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Quantifying the Impact of Nitrogen Concentration Variations on Quality Characteristics of Soilless Cultivated Cherry Tomato

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Within the domain of macronutrients, nitrogen has garnered significant recognition as a pivotal element due to its profound influence on both the vegetative growth and quality attributes of a crop. An abundance of scientific research has consistently demonstrated that attaining optimal productivity necessitates the meticulous management of soil moisture availability, complemented by the timely provision of nitrogen during critical growth stage intervals. The study aimed to optimize the nitrogen concentration in a hydroponic solution by testing a range of concentrations. The objective was to systematically examine the effects of different nitrogen levels and determine

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the optimal concentration for the desired outcomes. The assessment was carried out in a meticulously controlled greenhouse environment from October 2019 to April 2021, with the primary objective of systematically investigating the impact on quality characteristics specific to the rosa variety of cherry tomato. To investigate the effects of different nitrogen concentrations, four distinct levels of 4 mM, 6 mM, 8 mM, and 10 mM per litre of nutrient solution were employed. The nitrogen source consisted of a combination of $NO3^-$ and $NH4^+$, with a ratio of 40:60, respectively. The nutrient solution with an 8 mM nitrogen concentration exhibited a significantly augmented effect on increasing the equatorial and polar diameter of fruits, average fruit weight, pericarp thickness, as well as the accumulation of total chlorophyll, ascorbic acid, lycopene, β-carotene, and total soluble solids (TSS) content. These findings demonstrate the pronounced and positive influence of the 8 mM nitrogen concentration on the aforementioned quality characteristics.

Keywords: β-carotene; cherry tomato; chlorophyll; hydroponics; lycopene; nitrogen.

1. INTRODUCTION

Nitrogen is a vital macronutrient that directly influences vegetative growth and fruit yield in crops. However, determining the optimal nitrogen rates for solanaceous crops like tomato poses challenges. Existing studies have shown conflicting results regarding the exact concentrations of nitrogen that yield optimal quality and productivity in cherry tomatoes. Factors such as soil variability, nitrogen leaching, and soil denitrification further complicate precise application, often leading to suboptimal plant performance. Although several studies, such as those by Moreno et al. [1] and Mehmood et al. [2] have investigated the relationship between nitrogen levels and tomato growth, they have predominantly focused on soil-based cultivation systems, with limited data on hydroponic environments. Furthermore, the effects of nitrogen levels on specific quality attributes—such as fruit diameter, chlorophyll content, and nutrient accumulation—are still inadequately addressed for cherry tomatoes under soilless cultivation systems. Factors such as soil variability, nitrogen leaching, and soil denitrification complicate the precise application of nitrogen rates. Furthermore, prevailing practices employed by farmers and fertilizer companies tend to rely heavily on empirical approaches and recommendations, often disregarding the precise physiological demands of plants throughout the entire duration of their growth season [3]. A multitude of scientific investigations have consistently emphasized the fundamental association between achieving optimal productivity and the meticulous regulation of soil moisture levels, coupled with the timely provision of nitrogen during critical growth stage periods. Conversely, a deficient nitrogen supply significantly impedes root growth, thereby exerting profound repercussions on overall plant growth and subsequent yield outcomes.

Soil, as a conventional and extensively available growth medium for plants, fulfills crucial requirements for successful plant development, encompassing anchorage, nutrient provision, air circulation, and water retention. Nevertheless, soil also imposes constraints on plant growth, manifesting in challenges like the prevalence of soil-borne diseases, inadequate drainage capabilities, and degradation caused by erosion [4]. With the progression of climate change, the decline in biodiversity, and the growing global population, there is a pressing need to move away from traditional agricultural practices and embrace innovative, technology-driven approaches to food production [5]. Soilless cultivation, commonly known as hydroponic cultivation, represents a technique for cultivating economically valuable horticultural plants without utilizing traditional soil as a growth medium. This method entails cultivating plants in mineral nutrient solutions devoid of soil, where the roots may be immersed solely in the nutrient solution or supported by an inert medium, such as cocopeat, leca balls, perlite or gravel.

Controlled comparisons between soil and hydroponic systems have demonstrated that hydroponics provides significant benefits in terms of both water use efficiency and crop quality. In a study by Verdoliva et al., it was found that hydroponic systems, particularly deep water culture (DWC), exhibited higher water use efficiency and produced tomatoes with increased levels of lycopene and β-carotene compared to soil cultivation [6]. These findings suggest that hydroponics not only conserves water but also enhances the nutritional value of the produce, making it a promising alternative to traditional soil-based cultivation methods.

Protected vegetable cultivation ensures a continuous and uninterrupted provision of vegetables throughout the year, thereby facilitating market stability in terms of prices. Moreover, this agricultural approach enables effective exploitation of resources and facilitates off-season vegetable growth, commonly referred to as vegetable forcing. The adoption of greenhouse cultivation is gaining popularity among growers in various regions of India due to its capacity to prolong the growing season and enhance the overall quality of high-value horticultural crops.

It is widely believed that the cherry tomato (*Solanum lycopersicum* Mill. var. *cerasiforme*) serves as the progenitor of all domesticated tomato varieties. Due to its rich content of vitamin A and C, high solids content, favorable taste, and ability to set fruit even under high temperature conditions, the widespread popularity of this crop has been observed on a global scale [7]. Cherry tomatoes, characterized by their relatively diminutive size and enhanced sweetness in comparison to other tomato varieties, find frequent utilization in salads, sandwiches, and various culinary preparations. These tomatoes exhibit versatility in their growth environments, encompassing traditional garden settings, controlled environments such as greenhouses, and even hydroponic systems.

The primary objective of this study is to investigate the effects of varying nitrogen concentrations in a hydroponic nutrient solution on the growth and quality attributes of the Rosa variety of cherry tomato. Specifically, this research aims to determine the optimal nitrogen concentration that maximizes fruit yield while systematically evaluating its effects on several critical quality metrics. These metrics include the equatorial and polar diameters of the fruit, average fruit weight, dry weight of the fruit, thickness of the pericarp, total chlorophyll content, ascorbic acid content, lycopene content, β-carotene content, and total soluble solids (TSS) content. By providing a clear outline of these specific quality parameters, this study seeks to enhance the understanding of the relationship between nitrogen concentration and the quality attributes of soilless-cultivated cherry tomatoes, thereby contributing valuable insights to the field of hydroponic agriculture.

2. MATERIALS AND METHODS

The experiment was conducted within a controlled environment, utilizing a greenhouse, from October 2019 to April 2021. Completely Randomized Design (CRD) was opted to effectively control environmental variables in greenhouse conditions, allowing for clear attribution of observed differences in growth and quality attributes to nitrogen concentration. This design simplifies analysis while ensuring robust and reliable findings, with the independent variable being the concentration of nitrogen in the form of four levels (4, 6, 8, 10 mM). The objective of the study was to determine the optimal concentration of Nitrogen through the assessment of various growth and yield parameters of the plants under investigation. For the experiment, seeds of the Rosa variety of cherry tomatoes were utilized. The seeds were procured from Known-You Seed (India) Pvt. Limited. The plants were cultivated in polypackets using a growing medium composed of a mixture of cocopeat and perlite in a ratio of 3:1. The nutritional requirements were met by providing a modified Hoagland solution as the source of nutrients. To ensure optimal growth conditions, the experiment was conducted in a naturally ventilated polyhouse. The experiment involved manipulating nitrogen levels at four different concentrations (4, 6, 8, and 10 mM), with the nitrogen source divided in a ratio of 40:60 between nitrate (NO^{3-}) and ammonium (NH^{4+}).

In each treatment group, a selection of five fully matured fruits was made, and their equatorial and polar diameters were measured with precision using a vernier caliper. The equatorial diameter was determined at the point of maximum breadth of the fruit, while the polar diameter was measured from the fruit's stem end to its distal end. The resulting measurements were averaged and recorded in millimeters. To determine the average diameter of cherry tomato fruits, a set number of ten fruits were harvested from each labeled plant within each treatment. Subsequently, the fruits were weighed on an electronic balance, and the resulting mean weight in grams was recorded. Ten cherry tomato fruits were procured from the designated plants within each treatment and subjected to a drying process in an oven maintained at a temperature of 60°C. This drying process continued until a consistent weight was achieved. Subsequently, the weight of the dried fruits was meticulously recorded.

To assess the thickness of the rind in the selected fruits, a precise cut was made along the equatorial plane. This allowed for the measurement of the rind thickness using a Vernier caliper. Subsequently, the average value was calculated and meticulously recorded in millimeters. The estimation of the overall chlorophyll content was conducted in accordance with the methodology outlined by Sadasivam and Manickam [8]. which enabled the determination of the total chlorophyll present. The determination of the total soluble solids (TSS) content in the fruits was accomplished using an ERMA hand refractometer, which had a measurement range of 0 to 32 ºBrix. The concentration of β-carotene in the fruit pulp was assessed through the utilization of a spectrophotometric method, as detailed in the research conducted by Sadasivam and Manickam [8]. The obtained results were then expressed in milligrams per 100 grams of fruit pulp. The determination of lycopene content in the fruit pulp was carried out by employing the spectrophotometric method outlined by Sadasivam and Manickam [8]. Subsequently, the findings were presented in terms of milligrams of lycopene per 100 grams of fruit pulp. The quantification of ascorbic acid content in the fresh fruits was conducted using established biochemical techniques as prescribed by Sadasivam and Manickam [8]. For the estimation process, composite pulp samples obtained from 10 randomly selected ripe fruits were utilized per replication.

Statistical analyses were performed using OPSTAT software, employing Analysis of Variance (ANOVA) to compare means across treatments under the Completely Randomized Design (CRD). Prior to conducting ANOVA, we ensured that the assumptions of normality and homogeneity of variance were met using the Shapiro-Wilk test and Levene's test, respectively. For treatments that showed significant differences ($p < 0.05$), post-hoc comparisons were performed using Tukey’s Honestly Significant Difference (HSD) test to determine which specific means were significantly different. This comprehensive approach to statistical analysis allows for a robust evaluation of the data and ensures that observed differences are statistically valid.

3. RESULTS AND DISCUSSION

The cherry tomato variety Rosa demonstrated a significant variation in fruit diameter (mm) at a 5% level for both equatorial and polar diameter as a result of increasing nitrogen levels over the two-year period of study. As illustrated in Table 1, the equatorial diameter varied between 20.48 to 24.79 mm and 20.29 to 23.01 mm during the growing seasons of 2019-20, 2020-21, respectively. Similarly, the polar diameter varied between 28.28 to 33.63 mm and 28.38 to 32.34 mm during the growing seasons of 2019-20, 2020-21, respectively. These results provide evidence of the impact of nitrogen levels on fruit diameter in the Rosa cherry tomato variety. The results indicate a positive correlation between nitrogen concentration and fruit diameter. Specifically, T_3 (8 mmols/L) exhibited the highest equatorial diameter with values of 24.79 mm and 23.01 mm during the years 2019-20 and 2020-21, respectively, followed by treatments 2 and 4. Similarly, treatment 3 also exhibited the highest polar diameter with values of 33.63 mm and 32.34 mm during the years 2019-20 and 2020-21, respectively, followed by T_4 and T_2. These findings suggest that an increase in nitrogen concentration may lead to significant improvements in the size of fruits. Previous studies, such as those conducted by Moreno et al. [1] and Mehmood et al. [2] have demonstrated a positive correlation between nitrogen treatment and the dimensions of cherry tomato fruits. Specifically, these studies have shown that nitrogen application can result in an increase in both the equatorial and polar diameters of the fruit. These findings are consistent with the results of the current experiment, providing further support for the role of nitrogen in the development of cherry tomato fruit.

Table 1 presents a comparative analysis of the average fruit weight of the cherry tomato variety “Rosa” under various nitrogen concentrations. The analysis of variance (ANOVA) revealed a statistically significant variation among the treatments. Specifically, the mean fruit weight ranged from 8.00 to 8.71 g/fruit and 8.12 to 8.88 g/fruit during the 2019-20 and 2020-21 growing seasons, respectively. These findings illustrate the profound influence of nitrogen levels on the average fruit weight of the Rosa cherry tomato variety. The present investigation has demonstrated a statistically significant and positive correlation between increasing nitrogen levels in the nutrient solution and the average fruit weight of the Rosa cherry tomato cultivar. The highest increase in fruit weight was observed at an optimal nitrogen concentration of 8 mM/L. These results contribute to the scientific understanding of the impact of nutrient management on the productivity and quality of the Rosa cherry tomato cultivar.These findings indicate that nitrogen plays a crucial role in the development of tomato fruit weight. The results of this study closely align with previous research by Haque et al. [9] and Elia et al. [10] which have also reported a positive correlation between nitrogen application and fruit weight in tomato plants. This further supports the significance of nitrogen in the growth and development of cherry tomato plants.

Table 2 presents a comprehensive analysis of the dry weight (g/100g) of the cherry tomato cultivar, Rosa, grown under varying nitrogen concentrations. The results of the analysis of variance (ANOVA) indicate a statistically significant variation among the treatments. Specifically, the dry weight (g/100g) ranged from 5.98 to 6.65 g/100g and 6.12 to 6.60 g/100g during the growing seasons of 2019-20 and 2020-21, respectively. Specifically, T_3 (8 mM/L) exhibited the highest dry weight (g/100g) with values of 6.65 and 6.60 g during the years 2019-20 and 2020-21, respectively, followed by treatments 2 and 4. In summary, the study found that the cherry tomato variety Rosa had a significant increase in dry weight (g/100g) with increasing nitrogen levels in the nutrient solution. The results of this study align with previous research by Gouthami et al. [11] which has also reported a strong link between nitrogen consumption and dry weight in capsicum plants. The findings indicate the significance of nitrogen in the growth and development of cherry tomato plants.

Table 2 presents a comparative analysis of the pericarp thickness (in millimeters) of the Rosa cherry tomato fruit variety under different nitrogen concentrations. Analysis of variance indicated significant variation for treatments. During 2019–20 and 2020–21, the pericarp thickness ranged from 2.62 to 2.98 mm and 2.41 to 2.95 mm, respectively. Specifically, T_4 (10 mmols/L) exhibited the highest pericarp thickness (mm) with values of 2.98 and 2.95 mm during the years 2019-20 and 2020-21, respectively, followed by treatments 3 and 2. The present study has revealed that the cherry tomato variety Rosa exhibited a substantial increase in pericarp thickness with increasing nitrogen levels in the nutrient solution. Specifically, the highest increase was observed at 10 mmol/L. These findings demonstrate the positive impact of nitrogen on the structural characteristics of cherry tomato fruits, specifically pericarp thickness. The results of this study closely align with previous research by Kumar et al. [12] Gupta *et.al*. [13] and Gouthami et al. [11] which have also reported a positive correlation between nitrogen uptake and pericarp thickness in capsicum plants. These studies provide evidence for the crucial role nitrogen plays in the growth and development of tomato plants.

The total chlorophyll content of 100 g of cherry tomato unripe fruit at varying nitrogen concentrations is presented in Table 2. Significant variation was found for treatments according to the analysis of variance. The total chlorophyll content in 100 g of unripe fruit weight varied between 2.56 and 2.87 mg/100g and 2.62 and 2.81 mg/100g in 2019–20 and 2020–21, respectively. T_3 (8 mmols/L) exhibited the highest total chlorophyll content in 100 g of unripe fruit weight with values of 2.87 and 2.81 mg/100g during the years 2019-20 and 2020-21, respectively, followed by treatments 4 and 2. The study found that the cherry tomato variety Rosa had a substantial increase in total chlorophyll content with increasing nitrogen levels in the nutrient solution, with the highest increase observed at 8mmol/L. The results align with previous research by Park et al. [14] Oliveira et al. [15] and Hansda et al. [16] indicating the positive impact of nitrogen on chlorophyll content in tomato and Cherry tomato plants.

As depicted in Table 3, the ascorbic acid content in the cherry tomato cultivar Rosa exhibited a significant variation at 5% significance level due to the enhancement of nitrogen levels during the course of the two-year experiment. The ascorbic acid content ranged from 31.39 to 32.15 mg and 31.20 to 32.01 mg during the years 2019-20 and 2020-21, respectively. T_3 (8 mmols/L) exhibited the highest ascorbic acid content in 100 g of fruit weight with values of 32.15 and 32.01 mg/100g during the years 2019-20 and 2020-21, respectively, followed by treatments 4 and 2. The study found that the cherry tomato variety Rosa had a significant increase in ascorbic acid content with increasing nitrogen levels in the nutrient solution. The findings of the current study are consistent with previous research, such as that of Feijuan and Cheng [17] which demonstrated that nitrogen application improves ascorbic acid content in tomato fruits.

Significant variations in the lycopene content (mg/100g) were observed among the different treatments. Table 3 presents the data on the impact of varying nitrogen concentrations in the nutrient solution on the lycopene content

Table 1. Effect of different nitrogen levels on equatorial diameter, polar diameter and average fruit weight of cherry tomato

			Equatorial diameter (mm)		Polar diameter (mm)		Average fruit weight (g/fruit)	
Treatments	**NO_3^-: NH_4^+**	**Concentration**	**2019-20**	**2020-21**	**2019-20**	**2020-21**	**2019-20**	**2020-21**
T_1	40:60	4 mM	20.48	20.29	28.28	28.38	8.00	8.12
T_2	40:60	6 mM	23.86	22.51	29.62	29.08	8.52	8.48
T_3	40:60	8 mM	24.79	23.01	33.63	32.34	8.71	8.88
T_4	40:60	10 mM	23.35	22.25	33.33	31.65	8.65	8.73
MEAN			23.12	22.02	31.22	30.36	8.47	8.55
S.Em (±)			0.403	0.297	0.416	0.458	0.088	0.090
CD (P=0.05)			1.219	0.898	1.257	1.385	0.265	0.272

Table 2. Effect of different nitrogen levels on dry weight, thickness of pericarp and total chlorophyll of cherry tomato

			Dry weight (g/100g)		Thickness of pericarp (mm)		Total chlorophyll (mg/100g)	
Treatments	**NO_3^- : NH_4^+**	**Concentration**	**2019-20**	**2020-21**	**2019-20**	**2020-21**	**2019-20**	**2020-21**
T_1	40:60	4 mM	5.98	6.12	2.62	2.41	2.56	2.62
T_2	40:60	6 mM	6.36	6.25	2.80	2.60	2.71	2.67
T_3	40:60	8 mM	6.65	6.60	2.92	2.90	2.87	2.81
T_4	40:60	10 mM	6.22	6.51	2.98	2.95	2.80	2.75
MEAN			6.30	6.37	2.83	2.72	2.73	2.71
S.Em (±)			0.042	0.061	0.057	0.063	0.037	0.026
CD (P=0.05)			0.126	0.185	0.173	0.191	0.113	0.079

Table 3. Effect of different nitrogen levels on ascorbic acid, lycopene, β-carotene and T.S.S. content of cherry tomato

			Ascorbic acid (mg/100g)		Lycopene content (mg/100g)		β-Carotene (mg/100g)		T.S.S. (°brix)	
Treatments	**NO_3^-: NH_4^+**	**Concentration**	**2019-20**	**2020-21**	**2019-20**	**2020-21**	**2019-20**	**2020-21**	**2019-20**	**2020-21**
T1	40:60	4 mM	31.39	31.20	2.08	2.10	0.34	0.35	6.71	6.77
T2	40:60	6 mM	31.51	31.39	2.25	2.21	0.37	0.40	7.26	7.23
T3	40:60	8 Mm	32.15	32.01	2.45	2.39	0.43	0.43	7.89	7.70
T4	40:60	10 mM	31.57	31.52	2.31	2.30	0.40	0.41	7.72	7.56
MEAN			31.65	31.53	2.27	2.25	0.39	0.40	7.39	7.32
S.Em (±)			0.139	0.132	0.040	0.032	0.010	0.007	0.105	0.070
CD (P=0.05)			0.421	0.398	0.120	0.096	0.030	0.023	0.318	0.212

(mg/100g) of cherry tomato. The lycopene content (mg/100g) of the cherry tomato for the 2019–20 and 2020–21 growing seasons ranged from 2.08 to 2.45 mg/100g and 2.10 to 2.39 mg/100g, respectively. Treatment 3 (8 mmols/L) exhibited the highest lycopene content per 100 g of fruit weight, with values of 2.45 and 2.39 mg/100g during the 2019-20 and 2020-21 growing seasons, respectively, followed by treatments 4 and 2. The study found that the cherry tomato variety Rosa had a significant increase in lycopene content with increasing nitrogen levels in the nutrient solution. The results align with previous research, such as that of Kuscu et al. [18] and di Cesare et al. [19] which also found a correlation between nitrogen uptake and lycopene content in tomato fruits.

The data on β-Carotene content in Rosa, a cherry tomato cultivar, displayed a significant variance at 5% according to the changes in nitrogen levels throughout the two-year study. Table 3 showcases the β-Carotene content that ranged from 0.34 to 0.43 mg and 0.35 to 0.43 mg for the years 2019–20 and 2020–21, respectively. Treatment 3 (8 mmols/L) exhibited the highest β-Carotene per 100 g of fruit weight, with values of 0.43 and 0.43 mg/100g during the 2019-20 and 2020-21 growing seasons, respectively, followed by treatments 4 and 2. The study showed a positive correlation between increasing nitrogen concentration and β-Carotene content in cherry tomato variety Rosa. The highest increases in β-Carotene content were seen in treatments with 8mmol/L nitrogen, while all treatments showed increases compared to the control. These findings support previous research by Tzortzakis et al. [20] Nishat et al. [21] and Porto et al. [22] and Thapa et al. [23].

According to the varying nitrogen concentration in the nutrient solution, as depicted in Table 3, there were significant changes in the TSS (°brix). Different nitrogen concentrations applied were observed to have a positive influence on this trait. During 2019–20 and 2020–21, the TSS (°brix) content ranged from 6.71 to 7.89 °brix and 6.77 to 7.70 °brix, respectively. Treatment 3 (8 mmols/L) exhibited the highest fruit sugar (TSS) per 100 g of fruit weight, with values of 7.89 and 7.70 °brix during the 2019-20 and 2020-21 growing seasons, respectively, followed by treatments 4 and 2. The results of the data analysis revealed a noteworthy increase in TSS (°brix) content in all treatments compared to the control. This increase was proportional to the rise in nitrogen concentration in the nutrient solution. This finding confirms the prior studies by Roque et al. [24] and Jorge et al. [25]. The reason behind this growth could be attributed to the enhanced photosynthesis process due to the higher nitrogen supply, which led to an accumulation of more photoassimilates and reducing sugars. These, in turn, contributed to a higher concentration of soluble solids in tomato fruits, as stated by Wang et al. [26] and Kundu et al. [27].

The findings of this study have considerable practical implications for commercial cherry tomato cultivation, particularly in hydroponic systems. By determining the optimal nitrogen concentration of 8 mM, this research offers a scientifically-based guideline for enhancing critical quality attributes, including fruit size, weight, and nutrient content such as ascorbic acid, lycopene, and β-carotene. In commercial farming, the implementation of this optimized nitrogen level can significantly enhance both yield and quality, thereby increasing profitability. Moreover, efficient nitrogen management reduces the risk of excessive nitrogen application, thus minimizing environmental impacts and improving resource-use efficiency. These advantages can assist growers in achieving consistent product quality throughout the year, meeting market demands, and lowering production costs, especially under protected cultivation systems [28].

4. CONCLUSION

Collectively, the findings derived from this investigation indicate that the nitrogen concentration in the nutrient solution plays a significant role in determining the quality attributes of soilless-cultivated cherry tomatoes. Specifically, factors such as equatorial diameter, polar diameter, average fruit weight, dry weight, thickness of pericarp, total chlorophyll, ascorbic acid, lycopene content, β Carotene, and T.S.S were notably influenced. Notably, the treatment involving an 8 mmol/L nitrogen concentration (T3) demonstrated the highest efficacy in optimizing yield for the Rosa variety of cherry tomato plants.

FUTURE DIRECTIONS

The findings of this study highlight the significant positive effects of nitrogen concentration on the quality attributes of cherry tomatoes, suggesting practical applications for growers in optimizing nutrient management in hydroponic systems. By adopting the optimal nitrogen concentration of 8 mM, growers can enhance fruit yield and quality, ultimately leading to increased profitability and better marketability of their produce. Future research could focus on exploring the effects of varying nitrogen sources and ratios in conjunction with other nutrients, as well as investigating the long-term impacts of nitrogen management on soil health in integrated systems. Additionally, studies assessing consumer preferences regarding the sensory attributes of tomatoes grown under different nitrogen treatments could further inform growers' practices and enhance market outcomes.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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