), 8 m long with 0.5 m space between the rows. In each plot, different quantities of adult whiteflies (15, 30, 45, and 0 whiteflies) were counted and released [29]. Each plot was transplanted with eggplant seedlings and demarcated with 1x1m^2 mosquito nets for damage assessment. The seedlings were transplanted in the experimental plots at 60x60 cm and the recommended agronomic practices which include irrigation, weeding, and fertilizer application were provided uniformly in all the plots throughout the trial.

Parameters recorded for damage assessment

The plant growth parameters were recorded from the experimental field after the release of whiteflies on eggplant at an interval of 30 days (approximate time for a single whitefly's life cycle) throughout the plant growth period. The trial consists of four plots and four treatments (T_1 = 15 whiteflies/plot, T_2 = 30 whiteflies/plot T_3 = 45 whiteflies/ plot, and T_4 = control, with 0 whiteflies/plots) replicated four times. The parameters recorded were plant height (cm) using a measuring tape, leaf area (cm^2) using the formula, F (L x W) (F = constant factor, L = leaf length and W = width of the leaf), fresh weight of the eggplant leaves, dry weight (g) of the leaves using digital weighing device (M-METLAR digital balance) and number of leaves/plant. After determining the fresh weight of the leaves, they were sun-dried and their dry weights were weighed using the digital weighing device (M-METLAR digital balance) [51]. Then the dry matter (DM) in percentage (%) was determined using the formula: DM (%) = final dry weight (g)/initial wet weight (g) x 100. Plant yield per plot (g/plot) of the eggplant under study was then determined at harvest during the respective experiments (2022 and 2023), considering the weights of the fruits taken from the 3 respective plants in each of the experimental plots. The reduction (%) per each plant-growth parameter (plant height, leaf area, the number of leaves, fresh and dry weights of the leaves, etc) was determined using the following equation: Reduction (%) = (control – infested)/control x100 [52,53].

Data analysis

The data were collected in each plot by randomly selecting three leaves from each plant from the upper, middle, and lower regions of the plants. Analysis of variance (ANOVA) was used for data analysis using Statistical Tool for Agricultural Research (STAR version 2.0.1) and means were separated using least significant difference (LSD) at a 5% level of significance.

Results

Effects of whitefly infestation on the eggplant growth parameters

Effect of whitefly infestation on the plant height (cm): Table 1 presents the results of whitefly feeding effects on the plant height in the two consecutive cropping periods (2022 and 2023) in a field experiment. The treatments differed significantly from each other and from the untreated control (p < 5%) in most of the data recording periods during the two cropping seasons. In 2022, the treatments were similar (p = 0.705) at 48 h after infestation, with plant height being highest in T_4 (14.7 cm), followed by T_2 (14.3 cm) while the least was recorded in T_3 (13.7 cm). The plant height was also highest in T_4 (36.2, 51.0, and 69.0 cm) and lowest in T_3 (24.8, 41.9, and 44.7 cm) at 30, 60, and 90 days respectively as the treatments differed significantly (p = 0.001, 0.026 and 0.0001) during the respective periods. In 2023, the treatments were statistically similar at 48 h (p = 0.967) and 30 days (p = 0.063) after infestations. Plants in T_1 had the highest plant height (14.7 and 31.4 cm) during the respective periods. The results, however, differed significantly at 60 (p = 0.018) and 90 (p < 0.0001) days after infestation. Plants in T_3 were more affected (39.1 and 41.2 cm) while those in T_1 were least affected (45.7 and 47.2 cm) as compared to the control group(49.8 and 67.4 cm) at 60 and 90 days respectively (Table 1).

Effect of whitefly infestation on the number of leaves: The effect of whitely feeding on the number of leaves is shown in Table 2. In 2022, There is no significant difference between all the treatments at 48 h (P = 0.402) and 60 days (p = 0.145) after infestation. Plants in T_1 and the control group had the highest number of leaves (5.3 leaves/plant each) while those in T_3 had the lowest (4.3 leaves/plant) at 48 h after infestation. At 30 days, Plants in T_3 were most affected (7.8 leaves/plant) as they differed significantly (p = 0.004) from the remaining treatments. A similar result was recorded at 90 days, with plants in T_3 being more affected (40.3 leaves/plant) differing significantly (p < 0.0001) from all the treatments including the control (61.5 leaves/plant) during the 2022 trial. In 2023, the treatments had similar effects at 48 h (p = 0.197), but differed significantly at 30 days (p = 0.002) with plants in T_2 being more affected (8.6 leaves/plant), followed by those in T_3 (9.4 leaves/plant) while those inT_1 wereleast affected (10.3 leaves/ plant) as compared to the control (T_4)with 12.5 leaves/plant. The result also differed significantly at 60 (p = 0.044) and 90 (p < 0.0001) days with plants in T_3 being more affected with 37.7 and 39.5 leaves/plant while those in T_1 were the least affected with 43.4 and 52.1 leaves/plant (Table 2).

Table 1: Effect of whitefly infestation on the plant height.

Treatments	Data record periods							
	2022				2023			
	48HAI	30DAI	60DAI	90DAI	48HAI	30DAI	60DAI	90DAI
T_1	13.9a	31.1b	44.9b	49.4b	14.7a	31.4a	45.7ab	47.2b
T_2	14.2a	27.5c	43.4b	47.6b	13.9a	28.5a	42.7bc	43.6bc
T_3	13.7a	24.8c	41.9b	44.7b	14.5a	25.4a	39.1b	42.2c
T_4	14.7a	36.2a	51.0a	69.0a	14.4a	34.7a	49.8a	67.4a
C.D.	0.0	3.0	5.8	7.3	0.0	0.0	6.2	9.9
SEM±	0.6	1.2	2.5	3.2	1.7	3.0	2.7	2.1
C.V. (%)	8.4	6.2	8.0	8.5	16.9	14.2	8.6	6.0
p - value (5%)	0.705	0.001	0.026	0.0001	0.967	0.063	0.018	< 0.0001

Means with the same common letter in the same column are not significantly different from each other ($p < 0.05$. C.D: Critical Difference; C.V: Coeficient of Variance; SEM: Standard Error Means; HAI: Hours after Infestation; DAI: Days after Infestation; T: Treatment ($T_1 = 15$, $T_2 = 30$, $T_3 = 45$ and T_4 = (control) = 0 whiteflies/plot).

Table 2: Whitefly infestation effect on the number of leaves.

Treatments	Data record periods							
	2022				2023			
	48HAI	30DAI	60DAI	90DAI	48HAI	30DAI	60DAI	90DAI
T_1	5.3a	9.4ab	44.3a	50.3b	5.5a	10.3b	43.4ab	52.1^{b}
T_2	4.8a	8.6bc	38.9a	46.2b	5.0a	8.6c	40.9b	45.9^{c}
T_3	4.3a	7.8b	39.9a	40.3c	6.1a	9.4bc	37.7b	39.5^{d}
T_4	5.3a	10.6a	46.0a	61.5a	5.5a	12.5a	48.2a	57.5^{a}
C.D.	0.0	3.0	0.0	4.55	0.0	3.2	7.12	3.52
SEM±	0.5	0.6	3.2	2.0	0.3	0.7	3.1	1.5
C.V. (%)	15.6	8.7	10.5	5.7	11.1	9.9	10.2	4.5
p - value (5%)	0.402	0.004	0.145	< 0.0001	0.197	0.002	0.044	< 0.0001

Means with the same common letter in the same column are not significantly different from each other ($p < 0.05$. C.D: Critical Difference; C.V: Coefficient of Variance; SEM: Standard Error Means; HAI: Hours After Infestation; DAI: Days After Infestation; T: Treatment ($T_1 = 15$, $T_2 = 30$, $T_3 = 45$ and T_4 = (control) = 0 whiteflies/plot).

Table 3: Whitefly infestation effect on the leaf area of eggplant.

Treatments	Data periods							
	2022				2023			
	48HAI	30DAI	60DAI	90DAI	48HAI	30DAI	60DAI	90DAI
T_1	20.9a	93.4b	200.6b	226.3b	22.3a	90.8b	212.7b	220.6b
T_2	21.6a	78.6bc	170.6c	215.9b	23.6a	84.7b	177.9c	206.6c
T_3	20.2a	76.2c	157.7d	162.5c	21.2a	78.6b	160.6d	167.3d
T_4	22.7a	125.6a	230.7a	317.6a	21.3a	120.2a	227.2a	303.5a
C.D.	0.0	16.9	11.97	11.31	0.0	14.3	8.34	11.31
SEM±	1.3	7.4	5.2	3.9	1.5	6.2	3.6	4.9
C.V. (%)	8.6	11.1	3.9	3.0	9.7	9.4	2.6	3.1
p - value (5%)	0.337	0.0003	< 0.0001	< 0.0001	0.391	0.0004	< 0.0001	< 0.0001

Means with the same common letter in the same column are not significantly different from each other ($p < 0.05$. C.D: Critical Difference; C.V: Coefficient of Variance; SEM: Standard Error Means; HAI: Hours After Infestation; DAI: Days After Infestation, T: Treatment ($T_1 = 15$, $T_2 = 30$, $T_3 = 45$ and T_4 = (control) = 0 whiteflies/plot).

Effect of whitefly infestation on the leaf area (cm^2): Table 3 presents the result of the whitefly feeding effect on the leaf area of eggplant. The results revealed that at 48 h, the treatments were statistically similar ($p = 0.337$) to each other including the control in the 2022 trial. Plants in T_3 had the least leaf area (20.2 cm^2) while those in T_2 recorded the highest (21.6 cm^2) as compared to the control (T_4) (22.7 cm^2). The result differed significantly at 30 ($p = 0.0003$), 60 ($p < 0.0001$), and 90 ($p < 0.0001$) days, with plants in T_3 being more affected with 76.2, 157.7, and 162.5 cm^2 respectively. Similar results were found in 2023, as there is no significant difference between the treatments at 48 h ($p = 0.391$). The results differed significantly difference at 30 ($p < 0.0004$), 60 ($p < 0.0001$), and 90 ($p < 0.0001$) days during the experiment. Plants in T_3 had less leaf area on the 30^{th}, 60^{th}, and 90^{th} day (78.6, 160.6, and 167.3 cm^2) as compared to the control group with 120.2, 227.2, and 303.5 respectively during the 2023 trial (Table 3).

Effect of whitefly infestation on the fresh weight of leaves (g): Whitefly infestation also affects the leaf's fresh weight as presented in Table 4. In 2022, the effect was similar ($p = 0.249$) with all the treatments at 48 h, with T_1 recording the higher fresh weight value (6.2g), followed by T_4 (5.3g) while T_3 has the least (3.8g). The results differed significantly between the treatments at 30 ($p = 0.002$), 60 ($p = 0.043$), and 90 ($p = 0.001$) days after infestation. Plants in T_3 had the

Table 4: Fresh weight (g) of leaves and whitefly infestation effect.

Treatments	Data record periods							
	2022				2023			
	48HAI	30DAI	60DAI	90DAI	48HAI	30DAI	60DAI	90DAI
T_1	6.2a	6.9b	16.1b	14.6b	5.4a	7.8b	15.2b	17.1b
T_2	4.0a	6.7b	16.7ab	14.9b	4.6a	6.7b	13.9c	13.9b
T_3	4.0a	5.4b	14.5b	13.9b	5.3a	5.7c	12.9c	12.6b
T_4	5.3a	9.2a	19.4a	24.9a	5.5a	9.9a	17.3a	22.4a
C.D.	0.0	1.5	3.2	4.4	0.0	1.0	1.5	5.2
SEM±	0.8	0.6	1.4	1.9	0.7	0.5	1.5	2.3
C.V. (%)	25.1	13.0	11.9	15.9	19.7	8.6	14.2	19.5
p - value (5%)	0.249	0.002	0.043	0.001	0.660	< 0.0001	0.007	0.009

This means that the same common letters in the same column are not significantly different from each other ($p < 0.05$). C.D: Critical Difference; C.V: Coefficient of Variance; SEM: Standard Error Means; HAI: Hours After Infestation; DAI: Days After Infestation; T: Treatment (T_1 = 15, T_2 = 30, T_3 = 45 and T_4 = (control) = 0 whiteflies/plot).

least fresh weight (5.4, 13.5, and 13.9g) with those in T_1 and T_2 having the highest (6.9, 16.7, and 14.9 g) as compared to the control with 9.2, 19.4 and 24.9 g respectively. In 2023, the results differed significantly between the treatments (T_1-T_4) in all the data-taking periods except at 48 h after infestations. Plants in T_3 also had the least fresh weight values (5.7, 12.9, and 12.6 g) on the 30th, 60th, and 90th day respectively while those in T had the least (7.8, 15.2, and 17.1 g), as compared to the control with 9.9, 17.3 and 22.4g respectively during 2023 experiment(Table 4).

Effect of whitefly infestation on the leaf dry weight (g): The results on dry weight showed that the control plots have greater dry weight values at all the data record periods with 0.4, 0.9, 2.8, and 3.5g and 0.5, 0.9, 2.7, and 4.1g during the 2022 and 2023 experiments. The least dry weight values were recorded in T_1 and T_2 (0.3g at 48 h), T_3 (0.6g at 30 days), T_1 and T_2 (1.5g each at 60 days), and T_3 (1.1 g at 90 days) in 2022. In 2023, similar results were recorded with T_3 having the least dry weight (0.5, 1.6, and 1.3g) at 30, 60, and 90 days respectively. There is a significant difference between the treatments in all the data-taking periods ($p < 0.05$) during the respective experiments. However, no significant difference was observed at 48 h in 2022 and 2023, and at 30 days after infestation in the 2022 trial (Table 5).

Effect of whitefly infestation on the dry matter (%): The dry matter (%) was also affected by whitefly feeding as presented in Table 6. In the 2022 trial, the results showed that the treatments were at 48 h ($p = 0.182$) and 30 ($p = 0.625$) days after infestation. The highest effect was recorded in T_2 having less dry matter (5.9%) while the least effect was found in T_3 (9.7%) at 48 h after infestation. At 30 days, T_1 had the lowest dry matter (9.1%) with T_2 having higher (11.4%) than the control (T_4) (10.3%). The result differed significantly at 60 ($p = 0.007$) and 90 ($p = 0.023$) days, with T_2 and T_3 being more affected at 60 (9.0%) and 90 (8.0%) days with plants in T_1 being less affected (11.2 and 11.3%). In 2023, no significant difference was observed between the treatments at 48 h ($p = 0.564$) and 30 days ($p = 0.296$) after infestation. At 60 and 90 days, plants in T_3 were most affected with 7.9 and 7.3% respectively, as the treatments differed significantly ($p = 0.049$ and 0.002) with plants in T_1 being less affected with 10.7 and 11.2% respectively (Table 6).

Plant yield (kg/ha)

The infestation by whiteflies also affects the crop yield in both the field and pot experiments. The highest yield (563.3 and 556.6kg/ha) was recorded in the control plots (T_4) while the least was found in T_3 (44.6 and 55.1 kg/ha) during 2022 and 2023 experiments under field conditions. The results differed significantly ($p < 0.0001$) between the control and treated plots in the 2022 trial. Similar results were recorded in 2023, with T_4 differing significantly ($p < 0.0001$) from all the treated plots. However, T_2 and T_3 were statistically similar with respect to yield at harvest during the 2023 cropping season (Table 7).

Table 5: Effect of whitefly infestation on the plant dry weight.

Treatments	Data record periods							
	2022				2023			
	48HAI	30DAI	60DAI	90DAI	48HAI	30DAI	60DAI	90DAI
T_1	0.3a	0.7a	1.7b	1.7b	0.3a	0.6a	2.0b	1.8b
T_2	0.3a	0.7a	1.5b	1.3bc	0.4a	0.6b	1.8b	1.6b
T_3	0.4a	0.6a	1.5b	1.1c	0.3a	0.5b	1.6b	1.3b
T_4	0.4a	0.9a	2.8a	3.5a	0.5a	0.9a	2.7a	4.1a
C.D.	0.0	0.0	0.5	0.5	0.0	0.3	0.5	0.8
SEM±	0.1	0.1	0.2	0.2	0.1	0.1	0.2	0.3
C.V. (%)	18.3	20.7	17.9	17.3	26.9	24.8	16.3	22.0
p - value (5%)	0.110	0.102	0.001	< 0.0001	0.211	0.049	0.005	0.0001

This means that the same common letters in the same column are not significantly different from each other ($p < 0.05$). C.D: Critical Difference; C.V: Coefficient of Variance; SEM: Standard Error Means; HAI: Hours After Infestation; DAI: Days After Infestation; T: Treatment (T_1 = 15, T_2 = 30, T_3 = 45 and T_4 = (control) = 0 whiteflies/plot).

Table 6: Effect of whitefly feeding on the plant dry matter (%).

Treatments	Data record periods							
	2022				2023			
	48HAI	30DAI	60DAI	90DAI	48HAI	30DAI	60DAI	90DAI
T_1	6.3a	9.1a	11.2ab	11.3ab	6.1a	8.1a	10.7ab	11.2b
T_2	5.9a	11.4a	9.0c	8.9b	6.2a	9.2a	9.4ab	8.1bc
T_3	9.7a	10.1a	10.1bc	8.0b	7.1a	7.7a	7.9b	7.3c
T_4	10.9a	10.3a	13.3a	14.1a	8.4a	9.8a	12.2a	15.6a
C.D.	0.0	0.0	3.9	4.0	0.0	0.0	2.3	3.7
SEM±	2.5	1.7	1.0	1.7	1.8	0.8	1.3	1.6
C.V. (%)	42.9	23.4	12.2	12.7	36.9	18.5	18.8	21.5
p - value (5%)	0.182	0.625	0.007	0.023	0.564	0.296	0.049	0.002

This means that the same common letters in the same column are not significantly different from each other ($p < 0.05$). C.D: Critical Difference; C.V: Coefficient of Variance; SEM: Standard Error Means; HAI: Hours After Infestation; DAI: Days After Infestation; T: Treatment (T_1 = 15, T_2 = 30, T_3 = 45 and T_4 = (control) = 0 whiteflies/plot).

Table 7: Plant yield (kg/ha) during the 2022 and 2023 experiments.

Treatments	Yield (kg/ha) 2022	Yield (kg/ha)2023
T_1	74.2b	79.4b
T_2	61.3c	61.0c
T_3	44.6d	55.1c
T_4	563.3a	556.6a
C.D.	12.5	17.6
SEM±	3.8	7.7
C.V. (%)	2.6	3.6
p - value (5%)	< 0.0001	< 0.0001

This means that the same common letters in the same column are not significantly different from each other ($p < 0.05$). C.D: Critical Difference; C.V: Coefficient of Variance; SEM: Standard Error Mean; g: gram; T: Treatment (T_1 = 15, T_2 = 30, T_3 = 45 and T_4 = (control) = 0 whiteflies/plot).

Discussions and conclusions

The current findings demonstrate that whitefly feeding negatively affects the leaf morphology of eggplant, leading to the development of diverse symptoms, which consequently affect the entire growth parameters and yield of the crop cultivar examined. These effects were observed to be gradual with leaf yellowing/mosaic being the early symptoms observed while honeydew deposition, dehydration, and leaf darkening were the later symptoms observed on the leaves during the experiments. The combined effects culminated in serious disorder on the plants which led to severe leaf damage and almost entire crop destruction. It was observed that plants in T_3 were most affected in most of the data-taking periods with those in T_1 being the least affected while those in the control plots (T_4) remained healthy throughout the trial periods. This signified that the effects observed were whitefly density-dependent as the plots with high whitefly populations were the most affected. The effects of whitefly infestation on the growth parameters of eggplant such as plant height, number of leaves, leaf area, leaf fresh and dry weight, as well as dry matter showed that the control plots recorded no damages in most of the parameters compared to the infested plants at all the data record periods. The highest reduction (%) in plant heights in both the field and pot trials was recorded in T_3, which has the highest whitefly density/plant, at 90 days after infestation during the 2022 and 2023 cropping seasons. This indicates the influence of a longer infestation period and larger whitely density in causing damage to the eggplant variety examined. The result in the current research was higher than that reported by Farina, et al. [53] with (16.15%), Islam, et al. (2010) (20.6%), and Li, et al. [54] (32.7%) reductions in the plant height 21 days after infestation. The differences may be due to variations in infestation periods and the variety under study. Based on the result obtained, the number of leaves has been negatively affected with the highest reduction recorded at 90 days after infestation with the control plots (T_4) having the highest number of leaves/plants compared to the treated plots in the respective trials. Whitefly feeding also affects the leaf area of eggplant as recorded during the experiments. The control plots recorded the highest leaf area while that of plants in T_3 was reduced by up to 48.8 to 70.6% in the respective experiments. This indicates the significance of whitefly presence on eggplant leaves as it led to reduced surface area, which affects the light energy absorption, thereby affecting photosynthetic rate and crop yield. Previous studies reported similar results describing the negative effects of whitefly feeding on the leaf area of eggplant [46,53] reporting 26.6%, 12.7%, and 61.01% leaf area reduction respectively. This may be due to the fact that sap-sucking by the *Bemisia tabaci* induces leaf chlorosis, and leaf folding/distortion which is negatively associated with the crop photosynthetic activities and thus affects the entire growth parameters [54]. Moreover, due to sap suction by whiteflies, fresh and dry weights of eggplant leaves were negatively affected. The fresh weight was reduced by about 43.9 during the experiments. The dry weights were also reduced by 69.1 and 70.6% in the field and pot trials respectively. A lower reduction (%) in the fresh and dry weights (21.8 and 19.3%) was reported in the previous works [46,51] for one whitefly life cycle (21 days) after infestation. The higher reduction (%) in the current finding might be due to variations in the infestation period covering about three whitefly life cycles. The current findings are however, in contrast with what has been reported by Farina, et al. [53], who stated that the dry weight of eggplant is not affected by the presence of the whiteflies, and this could be related to the lower whitefly density and duration of their experiment.

The repetitive growth analysis during the experiments revealed that the growth parameters in whitefly-infested eggplants were lower than those of control plants. The effect on these parameters indicates the possibility of nutrient stress, revealing the detrimental effect of whitefly infestation on chlorophyll content and the photosynthetic rate of the crop [52,54], which consequently suppressed plant growth capacity in various crop plants. Feeding by adult and nymph whiteflies has been proven to cause leaf damage, and reduce the chlorophyll content and photosynthetic capacity in tomatoes (*Lycopersicum esculentum* Mill) [55]. This a similar to the report by Jimenez, et al. [56] who stated that feeding by whitefly(*B. tabaci* biotype A) has led to leaf chlorosis and decreased chlorophyll content in squash plants (*Cucurbita pepo* L.). Moreover, Islam and Shunxiang [46] reported a significant reduction of about 9.7% and 65.9% in the chlorophyll content and photosynthesis rate in eggplant due to infestation by *B. tabaci*. Contextually, the eggs deposited on the leaves by female whiteflies significantly reduced the stomata conductance, as they covered the stomata and reduced their access to sunlight as well as carbon dioxide which are required for photosynthesis [57]. Schutze, et al. [58] also reported a significant reduction in the grain weight and loss in protein contents in the whitefly-infested soybeans. Similar reports [59,60] proved that up to 35% and 45% of the squash and snap beans were lost due to whitefly infestation. The effects of whitefly infestation are thus of great economic importance as it affects the morphological and physiological features of different vegetables including eggplant. This necessitated the need for developing and deploying safe, cost-effective management strategies for sustainable eggplant cultivation.

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