Vegetative Behavior of Brinjal in Response to Different Nitrogen Supply in Hydroponics

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Abstract: Hydroponics represents an innovative technology for cultivating plants in nutrient solutions without soil. An experiment was conducted to investigate the growth of brinjal (*Solanum melongena* L.) under hydroponic conditions using a modified Cooper's solution. The study was conducted in the Department of Horticulture at the Faculty of Agriculture, Patuakhali Science and Technology University, Patuakhali, Bangladesh. Various concentrations of nitrogen (N) nutrients (25%, 50%, 75%, 100% and 125%), based on the modified Cooper's solution, were examined in the experiment. Among the different nitrogen (N) nutrient concentrations tested, plants cultivated with 100% of N (N4) from Cooper's solution (200 mgL^{-1} N) exhibited significantly greater plant height (27.33 cm), leaf area (284.3 cm^2), stem diameter (8.33 mm), fresh weight of shoot (119.57 g) and root (48.33), dry weight of shoot (17.90 g) and root (6.80 g), and a shorter time to flower induction (48.66 days).

Keywords: Brinjal, hydroponics, growth, Cooper's solution

Introduction

Bangladesh holds a prominent position as one of the major horticultural countries in South Asia (Ali, 2000). Agriculture, including horticulture, stands out as the largest single sector of the economy, contributing to approximately 13 percent of the country's GDP (BER, 2006). In 2022, the total value of horticultural crop production in Bangladesh reached 18,818 million taka (BBS, 2022). Brinjal (*Solanum melongena* L.) is a significant vegetable renowned for its commercial and nutritional value, both globally and within Bangladesh. According to Sowinska and Krygier (2013), brinjals are characterized by their low-calorie content and high nutritional value. Global brinjal production was estimated at 52,309,119 tons in 2017 (FAO, 2017). Brinjal holds a special place as one of the most important vegetables in Bangladesh, offering a wide range of nutritional benefits. Also known as eggplant, brinjal holds the second spot in the hierarchy of essential vegetables cultivated in Bangladesh. It is grown by approximately 150,000 resource-poor farmers across 34,973 hectares (BBS, 2020), contributing to a total production of 619,000 metric tons (BBS, 2023). Brinjal's significance is further underscored by its respective contributions of 4.7% and 9.6% to all winter and summer vegetable production (BBS, 2018).

Brinjal is cultivated across almost all agro-climatic zones, featuring an assortment of over 100 different varieties that yield fruits in diverse colors, sizes, shapes, and tastes. Despite its versatility, this crop encounters a substantial challenge in the form of insect infestations, primarily caused by the brinjal shoot and fruit borer (BSFB). These infestations lead to yield losses ranging from 30 to 60%, even with frequent insecticide applications throughout the crop's 4–5 month growing season (Mondal and Akter, 2018). In the major cultivation areas of Bangladesh, brinjal fields undergo an exceptionally high frequency of insecticide spraying, exceeding 80 times per season (Meherunnahar and Paul, 2009). The incessant use of insecticides brings about concerning consequences, including heightened pesticide residue levels on the fruit, the depletion of beneficial insects, increased risks for farm workers, and environmental pollution (Rahman, 2013). Brinjal, as a globally significant vegetable crop, faces common production challenges such as flooding, drought, salinity, plant parasitic nematodes, and soil-borne diseases (Keatinge et al., 2014). Additionally, traditional soil-based brinjal cultivation requires substantial quantities of various fertilizers. In light of these challenges, hydroponic cultivation emerges as a promising solution. Hydroponics represents a soilless cultivation system thriving within a controlled environment, effectively circumventing the aforementioned issues. Hydroponics involves cultivating plants by suspending their roots in a liquid nutrient solution instead of traditional soil (Schlegel, 2003).

Hydroponic crop production offers advantages such as efficient water and fertilizer usage. The quality and yield of crops are heavily influenced by the nutrient solution, making it a critical factor.

Numerous formulations of mineral composition nutrient solutions are available and commonly employed for brinjal cultivation (Sonneveld and Voogt, 2009). It's worth noting that a plant's nutrient requirements may evolve at different developmental stages (Sonneveld, 2002 and Savvas et al., 2013). Nitrogen, one of the three essential elements for plant growth, is the most utilized during fertigation. In plant growth and development, only a rational supply of nitrogen elements can ensure robust plant growth (Anas et al., 2020). In the context of brinjal, there has been a growing interest in recent years regarding soilless cultivation methods (Savvas and Lenz, 2000). Brinjal can thrive in various commercial soilless culture systems, encompassing substrate-based cultivation and nutrient solutions (Savvas et al., 2013). Brinjal can be cultivated in different substrates, such as coco peat, wood fiber, and rock wool, within hydroponic systems (Gajewski, 2009). The process of growing eggplant in a substrate culture is explained in relation to various nutrient solutions, as outlined by Iapichino et al. (2007). Sajiv et al. (2020) conducted a study on cultivating brinjal using the Hogland solution in a soilless cultivation system, employing different levels of nitrogen and potassium, as well as various growth media. In 2023, Sajiv et al. studied the growth of brinjal (*Solanum melongena* L.) under hydroponics using a modified Hoagland solution. Ulas et al. (2022) assessed the impact of various manganese (Mn) concentrations in hydroponic nutrient solutions on plant growth, leaf chlorophyll and carotenoid content, photosynthetic activity, and root morphological development in eggplant. There is a lack of information regarding the impact of varying nitrogen concentrations on the growth of brinjal using Cooper's hydroponic nutrient solution in Bangladesh. This study holds regional significance as it addresses a gap in research on fertigation techniques for brinjal in Bangladesh. To this end, the objective of this study is to assess how different concentrations of nitrogen fertilizer, when integrated into the hydroponic nutrient solution, impact the growth of brinjal.

Materials and Methods

The experiment was conducted at the Germplasm Center of the Department of Horticulture, Patuakhali Science and Technology University (PSTU) in Dumki, Patuakhali, Bangladesh. In this study, BARI Brinjal-6 was used as the experimental material, and it was procured from Siddique Bazar in Dhaka, Bangladesh. The seeds were sown in trays filled with square foam measuring (1×1 cm^2), following the standardized procedure outlined by Mallick et al. (2018). The brinjal plants were cultivated using a deep-water culture hydroponic system. A nutrient solution was prepared and stored in a 50-liter bucket reservoir, with the oxygen concentration of the nutrient solutions in the reservoir being maintained using an oxygen pump and aerator. Upon reaching the fourth true leaf stage, individual plants were transplanted into the 50-liter bucket, each containing the respective treatment's nutrient solution. The volume of the nutrient solution was consistently maintained by periodically adding more throughout the experimental period. Each plastic bucket received treatment with a nutrient solution, and this setup was replicated three times to ensure scientific validity. The electrical conductivity (EC) and pH of the nutrient solution were regularly monitored and adjusted as needed. EC and pH were measured and maintained using an EC meter, a pH meter, and an EC/TDS meter (Hanna, Japan) at specified intervals. The brinjal plants were subsequently grown within a well-maintained glass house to provide a controlled environment for the experiment. The study was extended from the transplanting of the plants to the onset of plant flowering. In the study, various nitrogen doses were applied (N1=50 mgL^{-1} N, N2=100 mgL^{-1} N, N3=150 mgL^{-1} N, N4=200 mgL^{-1} N, N5=250 mgL^{-1} N), while all other nutrients were maintained at consistent levels as per Cooper's (1979) hydroponic nutrient solution (Table 1). The treatments in this study were based on Cooper's (1979) hydroponic nutrient solution, which consisted of the following nutrient concentrations: 200 mgL^{-1} nitrogen (N), 60 mgL^{-1} phosphorus (P), 300 mgL^{-1} potassium (K), 170 mgL^{-1} calcium (Ca), 50 mgL^{-1} magnesium (Mg), 68 mgL^{-1} sulfur (S), 1 mgL^{-1} iron (Fe), 0.1 mgL^{-1} copper (Cu), 0.1 mgL^{-1} zinc (Zn), 2 mgL^{-1} manganese (Mn), 0.3 mgL^{-1} boron (B), and 0.2 mgL^{-1} molybdenum (Mo).

Table 1. Nutrient concentrations selected for the experiment.

Factors	**Nutrient solution**	**Cooper's (1979) hydroponic nutrient solution Nutrient concentration (mgL^{-1})**											
		N	**P**	**K**	**Ca**	**Mg**	**S**	**Fe**	**Cu**	**Zn**	**Mn**	**B**	**Mo**
N_1	25% of N	50	60	300	170	50	68	12	0.1	0.1	2.0	0.3	0.2
N_2	50% of N	100	60	300	170	50	68	12	0.1	0.1	2.0	0.3	0.2
N_3	75% of N	150	60	300	170	50	68	12	0.1	0.1	2.0	0.3	0.2
N_4	100% of N	200	60	300	170	50	68	12	0.1	0.1	2.0	0.3	0.2
N_5	125% of N	250	60	300	170	50	68	12	0.1	0.1	2.0	0.3	0.2

The electrical conductivity and pH of these treatments were maintained at 3 dSm^{-1} and 6.0, respectively. The nutrient solution was prepared by dissolving Ammonium nitrate (NH4NO3), Calcium chloride (CaCl2), Phosphoric acid (H3PO4), Potassium chloride (KCl), Magnesium sulfate (MgSO4), Copper sulfate (CuSO4), Zinc sulfate (ZnSO4), EDTA iron, Manganese sulfate (MnSO4), Boric acid, and Ammonium molybdate ((NH4)2MoO4) in distilled water. Throughout the experiment, Cooper's (1979) hydroponic nutrient solution was considered the standard. Fertilizer salts were selected to ensure compatibility with each other. The necessary amounts of Calcium Nitrate and EDTA Iron were combined in a 10-liter container to prepare nutrient solution A, while the remaining nutrients were mixed in another 10-liter container to prepare nutrient solution B. Subsequently, the nutrients from both containers were combined in the growth tank according to the assigned treatments.

All essential macro and micronutrients, as outlined in Cooper's (1979) hydroponic nutrient solution, were provided to the hydroponic plants in the form of a nutrient solution composed of dissolved fertilizer salts in distilled water. To successfully grow hydroponic eggplant, the pH of the solution was maintained at 6.0 by adding H3PO3. Lower pH levels were adjusted using hydrogen phosphate (HPO4), while higher pH levels were managed using sodium hydroxide (NaOH) throughout the experimental period (Gómez- Merino and Trejo-Téllez, 2012). The electrical conductivity (EC) of the nutrient solution was adjusted as needed by adding more nutrient solutions for higher EC levels and distilled water for lower EC levels.

Data on various parameters were collected during the study, which included the following:

Plant height was assessed by measuring the distance from the plant's base to the top of the canopy using a centimeter scale, recorded at 15-day intervals up to 60 days after transplanting (DAT), and expressed in centimeters (cm). The count of leaves per plant was conducted by enumerating the total leaves on a plant at 15-day intervals up to 60 DAT. Leaf area was quantified using a leaf area meter (LAM-A, Shandong, China) at 15-day intervals up to 60 DAT, expressed in square centimeters (cm^2). Stem diameter was measured with slide calipers, positioned 1 inch above the surface, at 15-day intervals up to 60 DAT, and expressed in millimeters (mm). Internodal distance was determined by measuring the gap between two internodes using a centimeter scale, expressed in centimeters (cm). The number of branches per plant was obtained by counting the total branches produced per plant. Days to flower bud formation were determined by counting the number of days until flower bud emergence (Fig. 1). Root length was measured from the base to the tip of the roots using a centimeter scale, at 15-day intervals up to 60 DAT, and expressed in centimeters (cm). Leaf chlorophyll content was gauged with a SPAD meter (Hanna, Japan). The first raceme height was noted by measuring the distance from the plant's base to the first flower bud and expressed in centimeters (cm). Fresh weight measurements for both the root and shoot were conducted using an electric balance (FA2004, 201111157), expressed as grams per plant (g/plant). To ascertain dry weight, shoot and root samples were oven-dried for 3 days at 70 degrees Celsius (°C) and then weighed using an electric balance (FA2004, 201111157), with the results expressed in grams per plant (g/plant). Statistical analysis of all the results was conducted using the Minitab 17 statistical software package developed by Pennsylvania State University. The experimental design followed a completely randomized design (CRD). Raw data was collected based on three replications, and subsequently, the gathered data was organized and tabulated in a suitable format for statistical analysis.

Mean differences among the treatments were computed, and statistical separation was achieved using Tukey's multiple comparison tests at a significance level of 5%.

Figure 1. Flower bud induction of brinjal as affected by different nitrogen levels in the hydroponic nutrient solution. Here, N1=50 mgL^{-1} N, N2=100 mgL^{-1} N, N3=150 mgL^{-1} N, N4=200 mgL^{-1} N and N5=250 mgL^{-1} N.

Results and Discussion

Effect of different nitrogen levels on plant height

The impact of different nitrogen concentrations on the height of brinjal plants is presented in Table 2. Significant ($p < 0.05$) effects on plant height were observed at 30 DAT and 45 DAT, while the effects were found to be insignificant at 15 DAT and 60 DAT. At 30 DAT and 45 DAT, the plants grown with 200 mgL^{-1} N (N_4) in the nutrient solution exhibited the highest plant height (9.66 cm and 16.0 cm, respectively), followed by those with 150 mgL^{-1} N (N_3), while the lowest plant height (5.40 cm and 7.27 cm, respectively) was associated with N_1 (50 mgL^{-1} N). This finding is consistent with the results of Sajiv et al. (2023), who observed a significant improvement in brinjal plant height with an increase in nitrogen concentration in the hydroponic nutrient solution up to 298 mgL^{-1}, after which the plant height decreased with a further rise in nitrogen content. Similarly, Erabadupitiya et al. (2020) and Chrysargyris et al. (2017) reported an increase in plant height associated with elevated nitrogen levels in greenhouse-grown

Table 2. Effect of different concentrations of nitrogen in nutrient solution on plant height and number of leaves per plant of brinjal.

Treatments	Plant height (cm)				Number of leaves per plant			
	At 15 days	At 30 days	At 45 days	At 60 days	At 15 days	At 30 days	At 45 days	At 60 days
N_1	4.76	5.40^{b}	7.27^{b}	14.77	5.33	6.33	12.00^{b}	20.00
N_2	6.30	6.93^{ab}	9.83^{ab}	19.10	6.00	6.66	16.33^{ab}	23.33
N_3	7.03	8.90^{ab}	14.83^{ab}	23.87	8.33	9.00	22.33^{a}	25.67
N_4	6.66	9.66^{a}	16.00^{a}	27.33	6.00	6.66	18.67^{ab}	26.33
N_5	6.13	7.06^{ab}	9.63^{ab}	19.57	5.66	7.00	18.66^{ab}	22.67
level of significance	NS	*	*	NS	NS	NS	*	NS

Here, N_1=50 mgL^{-1} N, N_2=100 mgL^{-1} N, N_3=150 mgL^{-1} N, N_4=200 mgL^{-1} N and N_5=250 mgL^{-1} N. Values in the columns having dissimilar letters differ significantly. NS = not significant, * = significant at 5% level of probability.

Tomatoes and spearmint, respectively, in hydroponic systems. Conversely, lower nitrogen levels inhibit plant height. The increase in plant height can be attributed to enhanced nitrogen supply, potentially expediting the synthesis of chlorophyll and amino acids, thereby promoting robust vegetative growth. On the other hand, the reduction in plant height at higher nitrogen levels may be attributed to the adverse effects of excessive nitrogen, which can hinder food production (Rajendra et al., 2021).

Effect of different nitrogen levels on number of leaves per plant

The effect of different nitrogen concentrations on the number of leaves per brinjal plant is presented in Table 2. The number of leaves per plant was significantly ($p < 0.05$) affected by varying nitrogen concentrations only at 45 DAT, with no significant ($p > 0.05$) effects observed at 15 DAT, 30 DAT, and 60 DAT. At 45 DAT, the highest number of leaves per plant (22.33) was recorded for N3 (150 mgL^{-1} N) followed by N4 (200 mgL^{-1} N), while the lowest (12.0) was noted for N1 (50 mgL^{-1} N). Sajiv et al. (2023) observed an increase in the number of leaves per brinjal plant with an increase in nitrogen content in the nutrient solution up to 238 mgL^{-1}. However, the number of leaves decreased with a further increase in nitrogen content. This decrease might be attributed to the depletion of carbohydrate reserves in the plant due to increased nitrogen levels.

Effect of different nitrogen levels on leaf area

The influence of different nitrogen concentrations on the leaf area of brinjal plants is presented in Table 3. Varying nitrogen concentrations had a significant ($p < 0.05$) effect on the leaf area of brinjal at 30, 45, and 60 DAT, while their effects were found to be insignificant ($p > 0.05$) at 15 DAT. At 30, 45, and 60 DAT, the highest leaf area (134.1 cm², 203.7 cm², and 284.3 cm², respectively) was observed with a nitrogen supply of 200 mgL-1 (N4), followed by 150 mgL-1 nitrogen supply (N3). In contrast, the lowest leaf area (47.2 cm², 63.4 cm², and 125.0 cm², respectively) was associated with 50 mgL-1 nitrogen (N1). The increase in leaf area could be a result of heightened cell division and elongation, fostering expanded leaf size and increased leaf count, owing to the positive influence of supplementary nitrogen. This discovery aligns with the findings of Kumar et al. (2018). Similarly, Li et al. (2023) and Erabadupitiya et al. (2020) observed a rise in leaf area when nitrogen levels increased in the hydroponic nutrient solution for grapevine and tomatoes, respectively.

Table 3. Effect of different concentrations of nitrogen in nutrient solution on leaf area and tem diameter of brinjal.

Treatments	**Leaf area (cm^2)**				**Stem Diameter (mm)**			
	At 15 days	**At 30 days**	**At 45 days**	**At 60 days**	**At 15 days**	**At 30 days**	**At 45 days**	**At 60 days**
N_1	35.9	47.2^{b}	63.4^{b}	125.0^{c}	3.16	4.00	5.00^{b}	5.33^{b}
N_2	65.95	89.7^{ab}	101.5^{b}	155.71^{bc}	4.00	5.33	6.33^{ab}	6.66^{ab}
N_3	77.3	121.9^{ab}	160.9^{ab}	250.7^{ab}	3.33	5.00	7.66^{ab}	7.66^{ab}
N_4	82.0	134.1^{a}	203.7^{a}	284.3^{a}	3.66	5.33	8.00^{a}	8.33^{a}
N_5	57.2	83.1^{ab}	111.7^{ab}	190.9^{abc}	4.00	5.00	7.33^{b}	7.66^{ab}
level of significance	NS	*	*	*	NS	NS	*	*

Here, N1=50 mgL^{-1} N, N2=100 mgL^{-1} N, N3=150 mgL^{-1} N, N4=200 mgL^{-1} N and N5=250 mgL^{-1} N. Values in the columns having dissimilar letters differ significantly. NS = not significant, * = significant at 5% level of probability.

Effect of different nitrogen levels on stem diameter

The stem diameter of brinjal plants was significantly ($p < 0.05$) influenced by different nitrogen concentrations at 45 and 60 DAT, with insignificant ($p > 0.05$) effects observed at 15 DAT and 30 DAT. At 45 DAT and 60 DAT, the highest stem diameter (8.00 mm and 8.33 mm, respectively) was recorded for N4 (200 mgL^{-1} N), followed by N3 (150 mgL^{-1} N), while the lowest (5.00 mm and 5.33 mm, respectively) was noted for N1 (50 mgL^{-1} N). Similarly, an increase in stem diameter associated with an increase in nitrogen concentration has been documented in brinjal by Sajiv et al. (2023) and in tomato by Francisco et al. (2015) and Erabadupitiya et al. (2020). However, Chrysargyris et al. (2017) reported that the stem thickness of spearmint showed no significant influence from different levels of nitrogen in hydroponics. This variation could be attributed to differences among plant species. Research has indicated that elevated levels of nitrogen (N) play a crucial role in the development of above-ground plant structures (Singh et al., 2003). This is likely because nitrogen availability is intricately linked to the utilization of carbohydrates, facilitating protein synthesis. Consequently, this promotes accelerated plant growth, heightened metabolic rates, cell division, cell elongation, stimulation of apical growth, and the formation of leaves, contributing to overall plant expansion (Mastiholi et al., 2009). The diminished performance observed in the N1 (50 mgL^{-1} N) treatment (25% of Cooper's solution) can be attributed to nutrient deficiencies, which adversely affect plant height, branch production, stem girth, and the number of leaves (Sat Pal Sharma and Brar, 2008).

Effect of different nitrogen levels on internodal distance

The impact of varying nitrogen concentrations on the internodal distance of brinjal plants is presented in Table 4. Different nitrogen concentrations did not show a significant effect ($p > 0.05$) on the internodal distance of brinjal plants, ranging from 1.63 cm to 3.13 cm. However, the longest internode (3.13 cm) of brinjal plants was observed in N4 (200 mgL^{-1} N) treated plants, and this was statistically similar to all other treatments. The shortest internode (1.63 cm) was observed in treatment N1 (50 mgL^{-1} N). A similar result concerning internodal distance in tomatoes was reported in a previous study by Francisco et al. (2015).

Table 4. Effect of different concentrations of nitrogen in nutrient solution intermodal distance, number of branches per plant, days to first flower bud formation and root length of brinjal.

Treatments	Internodal Distance (cm) At 60 Days	Number of Branches per Plant At 60 Days	Days to first flower bud formation	Root Length (cm)			
				At 15 days	At 30 days	At 45 days	At 60 days
N_1	1.63	3.00	60.33^{a}	24.07^{b}	25.33	34.43	39.33^{ab}
N_2	2.73	2.33	55.66^{b}	25.37^{ab}	27.67	37.33	44.67^{a}
N_3	2.76	3.33	52.66^{c}	29.90^{a}	31.93	32.57	34.00^{ab}
N_4	3.13	4.00	48.66^{e}	26.03^{ab}	28.67	33.97	35.67^{ab}
N_5	2.43	3.66	50.66^{d}	21.90^{b}	24.67	28.00	29.43^{b}
level of significance	NS	NS	*	*	NS	NS	*

Here, N1=50 mgL^{-1} N, N2=100 mgL^{-1} N, N3=150 mgL^{-1} N, N4=200 mgL^{-1} N and N5=250 mgL^{-1} N. Values in the columns having dissimilar letters differ significantly. NS = not significant, * = significant at 5% level of probability.

Effect of different nitrogen levels on the number of branches per plant

The influence of varying nitrogen concentrations on the number of branches per brinjal plant is presented in Table 4. Different nitrogen concentrations did not have a significant ($p > 0.05$) effect on the number of branches per brinjal plant. The number of branches per brinjal plant ranged from 2.33 to 4.0 concerning different nitrogen levels in the nutrient solution. However, the highest number of branches per plant (4.0) was observed in brinjal plants treated with 200 mgL^{-1} N (N_4), and the lowest number of branches per plant (2.33) was recorded in those treated with 100 mgL^{-1} N (N_2).

Effect of different nitrogen levels on days required to first flower bud formation

The effect of different nitrogen concentrations on the time required for the first formation of flower buds in brinjal is presented in Table 4. The number of days needed for the first formation of flower buds in brinjal plants was significantly ($p < 0.05$) influenced by various nitrogen concentrations in the nutrient solution. The range for the days to the formation of the first flower buds was between 48.66 and 60.33 days. The longest duration (60.33 days) for flower bud formation was recorded for N1 (50 mgL^{-1} N), followed by N2 (100 mgL^{-1} N) and N3 (150 mgL^{-1} N), while the shortest duration (48.66 days) was observed for N4 (200 mgL^{-1}

N). Consequently, nitrogen treatments reduced the time to the first flowering, and N4 (200 mgL^{-1} N) flowered at least 2 days earlier than the other treatments. Nitrogen deficiency hindered both vegetative and reproductive growth, leading to an extended time to flowering. Conversely, an excess of nitrogen resulted in an increased duration until flowering. This suggests that nitrogen promotes vegetative growth while inhibiting reproductive growth (Jilani et al., 2008). Therefore, a fertilizer dose of 200 mgL^{-1} N (N4) in hydroponic brinjal cultivation proved optimal for minimizing the time to flowering and facilitating early fruit setting. This finding is consistent with the results of Aminifard et al. (2010), who reported a decrease in flowering time with an increase in nitrogen concentrations in brinjal.

Effect of different nitrogen levels on root length

The influence of different nitrogen concentrations on the root length of brinjal plants is detailed in Table

4. The root length of brinjal plants was significantly (p <0.05) affected by various nitrogen concentrations at both 15 and 60 days after transplanting (DAT), with no significant effects observed at 30 DAT and 45 DAT. At 15 DAT and 60 DAT, the longest roots (29.90 cm and 44.67 cm, respectively) were recorded for N_3 (150 mgL^{-1}) and N_2 (100 mgL^{-1}), respectively, while the shortest roots (21.90 cm and 29.43 cm, respectively) were observed for N_5 (250 mgL^{-1}). In contrast to our findings, Chrysargyris et al. (2017) reported that the root length in spearmint plants was not significantly affected by different nitrogen concentrations in hydroponic nutrient solutions. They observed the greatest root length within the nitrogen range of 100 to 150 mgL^{-1}. Within this range, plants benefit from increased mineral acquisition, providing an abundant supply of carbohydrates and recycled nitrogen to support root development (Thornley, 1972; Millard and Grelet, 2010). High nitrogen levels in the nutrient solution can result in excessive nitrogen uptake by the plant. In such cases, the plant may allocate more energy and resources to above-ground growth, such as leaves and stems, rather than investing in root development. This is because nitrogen is a crucial component of proteins and chlorophyll, essential for photosynthesis and overall plant growth (Davis et al., 1999; Cruz et al., 2003). Conversely, elevated nitrogen levels might paradoxically restrict the availability of nitrate to the roots, as it is likely assimilated in the shoots, where nitrate reductase is most active (Cruz et al., 2004).

Effect of different nitrogen levels on leaf chlorophyll content

The effects of different nitrogen concentrations on the chlorophyll content of brinjal plant leaves are presented in Table 5. Leaf chlorophyll content was significantly ($p < 0.05$) affected by varying nitrogen

Table 5. Effect of different concentrations of nitrogen in nutrient solution on leaf chlorophyll content, first raceme height and fresh weight and dry weight of brinjal shoot and root.

Treatments	Leaf chlorophyll content (SPAD Value) at 60 days	First raceme height (cm)	Fresh Weight (g) at 60 days		Dry Weight (g) at 60 days	
			Shoot	**Root**	**Shoot**	**Root**
N_1	30.07^{b}	21.27	30.60^{d}	23.00^{c}	5.50^{c}	3.30^{b}
N_2	35.80^{ab}	19.13	39.73^{cd}	34.80^{b}	6.40b^{c}	4.10^{b}
N_3	38.53^{a}	10.60	44.80^{c}	35.10^{b}	7.40b^{c}	4.30^{b}
N_4	40.00^{a}	17.13	119.57^{a}	48.33^{a}	17.90^{a}	6.80^{a}
N_5	40.33^{a}	21.96	76.13^{b}	35.60^{b}	10.20^{b}	4.53^{b}
level of significance	*	NS	*	*	*	*

Here, N1=50 mgL^{-1} N, N2=100 mgL^{-1} N, N3=150 mgL^{-1} N, N4=200 mgL^{-1} N and N5=250 mgL^{-1} N. Values in the columns having dissimilar letters differ significantly. NS = not significant, * = significant at 5% level of probability.

Doses, with values ranging from 30.07 to 40.33. The highest leaf chlorophyll content (40.33) was observed with the highest nitrogen doses (250 mgL-1 N), specifically N5, followed by N4. Conversely, the lowest leaf chlorophyll content (30.07) was recorded in N1 (50 mgL-1 N). Similar findings were reported in a study conducted by Aminifard et al. (2010). In a prior investigation, Chrysargyris et al. (2017) noted a significant increase in chlorophyll content at the highest nitrogen level (250 mgL-1) in spearmint grown under different nitrogen levels in hydroponics. The positive influence of inorganic fertilizers on chlorophyll content can be explained by the presence of nitrogen in the chlorophyll molecule (Aminifard et al., 2010; El Gendy et al., 2015). According to Hokmalipour and Darbandi (2011), nitrogen fertilization activates enzymes involved in chlorophyll formation, resulting in a higher chlorophyll concentration than lower doses.

Effect of different nitrogen levels on first raceme height

The impact of different nitrogen concentrations on the first raceme height of brinjal is outlined in Table 5. The first raceme height of the brinjal plant was not significantly ($p > 0.05$) affected by varying nitrogen doses in the nutrient solution and ranged from 10.60 cm to 21.96 cm. However, the highest first raceme height (21.96 cm) was observed in N5 (250 mgL-1 N), followed by N1 (50 mgL-1 N), while the lowest raceme height (10.60 cm) was recorded in N3 (150 mgL-1 N).

Effect of different nitrogen levels on fresh weight of shoot

The effect of different nitrogen concentrations on the fresh weight of the brinjal plant shoot is outlined in Table 5. The fresh weight of the brinjal plant shoot was significantly influenced by varying nitrogen concentrations in the nutrient solution ($p < 0.05$) and ranged from 30.60 g to 119.57 g. The highest fresh weight for the brinjal plant shoot (119.57 g) was recorded for N4

(200 mgL-1 N), followed by N5, while the lowest weight (30.60 g) was observed for N1 (50 mgL-1 N). In a study by Chrysargyris et al. (2017), different nitrogen levels in hydroponic nutrient solutions were reported to have an insignificant effect on the fresh weight of upper plant parts in spearmint.

Effect of different nitrogen levels on fresh weight of root

The influence of different nitrogen concentrations on the fresh weight of the brinjal plant root is presented in Table 5. The fresh weight of the brinjal plant root was significantly (p < 0.05) influenced by varying nitrogen concentrations in the nutrient solution and ranged from 23.0 g to 48.33 g. The highest fresh weight for the brinjal plant root (48.33 g) was recorded for N4 (200 mgL-1), followed by N5 (250 mgL-1 N), while the lowest weight (23.0 g) was observed for N1 (50 mgL-1). In a study by Chrysargyris et al. (2017), different nitrogen levels in hydroponic nutrient solutions were reported to have an insignificant effect on the fresh weight of roots in spearmint.

Effect of different nitrogen levels on dry weight of shoot

The impact of different nitrogen concentrations on the dry weight of the brinjal plant shoot is presented in Table 5. The dry weight of the brinjal plant shoot was significantly (p < 0.05) influenced by varying nitrogen concentrations in the nutrient solution and ranged from 5.50 g to 17.90 g. The highest dry weight for the brinjal plant shoot (17.90 g) was recorded for N4 (200 mgL-1), followed by N5 (250 mgL-1 N), while the lowest weight (5.50 g) was observed for N1 (50 mgL-1). In a previous study by Erabadupitiya et al. (2020), it was reported that the shoot dry weight of tomatoes exhibited a positive response to nitrogen treatments, resulting in higher shoot dry weight with nitrogen rates of 130–175 mgL-1. The dry weight of spearmint plant shoots was found to be highest at 200 mgL-1 nitrogen in hydroponics and decreased with a further increase in nitrogen content (Chrysargyris et al., 2017).

Effect of different nitrogen levels on dry weight of root

The impact of different nitrogen concentrations on the dry weight of the brinjal plant root is presented in Table 5. The dry weight of the brinjal plant root was significantly influenced by varying nitrogen concentrations in the nutrient solution ($p < 0.05$) and ranged from 3.30 g to 6.80 g. The highest dry weight for the brinjal plant root (6.80 g) was recorded for N_4 (200 mgL^{-1}), followed by N_5 (250 mgL^{-1} N), while the lowest weight (3.30 g) was observed for N_1 (50 mgL^{-1}). The dry weight of spearmint plant roots was found to be highest at 200 mgL^{-1} nitrogen in hydroponics and decreased with a further increase in nitrogen content (Chrysargyris et al., 2017).

Conclusion

In conclusion, the investigation into various nitrogen concentrations in hydroponic nutrient solutions has provided valuable insights into their impact on the vegetative growth of brinjal. The findings indicate that nitrogen plays a crucial role in influencing plant height, number of leaves per plant, leaf area, stem diameter, early flower bud formation, root length, leaf chlorophyll content and fresh and dry weight of shoot and root. The study revealed an optimal nitrogen concentration range of 200 mgL-1 (N4), demonstrating that an adequate supply positively influenced vegetative development. The observed increase in vegetative parameters suggests that an enhanced nitrogen supply accelerates chlorophyll and amino acid synthesis, contributing to vigorous plant growth. Additionally, the positive influence on stem diameter further emphasizes the role of nitrogen in promoting structural development. However, it is noteworthy that excessive nitrogen levels beyond the identified optimum may restrict the vegetative growth of brinjal. The study indicates that an imbalance, either deficiency or excess of nitrogen, can hinder the desired vegetative outcomes.

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