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Comparison of the growth, fruit quality, and physiological characteristics of tomato nourished by three different nutrient solutions in soil and soilless culture systems

Alireza Khaleghi [a]*, Hossein Sharifi Azad [b], Seyed Hossein Mirdehghan [b]

[a] *Department of Horticultural Sciences, Faculty of Agriculture and Natural Resources, Arak University, 38156-8-8349 Arak, Iran*
[b] *Department of Horticultural Sciences, College of Agriculture, Vali-e-Asr University of Rafsanjan, Rafsanjan, Kerman, Iran*

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ABSTRACT

To evaluate the effect of different nutrient solutions on growth and yield characteristics of tomato plants, as well as to evaluate the quantitative and qualitative characteristics of fruit in soil- and soilless-cultivation, factorial experiment was carried out with two factors of cultivation system at two levels (soil cultivation and soilless cultivation) and three levels of nutrient solution (Hoagland, Hochmat and Shan) in a completely randomized design with three replications in greenhouse conditions. The results showed that soilless culture medium (cocopeat-perlite) increased vegetative and reproductive characteristics, such as plant height, number of nodes, flowers and fruits, internode distance, number of leaves, leaf area, fresh and dry weight of shoots, fresh and dry weight of roots, stem diameter, and fruit diameter in tomato plants. Many growth and morphological traits, such as leaf area, stem length, stem fresh weight, root dry weight, fruit diameter, leaf number, fruit number and yield were influenced by the interaction effect of nutrient solution and cultivation system. The photosynthetic pigments, and fruit quality traits including fruit appearance color (three components a*, b* and L*), Hue angle, chroma, total soluble solids (TSS), and vitamin C increased in soilless system compared with soil-based system. Hoagland nutrient solution had higher significant effect on increasing quantitative and qualitative traits than other nutrient solutions. In general, soilless cultivation with Hoagland nutrient solution had a significant positive effect on growth and yield characteristics, as well as the quantitative and qualitative characteristics of fruit compared with the other treatments.

* Corresponding author: A. Khaleghi
E-mail address: khaleghi979@gmail.com

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1. Introduction

In recent years, there have been some problems in soil-based cultivation, such as salinity, inappropriate soil structure, and water resource limitations in some countries, especially in Iran. These problems have led to the development of soilless cultivation (hydroponics). Soil degradation, increased salinity, and the occurrence of soil-borne diseases after consecutive crops are observed. Therefore, soilless cultivation is considered as an alternative to soil-based cultivation. Research has shown that if nutrients are provided to the plant through fertigation and nutrigation, the plant does not require soil for growth (Hayden, 2006; Papadopoulos, 1994). However, continuous research is necessary to determine the best nutrient solutions for specific crops, as any deficiency in the elements becomes quickly evident in this method (Papadopoulos, 1994). Therefore, determining the optimal type and composition of nutrient solutions is considered one of the methods of managing the nutrition of crops under controlled conditions (Cardoso *et al.*, 2017). However, the impact of different nutrient solutions on high-yield crops, such as tomatoes has been less studied. Additionally, in soilless cultivation systems, materials are typically used to support the root system, and plant nutrition is carried out through the nutrient solution added to the medium. The properties of different materials used as growing media, directly or indirectly, effect plant growth and performance. The choice of growing media depends on various factors, including high water-holding capacity, sufficient ventilation, and proper drainage (Asaduzzaman, 2015).

Tomato (*Lycopersicon esculentum* Mill.) is a strategically produced crop under controlled conditions, and a wide range of greenhouses are dedicated to its production outside the season. Therefore, producing high-quality and high-performance tomato requires proper management of its production under controlled conditions (Naureen *et al.*, 2018). It has been reported that the use of Hoagland nutrient solution improves growth properties and enhances the concentration of leaf elements in cucumber plants. Furthermore, the application of different ratios of potassium and nitrogen in hydroponic conditions has led to changes in growth and performance indices in cucumber plants such as stem length, leaf surface area, stem diameter, fruit length, fruit diameter, and fruit weight (Cardoso *et al*., 2017). It has been reported that the separate application of potassium, phosphorus, calcium, magnesium, and nitrogen under field conditions increases growth indices in tomato plants by increasing chlorophyll content and nutrient concentration in leaf tissues (Cole *et al*., 2016). In a study on the effect of three growing media (perlite, palm peat, and soil) on the growth of greenhouse cucumbers, it was shown that the palm peat medium significantly increased root and fruit biomass weight than perlite medium. Additionally, the height of the plant, stem diameter, and leaf surface area of the plants grown in palm peat medium were greater compared to the other two media (Borji *et al*., 2010). In a study on the effect of eight growing media on tomatoes, Borji *et al*. (2010) reported that the growing media had a significant impact on the growth factors of tomatoes. Given the increasing trend of soilless tomato production, it is essential to study the growth and physiological differences between soil-based and soilless cultivation and identify the best nutrient solution for them. Therefore, an experiment was conducted with the following objectives: 1) determining the best nutrient solution for tomato by changing the concentration of essential elements in the nutrient solution, 2) comparing the growth and physiological characteristics of tomato in soil-based and soilless cultivation, and 3) determining the optimal combination of nutrient concentrations on performance and fruit quality of tomatoes.

2. Materials and methods

The present study was conducted in 2021 in a commercial polyethylene-covered greenhouse located in Shahrebabak city, Kerman Province, Iran. In this experiment, the effect of different nutrient solutions in soil-based and soilless cultivation were investigated on physiological and morphological characters of tomato 'Dafnis' cultivar. The plants were cultivated at temperature of 24± 3°C at day and 21± 3°C at night and 54 ± 3% relative humidity. When the plants were ready to be harvested, plants with roots were transferred to the laboratory and the traits were measured. For soilless cultivation of tomato, grow bags were used, with three plants grown in each bag. For soil-based cultivation, 10-liter pots were used, with one plant grown in each pot. The experimental treatments included two levels of cultivation system (soil-based and soilless) and three levels of nutrient solution types (Hoagland, Hochmat, and Shan). A mixture of cocopeat and perlite in a 1:1 ratio was used in the grow bags. Three seedlings were planted in each grow bag. Based on previous investigations (Papadopoulos, 1994; Farran and Mingo-Castel, 2006; Chang *et al*., 2008), the nutrient solution used in the hydroponic system consisted of macro ($Ca(NO_3)_2$, KNO_3, KH_2PO_4 and $MgSO_4$) and micro (H_3BO_3, $MnSO_4$, $ZnSO_4$, $CuSO_4$, $(NH_4)6Mo_7O_{24}$ and Fe-EDDHA) salts.

In the hydroponic system, nutrient solution replenishment was performed twice a day (Table 1). Plants in the soil-based cultivation were irrigated with nutrient solution once every 12 days. To maintain moisture, the plants in the soil-based cultivation were also watered with tap water twice during the 12-day interval (once every 4 days). The nutrient solution used had a pH of 5.8-6.5 and an EC of 1.7.

2.1. Measurement of morphological and physiological traits

Data associated with growth parameters, including plant height, node number, internode distance, leaf number, leaf area, sucker number, stem diameter, fresh and dry shoot weight, and fresh and dry root weight were recorded 120 days after transferring the plants to the cultivation systems. The stem and root diameter were measured using a digital caliper. Leaf area was measured using a Leaf Area Meter (CI-202). Developmental traits measured in this experiment included flower number, fruit number, flower drop percentage, fruit diameter, fruit weight, fruit yield per plant, and yield per hectare.

To measure the total soluble solids, the fruit extracts were used. The total soluble solid content was measured using a digital refractometer (ATAGO PAL1, Japan). The vitamin C content was measured using the iodine-potassium titration method (AOAC. 1990). The color of the fruits was measured using a colorimeter (Konica Minolta CR 400, Japan) at three points on each fruit. After measuring the L*, a*, and b* parameters, the hue and chroma scale were calculated by the following equation.

Chroma= √ (a*2 + b*2)

Hue = tan-1($b^*{}_{/}a^*$)

For measurement of total carotenoids and chlorophylls a and b, Fresh leaves (0.5 g) were homogenized in 20 ml of 80% acetone in complete darkness and then centrifuged at 6000 g for 10 min. The absorbance of supernatant was recorded at 646, 663, and 470 nm and then total carotenoids and chlorophylls *a* and *b* were calculated using the methods as described by Lichtenthaler and Wellburnt (1983) as follows:

Chlorophyll a (μg/g FW)= $[12.21(A_{663})-2.81(A_{646})] \times V/W$

Chlorophyll b (μg/g FW)= $[20.13(A_{646})-5.03(A_{663})] \times V/W$

Total Chlorophyll (µg/g FW)= $(Chl_a)+(Chl_b)$

Carotenoids (µg/g FW)= $\frac{[1000(A_{470})-3.27C_a-104C_b]}{229} \times V/W$

Where V is volume of supernatant and W is fresh weight of leaves.

The measured nutrient elements in this experiment included nitrogen, phosphorus, potassium, calcium, magnesium, zinc, copper, manganese, and iron in the leaves and roots. Phosphorus and potassium contents were determined by flame photometer method (Hamada and Elenany 1994; Creus *et al*. 2004). Copper, zinc, manganese, and iron were measured using an atomic absorption spectrophotometer. Calcium was measured using a titration method, and the calcium content was calculated using the following equation (Klute *et al*., 1986).

Ca^{2+} (meq/l) = (meq/l EDTA ×N EDTA)/ (meq/l Extract) ×1000

For magnesium measurement, the method described by Ryan *et al*. (2001) was used, and the magnesium content was calculated using the following equation.

Mg^{2+} (meq/l) = (meq/l EDTA × N EDTA)/ (meq/l Extract) × 1000

2.2. Statistical analysis

The experiment was carried out as factorial arrangement in a completely randomized design with three replications. Significant differences among means were estimated at the 5% ($P < 0.05$) level, using Duncan test. All statistical analysis was performed using the SAS (v. 9.1.3.) software. Minitab software was used to normalize the data.

3. Results and discussion

3.1. Growth and morphological traits

Many growth and morphological traits, such as leaf area, stem length, stem fresh weight, root dry weight, fruit diameter, internode length, leaf number, fruit number and yield were influenced by the interaction effect of nutrient solution and cultivation system. In all mentioned traits, the best treatment was the use of Hoagland nutrient solution in a soilless system (Table 2), followed by the best results in a soilless medium with Shan nutrient solution. The lowest values of mentioned traits were observed in the soil-based system with Hochmat nutrient solution. Based on the obtained results, there was no significant difference in many growths and morphological traits, including leaf area, stem length, and root dry weight, between the Shan and Hochmath nutrient treatments, both in soilless system and soil-based system. According to the results, the use of a soilless system improved the growth and morphological traits compared to the soil-based system. The Hoagland solution was the best among the nutrient solutions. Additionally, among the nutrient treatments, the highest number of flowers, stem diameter, and root fresh weight were obtained with the Hoagland nutrient solution, which showed an increase of 6.9%, 21.3%, and 26% in flower number, stem diameter, and root fresh weight, respectively, compared to the Hochmuth nutrient solution and an increase of 3.7%, 8.9%, and 10.1% compared to the Shan nutrient solution. Furthermore, the use of a soilless system resulted in improvements of 9.34%, 23%, and 26% in flower number, stem diameter, and root fresh weight, respectively, compared to the soil-based system (Table 4).

Table 1 Concentrations of elements (mg/L) in Hoagland (Hoagland and Arnon, 1950), Hochmat (Florida, 2001), and Shan (Shahn, 1992) nutrient solutions for tomato plants

Nutrient elements	Hoagland and Arnon	Hochmat	Shan
N	242	120	200
P	31	50	50
K	232	150	360
Ca	224	150	185
Mg	49	50	45
S	113	65	65

Table 2 The interaction between nutrient solution and cultivation system on physiological and morphological traits of tomato cv. Dafnis

Cultivation system	Nutrient solution	Leaf area (cm^2)	Stem length (cm)	Stem fresh weight (g)	Root dry weight (g)	Fruit diameter (cm)	Chlorophyll *a* (mg/g FW)	Total chlorophyll (mg/g FW)	Carotenoid content (mg/g FW)	Total soluble solid content (Brix)	Leaf number	Internode length (cm)
Soilless	Hoagland	15715.9 a	310.5 a	744.7 a	53.77 a	6.41 a	0.97 a	1.45 a	2.5 a	7.28 a	28.01 a	11 a
Soilless	Hochmat	12393.6 c	273.5 cd	565.8 c	40.03 c	6.04 c	0.79 c	1.17 bc	2.16 cd	5.75 cd	27.16 c	10 c
Soilless	Shan	12905.2 bc	285.1 b	600.8 bc	43.85 bc	6.2 b	0.83 b	1.26 b	2.23 bc	6.1 bc	27.52 b	10.3 b
Soil-based	Hoagland	11761.3 c	269.6 d	502.4 cd	37.85 c	5.9 d	0.75 d	1.09 c	2.06 d	5.48 d	26.87 d	10 c
Soil-based	Hochmat	9418.2 e	256.7 e	398.9 e	30.65 d	5.71 e	0.63 f	0.89 d	1.3 f	4.71 e	25.93 f	9.9 cd
Soil-based	Shan	9929.7 de	258.6 e	473.8 d	32.38 d	5.76 de	0.69 e	0.98 cd	1.37 e	5.04 ef	26.56 e	9.7 d

The same letters indicate there is no significant difference at $p \leq 0.05$.

Table 2 continued

Cultivation system	Nutrient solution	Fruit yield (Kg/plant)	Vitamin C (mg/g FW)	Fruit number	L*	b*	a*	N (mg/g DW)	P (mg/g DW)	Ca (mg/g DW)	Mn (µg/g DW)	Cu (µg/g DW)
Soilless	Hoagland	8.4 a	7.28 a	46.8 a	47.85 a	52.37 a	44.29 a	56.36 a	3.19 a	15.05 a	260.9 a	2.80 a
Soilless	Hochmat	8 bc	5.75 cd	44.56 c	45.03 bc	48.78 bc	42.15 b	52.54 cd	2.91 bc	11.21 cd	254.3 ba	2.51 bc
Soilless	Shan	8.2 ab	6.1 bc	45.72 b	45.73 ab	49.81 b	43.71 a	53.12 bc	3.07 ab	13.37 b	257.4 ab	2.71 a
Soil-based	Hoagland	7.8 c	5.48 d	43.8 d	43.89 c	48.2 c	41.44 b	51.93 d	2.79 c	10.78 d	250.5 c	2.43 c
Soil-based	Hochmat	7.1 e	4.71 ef	39.88 f	42.71 d	46.58 d	38.85 cd	49.93 f	2.29 e	8.13 f	236.8 d	2.27 d
Soil-based	Shan	7.4 d	5.04 e	41.37 e	43.13 cd	46.88 d	41.13 c	51 ef	2.54 d	9.47 e	237.9 d	2.29 d

The same letters indicate there is no significant difference at $p \leq 0.05$.

Table 3 Effect of nutrient solution on physiological and morphological traits of tomato cv. Dafnis

Nutrient solution	Root fresh weight (g)	Stem diameter (cm)	Chlorophyll *b* (mg/g FW)	Flower number	Hue	Chroma	K (mg/g DW)	Zn (µg/g DW)	Fe (mg/g DW)
Hoagland	467.55 a	1.59 a	0.41 a	61.5 a	44.25 a	63.88 a	67.67 a	59.11 a	115.8 a
Hochmat	371.02 c	1.31 c	0.32 c	57.5 c	42.46 b	57.29 c	64.4 b	55.69 b	112 b
Shan	462.56 b	1.46 b	0.35 b	59.3 b	42.87 ab	60.04 b	67.12 a	57.48 a	113.5 a

The same letters indicate there is no significant difference in levels p≤0.05

Table 4 Effect of cultivation system on physiological and morphological traits of tomato cv. Dafnis

Nutrient solution	Root fresh weight (g)	Stem diameter (cm)	Chlorophyll *b* (mg/g FW)	Flower number	Hue	Chroma	K (mg/g DW)	Zn (mg/g DW)	Fe (mg/g DW)
Soilless	467.55 a	1.65 a	0.42 a	62 a	44.13 a	64.47 a	67.98 a	59.15 a	115.8 a
Soil-based	371.02 b	1.26 b	0.29 b	56.7 b	42.27 b	56.34 b	64.81 b	55.7 b	111.7 b

The same letters indicate there is no significant difference in levels p≤0.05.

Consistent with these results, Mobini *et al*. (2009) reported that stem diameter and plant height of potato plants were greater in hydroponic system compared to soil-based system, which was attributed to the better growth of seedlings in hydroponic system in terms of porosity and adequate ventilation. Plants grown in soilless system had the highest number of leaves, indicating the beneficial effect of soilless system in water and nutrient retention, which provides better growth conditions for the plants. Additionally, it was reported in an experiment that the dry weight of aerial parts and root of potato plants was higher in hydroponic system compared to soil-based system (Novella *et al*., 2008). It appears that the presence of perlite along with cocopeat in the root medium increases the drainage capacity of the growing medium and improves root ventilation, which in turn contributes to an increase in the fresh and dry weight of roots and stems. Furthermore, the high water and nutrient retention capacity of cocopeat improves the growth conditions and increases the leaf area of the plants (Asaduzzaman *et al*., 2013).

It has been shown that increasing the concentration of nutrient solutions not only affects dry matter accumulation but also influences stem diameter and plant height (Sambo *et al*., 2006). According to the present results, it has been reported that the stem diameter of potato plants is greater in hydroponic systems compared to soil cultivation, and increasing the concentration of nutrient solutions also increases the stem diameter (Mobini *et al*., 2009). Moreover, leaf area is an important characteristic in plant growth, as an increase in leaf area leads to higher photosynthesis and consequently the accumulation of carbohydrates and increased yield (Pessarakli, 2002). Additionally, increasing nitrogen levels affects chlorophyll concentration, photosynthesis rate, leaf number, and dry matter accumulation. Therefore, nitrogen plays a crucial role in canopy development, especially in the dry weight of shoots and leaf surface area in plants (Najm *et al*., 2010).

3.2. Photosynthetic pigments

The highest levels of photosynthetic pigments, including chlorophyll *a*, total chlorophyll, and carotenoids content, were observed in the soilless system along with Hoagland nutrient solution, with values of 0.97 mg/g FW, 1.45 mg/g FW, and 2.5 mg/g FW, respectively (Table 2).

Furthermore, the use of Hoagland nutrient solution improved the chlorophyll *b* content compared to the Hochmat and Shan nutrient solutions, with increases of 28% and 17%, respectively. The soilless system also resulted in a 45% increase in chlorophyll *b* content compared to soil-based system. These results indicate that the use of a soilless system improves the content of photosynthetic pigments compared to soil-based system. Among the nutrient solutions, the Hoagland nutrient solution was found to be the best for obtaining the highest photosynthetic pigments, followed by the Shan nutrient solution.

Leaf chlorophyll content is a key factor in determining the rate of photosynthesis and dry matter production. Carotenoids, on the other hand, are plant pigments that act as antioxidants and essential compounds in the photosynthetic system (Žnidarčič *et al*., 2011). Nitrogen is one of the factors that affect Chlorophyll production (Lehr *et al*., 1962), and it has been reported that leaf chlorophyll content increases with nitrogen treatments (Mandal *et al*., 2007). This increase in chlorophyll content has also been observed in cucumber plants (Guler *et al*., 2006). Since the Hoagland nutrient solution has higher nitrogen content compared to the Hochmat and Shan nutrient solutions, these results are consistent with the findings of this study.

3.3. Quality traits

Total soluble solid content, fruit color (components a*, b*, and L*), and vitamin C content are among the quality traits of fruit evaluated in this study. According to the results, the cultivation system and nutrient solution had a significant effect on all quality traits at a significance level of 1%. Additionally, their interaction had a significant effect on all quality traits except Hue and Chroma at a significance level of 1%. The highest total soluble solid content was obtained in the soilless system along with Hoagland nutrient solution, while the lowest total soluble solid content was observed in the soil-based system along with Hochmat nutrient solution (Table 2). Moreover, according to the results (Table 2), the highest value of color brightness was observed in plants grown in the cocopeat-perlite (soilless system) growing medium along with the application of Hoagland nutrient solution, while the lowest value was associated with fruits from soil-based system along with Shan nutrient solution. The lowest value of component a* was observed in fruits from the soil-based system along with Hochmat nutrient solution, and the highest value was observed in fruits from soilless system along with Hoagland nutrient solution. Furthermore, the lowest value of component b* was observed in fruits from the soil-based system with Hochmat nutrient solution, and the highest value was observed in fruits from the soilless system with Hoagland nutrient solution.

The highest level of Hue was obtained in soilless system, while the lowest level was observed in soil-based system. Furthermore, the highest level of Hue was observed in the Hoagland nutrient solution, and the lowest level was observed in the Hochmat nutrient solution (Table 3). The highest amount of Chroma was found in fruits grown in soilless system, and the lowest amount was observed in soil-based system. Additionally, fruits from plants treated with the Hoagland nutrient solution had higher Chroma levels compared to fruits from plants treated with the Hochmat nutrient solution. The highest level of vitamin C was obtained in soilless system along with the Hoagland nutrient solution, and the lowest level was observed in soil-based system with the Hochmat nutrient solution.

The color of tomato is an important factor in fruit quality for consumers and develops with fruit maturity (Bertin, 2005). In a study on the effect of different cultivation substrates on tomato fruit quality under controlled conditions in a hydroponic system, it was reported that tomatoes grown in a perlite-zeolite (2:1) substrate had the highest level of total soluble solid content (Dubský and Šrámek, 2009). It appears that the high level of total soluble solid content in tomatoes grown in soilless system is due to the presence of nutrients in this substrate, which played a role in increasing the total soluble solid content. Increased levels of total soluble solid content and vitamin C due to potassium application have been reported in peppers and other studies (Khayyat *et al*., 2007; Arancon *et al*., 2006; Almeslemani *et al*., 2009). Additionally, in a study on the effect of different potassium concentrations on cantaloupe fruit quality, it was found that increasing potassium levels increased the total soluble solids content of the fruit flesh (Lin *et al*., 2004). Increases in fruit quality factors such as vitamin C and total soluble solid content have also been reported in pepper (El-Bassiony, 2010; Rubio *et al*., 2010), strawberry (Khayyat *et al*., 2007), and tomato (Almeslemani *et al*., 2009) as a result of potassium application. Potassium improves chemical compounds by increasing protein, starch, soluble solids, and vitamin C content in fruits (Khayyat *et al*., 2007). It has been reported that the percentage of total soluble solid content in strawberry plants increases with increasing nitrogen ratio. There is a direct relationship between sugar concentration and nitrogen content in fruits (Locascio and Saxena, 1967).

3.4. Nutrient Uptake

According to the results, nutrient uptake was also influenced by the experimental treatments. The uptake of nitrogen, phosphorus, calcium, manganese, and copper was influenced by the interaction of the cultivation system and nutrient solution. The highest uptake of nitrogen, phosphorus, calcium, manganese, and copper was achieved in the soilless system along with the Hoagland nutrient solution. Whereas the lowest levels of nitrogen, phosphorus, calcium, manganese, and copper were observed in the soil-based system along with the Hochmat nutrient solution (Table 2). Additionally, the use of soilless system improved the uptake of potassium, zinc, and iron compared to soil-based system by 4.9%, 6.2%, and 3.7%, respectively. Furthermore, the uptake of potassium, zinc, and iron was influenced by the type of nutrient solution, with the highest uptake of these elements associated with the Hoagland nutrient solution and the lowest with the Hochmat nutrient solution.

It has been reported that increasing nitrogen levels also affects the uptake of other elements such as potassium, magnesium, calcium, and phosphorus and can enhance the uptake of certain elements (Rajiv and Misra, 2011). Fallovo *et al*. (2009) reported that the nitrogen concentration in the aerial part of leafy lettuce was positively influenced by the application of nutrient solutions with a high nitrogen ratio. Additionally, the use of ammonium nitrogen increases the uptake of anions compared to cations due to the release of H^+ from the roots, which acidifies the root environment and increases the availability of cationic micronutrients such as iron, manganese, zinc, and copper (Marschner, 2012). Kilinc *et al*. (2007) reported the highest growth performance in fig cuttings treated with Hoagland nutrient solutions containing 234 mg/L of potassium.

4. Conclusions

The results of this study showed that the use of soilless systems and cocopeat-perlite as a growing medium in greenhouse tomato cultivation led to an increase in growth traits such as plant height, stem diameter, node number, leaf number, internode length, leaf area, fresh weight, and dry weight of stems and roots; reproductive traits including flower number, fruit number, fruit diameter, and fruit yield; biochemical traits such as photosynthetic pigments (chlorophyll *a*, *b*, total chlorophyll and carotenoids); fruit quality traits such as fruit color (a*, b*, and L*), Hue, and Chroma, Total soluble solid content, and vitamin C; as well as an increase in nutrient elements present in the leaves, such as nitrogen, phosphorus, potassium, calcium, magnesium, manganese, copper, zinc, and iron compared to soil-based system. Based on the results of this study, the use of the Hoagland nutrient solution in soil-based and soilless tomato cultivation resulted in increased growth, reproductive, biochemical, quality traits, and nutrient content in plants. Therefore, based on the findings of this study, the use of soilless system and the Hoagland nutrient solution is recommended to increase the quantitative and qualitative yield of greenhouse tomato.

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