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# Nutrient Uptake, Fruit Quality, and Yield of Greenhouse Tomato (*Solanum lycopersicum*, cv. Hirad) as Influenced by the Interaction of Nitrogen and Potassium

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**ABSTRACT**

Plant growth in hydroponic systems is affected by the nutrient solution concentration. The present study evaluated the effects of nitrogen (N) and potassium (K) on the concentration of some nutrients, chemical fruit qualities, and yield in tomatoes (*Solanum lycopersicum*, cv. Hirad). The experiment was arranged as a completely randomized design with four treatments (T1: N160 + K350 ppm at the vegetative stage and N130 + K250 ppm at the reproductive stage, T2: N170 + K360 ppm at the vegetative stage and N140 + K260 ppm at the reproductive stage, T3: N180 + K370 ppm at the vegetative stage and N150 + K270 ppm at the reproductive stage and T4: N190 + K380 ppm at the vegetative stage and N160 + K280 ppm at the reproductive stage). Results indicated that higher N and K supplies in the nutrient solution decreased Ca, Na, Mn, and Zn concentrations in leaf samples. In contrast, the concentration of various elements in fruits was unaffected by the increase in N and K (except for Cu). The second treatment (T2) had the most beneficial effect on the Cu concentration in tomato leaves and fruits. The increase in total soluble solids, chlorophyll, lycopene, and total acids could improve fruit quality in tomato fruits. The best treatment in the present study was N170 + K360 ppm at the vegetative stage and N140 + K260 ppm at the reproductive stage.

## Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most popular and commonly consumed vegetable crops worldwide, with an annual production of 182a MT (Zarei et al., 2019; Anonymous, 2020). This plant is highly pigmented and contains many types of antioxidants, such as ascorbic acid, lycopene, β-carotene, essential minerals, and flavonoids, which contribute to ROS scavenging (Casals et al., 2018; D'Angelo et al., 2019). Good

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agricultural techniques are crucial to increasing crop quality and yield, including those under greenhouse production (Souri and Hatamian, 2019). Hydroponics is a water-saving cultivation method that offers significant advantages, including preventive measures for soil-borne diseases and enriched nutrient supply via solutions (Kaur et al., 2018). Hydroponics cultivation of fresh-market tomatoes has gained popularity worldwide in recent years due to improved growth, quality, and yield in these systems (Lee and Lee, 2015).

Nitrogen is an essential mineral needed by tomatoes for optimum quality and yield, as many physiological and metabolic processes are associated with nitrogen nutrition (Maathuis, 2009; Souri and Hatamian, 2019; Souri et al., 2017). The production of tomatoes requires a high amount of N (Khan et al., 2017; Youssef and Eissa, 2017). The availability of this element can affect fruit composition, taste, and quality parameters in hydroponic culture (Dehnavard et al., 2017). Potassium (K) is a cationic nutrient in most demand by tomatoes. K is involved in various physiological and biochemical processes in plants, such as photosynthesis, enzymatic activity, secondary metabolism, protein synthesis, and many food quality traits (Saghaiesh and Souri, 2018; Tohidloo et al., 2018). The biosynthesis of the carotenoids can be affected by potassium in tomato fruits (Constán-Aguilar et al., 2015). An adequate application of K to the plant can entail a larger fruit size, greater yield, increased ascorbic acid contents, and a higher soluble solids content (Bidari and Hebsur, 2011). Consequently, K fertilization is required to increase fruit yield, quality, disease resistance in fruits and vegetables, and beneficial effects on consumer health (Caretto et al., 2008; Daoud et al., 2020).

Precise N and K concentrations at various stages during plant growth assist in increasing quality traits in tomatoes (Soares et al., 2005). N levels of 0 to 120 and 180 kg $ha^{-1}$ during cultivation increase sugar, lycopene, protein, and ascorbic acid concentrations in tomato fruits (Hui et al., 2017). Increasing the K dose from 200 to 400 mg $L^{-1}$ in hydroponic conditions improved fruit sugar, protein, ascorbic acid, and lycopene content (Ahmad et al., 2015). There was a significant improvement in total soluble solids, lycopene, ascorbic acid, and protein, thus reducing acids and sugar content in the fruit as the K level increased to 300 mg $L^{-1}$ in the hydroponic system (Almeselmani et al., 2009). Given the role of K and N, the best combination of these elements in nutrient solution can promote plant growth and development, thus increasing fruit quality and yield.

Our studies and experience in commercial greenhouses in the country, almost all of which use imported cocopeat substrates, show that an accumulation of potassium occurs in the cocopeat substrate and disturbs the balance of elements, such as nitrogen and others. Thus, it leads to the uneven coloring of the fruit. Our hypothesis in this experiment was to reduce the potassium concentration in the reproductive stage and increase it in the vegetative stage. The reason was a lack of excessive accumulation in the substrate to improve fruit quality. Thus, this experiment aimed to assess the nutritional value, ascorbic acid and lycopene concentrations, and fruit yield under hydroponic systems supplied with a nutrient solution that comprised different N and K ratios. Applications occurred during the different vegetative and reproductive stages of tomato plants.

## Materials and Methods

The experiment was carried out in a multi-span greenhouse (September 2019-June 2020) at Ebrahim Abad Agricultural Complex, Kerman province, Iran ((31°47′ N, 41°81′ E). Tomato seeds (Hirad) were germinated in 50-cell trays containing a mixture of perlite and cocopeat substrate (75:25 v:v) and germinated under greenhouse conditions. Twenty-five days after sowing (at the four-leaf stage), we removed the transplants from the substrate and transplanted them into cocopeat bags (100 × 18 × 16 cm). The distance between tomato rows was 130 cm, and between two tomato plants within each row was 25 cm. Greenhouse conditions remained stable at 26/18 °C (day/night) at 85/65% relative humidity, monitored through a thermostat while using automatic heating and cooling. The hydroponics experiment was a completely randomized design, with five replicates and four treatments. Nitrogen was supplied as $NH_4NO_3$ and potassium as KCl.

1) T1 (vegetative stage, N160 + K350 ppm; reproductive stage, N130 + K250 ppm)
2) T2 (vegetative stage, N170 + K360 ppm; reproductive stage, N140 + K260 ppm)
3) T3 (vegetative stage, N180 + K370 ppm; reproductive stage, N150 + K270 ppm)
4) T4 (vegetative stage, N190 + K380 ppm; reproductive stage, N160 + K280 ppm)

Other macronutrients were P (50 ppm), Mg (60 ppm), S (140 ppm), and Ca (200 ppm) (Eurosolids, Netherland). Micronutrients in the solution were Fe (3.3 ppm), Mn (0.9 ppm), B (0.7

ppm), Cu (0.1 ppm), and Mo (0.02 ppm) (Tradecorp, Spain) in all treatment groups. The solutions were renewed every week to maintain pH values between 5.8 and 6.2. Ten months after transplanting, four ripe fruits at their firm stage were randomly selected per experimental unit to measure the quality of tomato fruits and mineral nutrient concentrations in the leaves and fruits.

### *Chlorophyll and carotenoid compounds*

Fresh frozen leaves (0.5 g) were ground and then homogenized with 50 mL of acetone 90% (v/v). The extract was centrifuged at 3500 xg. The optical densities were measured at different wavelengths, i.e., 663 nm for chlorophyll 'a', 645 nm for chlorophyll 'b' and 470 nm for carotenoids. Calculating the concentrations was according to the following formulas (Baroud et al., 2021):

$$Chlorophyll\ \text{“}a\text{”}\ (Chl\ \text{“}a\text{”})(mg\ g^{-1}\ Fresh\ Matter) = \frac{(11.75 \times DO663 - 2.35 \times DO645) \times 50}{500}$$

$$Chlorophyll\ \text{“}b\text{”}\ (Chl\ \text{“}b\text{”})(mg\ g^{-1}\ FM) = \frac{(18.61 \times DO645 - 3.96 \times DO663) \times 50}{500}$$

$$Carotenoids\ (mg\ g\text{^}(-1)\ \ FM)\ = (\frac{\frac{(1000 \times DO470) - (2.27 \times Chl\ \text{“}a\text{”}) - ((81.4 \times Chl\text{“}b\text{”}))}{227} \times 50}{500}$$

### *Mineral nutrients*

Total N was estimated using the Kjeldahl method (Bremner and Mulvaney, 1982). Total K was measured by flame atomic absorption spectrometry (Z-5300, Polarized Zeeman Atomic Absorption Spectrophotometer) (Sparks et al., 1996). The concentration of Ca, Mg, Na, Fe, Mn, Zn, Cu, and B were measured by flame atomic absorption spectroscopy (Alghobar and Suresha, 2017).

### *Ascorbic acid*

The measurement of ascorbic acid content in fresh tomato samples was performed by titration, according to the 2, 6-dichloroindophenol (DCIP) method, and reported as mg ascorbic acid per 100 mL.

### *Total acids*

Total acid contents were measured by dilution with 10 mL of tomato juice titrated with 0.1 NaOH up to pH 8.1. Citric acid was used for indicating the total acids.

### *Total soluble solids (TSS)*

TSS of the juice samples were estimated by a digital refractometer at 20 °C and expressed as °Brix.

### *Statistical analysis*

SAS was employed to analyze data statistically (Version 9.1, SAS Institute Inc., Cary, NC). The hypothesis of homogeneity in variance was tested before data analysis. Duncan's multiple-range test was utilized to compare significant differences ($p \leq 0.05$).

## Results

Our results showed that N and K application significantly affected mineral nutrient concentration. The increased supply of N and K concentrations did not influence the accumulation of all nutrients (except for Cu nutrient) in fruits (Fig. 1A-I). The highest N content in leaves (4.26%) was observed in plants grown with N180 + K370 ppm at the vegetative stage, and with N150 + K270 ppm at the reproductive stage (Fig. 1A).

The Ca content in tomato leaves and fruits (Fig. 2B) showed that the Ca concentration in the leaves decreased by up to 31% when using N180 + K370 ppm at the vegetative stage, and N150 + K270 ppm at the reproductive stage. There was no significant difference between T3 and T4 regarding Ca content in the leaves (Fig. 2B). The Mg concentration decreased with increasing N and K (N180 + K370) at the vegetative stage and N150 + K270 ppm at the reproductive stage. Then, it improved with increasing N and K levels (Fig. 2C). Tomato leaves exhibited a decrease in Na concentration while the N and P levels increased. The highest Na concentration in the leaves appeared in plants grown with T1 and T2 (Fig. 2D).

Increasing the concentrations of N and K in treatment applications affected the Fe concentration in tomato leaves and fruits (Fig. 1E). There was a higher concentration of Fe in the leaves of plants treated with T2 and T4 treatments (Fig. 1E). A high level of N and K supply decreased the Fe concentration in tomato leaves. Our results suggest that N and K application significantly affected Mn and Zn contents in tomato leaves (Fig. 1F, G). Mn and Zn contents decreased with increasing N and K levels.

Plants treated with N160 + K350 ppm and N130 + K250 ppm at the reproductive stage showed the highest Mn and Zn concentrations. In contrast, by increasing the N and K supply up to N170 + K360 ppm at the vegetative stage and N140 + K260 ppm at the reproductive stage (T2), an increase occurred in Cu concentration by 10%, 12% and 13.6% in the fruits of plants treated with T1, T3, and T4, respectively. Significant differences in the accumulation of Cu in fruits appeared between treatment T2 and the rest of the treatments (Fig. 1H). B concentration in the leaves of tomatoes was significantly affected by increasing the supply of N and K nutrients. Significantly higher amounts of B occurred in tomato leaves grown in T2 and T3 (Fig. 1I). A lower B content (90.25 mg $kg^{-1}$) occurred in response to T4.

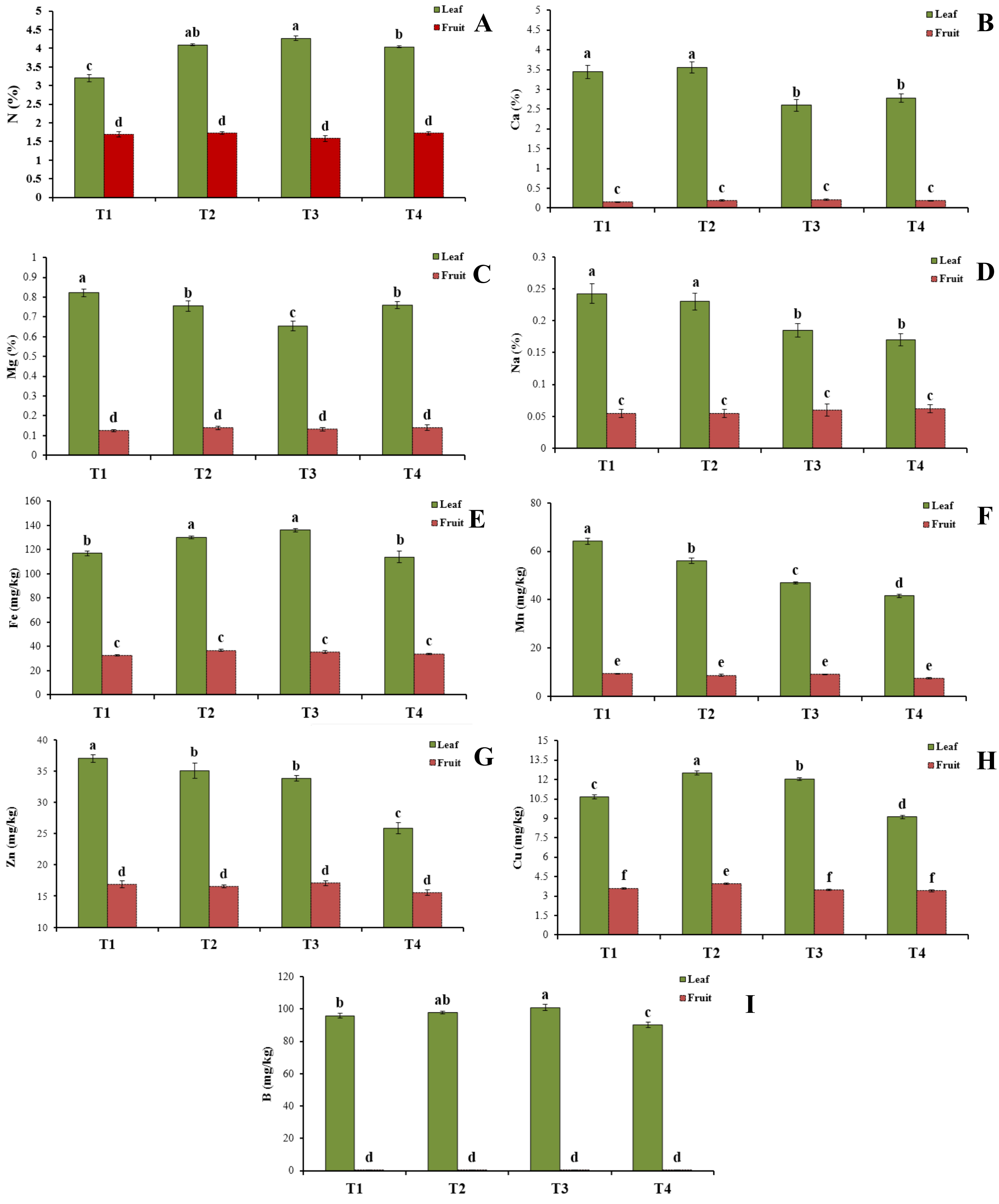


**Fig. 1.** Effects of increasing N and K application on (A) N, (B) Ca, (C) Mg, (D) Na, (E) Fe, (F) Mn, (G) Zn, (H) Cu, and (I) B in tomato leaves and fruits. Data were mean values of triplicates and bars represent standard errors. T1: vegetative stage, N160 + K350 ppm; reproductive stage, N130 + K250 ppm; T2: vegetative stage, N170 + K360 ppm; reproductive stage, N140 + K260 ppm; T3: vegetative stage, N180 + K370 ppm; reproductive stage, N150 + K270 ppm; T4: vegetative stage (N190 + K380 ppm), reproductive stage (N160 + K280 ppm).

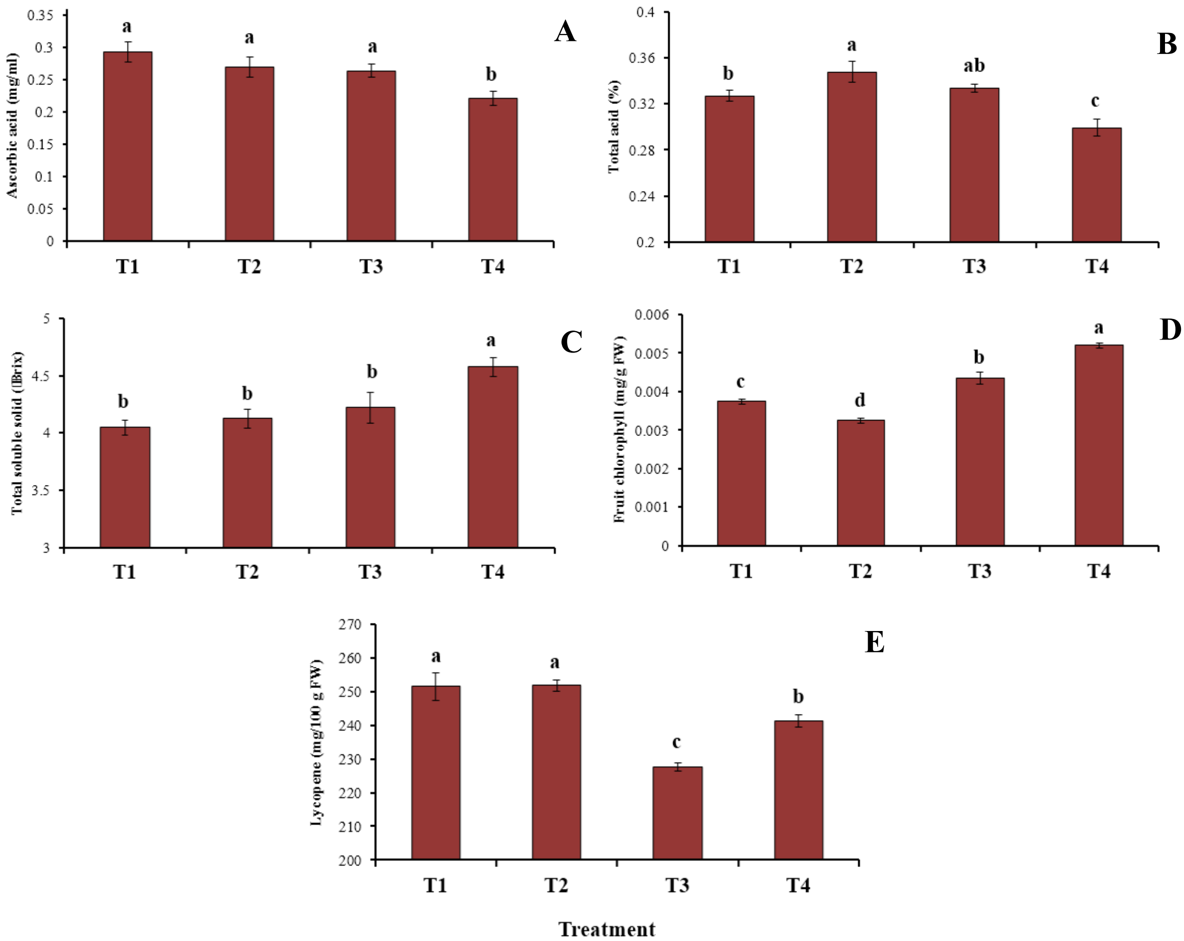


**Fig. 2.** Effects of increasing N and K application on the (A) Ascorbic acid, (B) Total acid, (C) Total soluble solids, (D) Fruit chlorophyll, and (E) Lycopene in fruits of tomato. Values were the means of three replicates and bars represent the standard errors. T1: vegetative stage, N160 + K350 ppm; reproductive stage, N130 + K250 ppm; T2: vegetative stage, N170 + K360 ppm; reproductive stage, N140 + K260 ppm; T3: vegetative stage (N180 + K370 ppm), reproductive stage (N150 + K270 ppm); T4: vegetative stage (N190 + K380 ppm), reproductive stage (N160 + K280 ppm).

The current findings demonstrated that higher N and K in the nutrient solution caused differences in fruit ascorbic acid, total acids, total soluble solids, chlorophyll, and lycopene contents (Fig. 2). Increasing the N and K levels negatively affected fruit ascorbic acid and treatment T4 resulted in the lowest ascorbic acid concentration (0.22 mg $mL^{-1}$). However, no differences were in the ascorbic acid contents of plants treated with T1, T2, or T3 (Fig. 2A).
The application of different levels of K and N differently impacted the total acids. The application of N170 + K360 ppm at the vegetative stage and N140 + K260 ppm at the reproductive stage (T2) caused an increase in total acids. However, the values of total acids did not differ significantly between T2 and T3 (Fig. 2B).
Higher N and K supplies significantly improved fruit soluble solids (Brix) and chlorophyll accumulation in tomatoes (Fig. 2C, D). Plants treated with N190 + K380 ppm and N160 + K280 ppm at the reproductive stage achieved the highest concentration of soluble solids (Brix) and chlorophyll. Therefore, this treatment was the most effective in improving TSS and chlorophyll content in tomato fruits (Fig. 2C, D). Figure 2E shows that lycopene content was maximum in fruits of plants in the T1 and T2 treatment groups. Treatment T3 caused the lowest concentration of lycopene in comparison to other treatments.
Stem diameter and fruit production varied in response to nutrient solution concentration (Fig. 3). At the vegetative stage, increasing N and K concentrations significantly increased stem

diameter, which became more pronounced in response to T3 (Fig. 3A).
Stem diameter at the reproductive stages increased in response to higher N and K supplies. No differences in fruit production occurred between T3 and T4 (Fig. 3B). Variations in fruit yield depended on the applied treatment. Total fruit yield was significantly higher at T2 than in response to other treatments. However, a similar statistical level occurred in the case of treatments other than T2 (Fig. 3C).

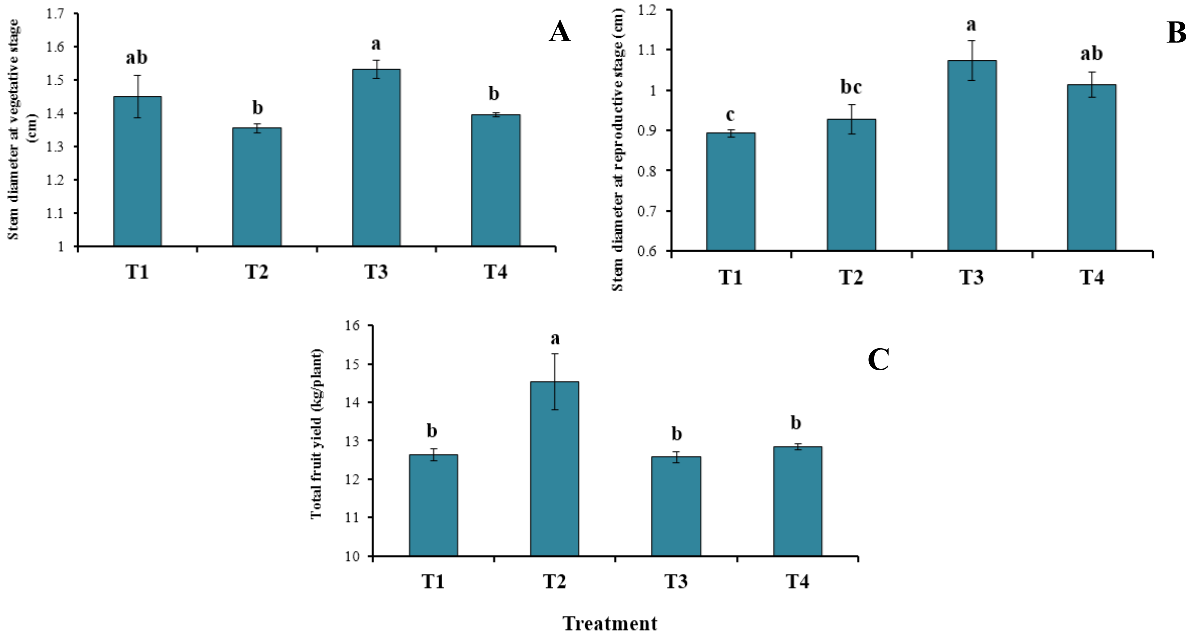


**Fig. 3.** Effects of increasing N and K application on the (A) Stem diameter at the vegetative stage, (B) stem diameter at the reproductive stage, and (C) Total fruit yield in tomato. Values were the means of three replicates and bars represent the standard errors. T1: vegetative stage, N160 + K350 ppm; reproductive stage, N130 + K250 ppm; T2: vegetative stage, N170 + K360 ppm; reproductive stage, N140 + K260 ppm; T3: vegetative stage, N180 + K370 ppm; reproductive stage, N150 + K270 ppm; T4: vegetative stage, N190 + K380 ppm; reproductive stage, N160 + K280 ppm.

## Discussion

The results showed that mineral nutrients, fruit quality, and growth traits of tomatoes were significantly affected by increasing N and K levels. The concentration of N and Fe in leaves increased in response to increasing N and K concentrations (N180 + K370 ppm at the vegetative stage and N150 + K270 ppm at the reproductive stage). These results confirmed that a combined supply of essential elements, such as N and K, at appropriate times during the growth season can impact the internal solubility of nutrients directly or indirectly. The increase in N and Fe contents of tomato leaves by increasing N and K is consistent with changes in the vegetative parts of grapes observed by Karimi (2017).

Higher doses of N and K led to a decrease in Ca in leaf content. Since excess K reduces Ca mobility, increasing the K supply may also reduce the economic benefit (Liu et al., 2019). Magnesium is central to chlorophyll structure and participates in many physiological processes, such as energy metabolism, pigment synthesis, and photosynthetic carbon fixation (Alharthi et al., 2021). Lower concentrations of N and K (N160 + K350 ppm at the vegetative stage and N130 + K250 ppm at the reproductive stage) improved the Mg content in tomato leaves. According to Grzebisz (2013), higher $Mg^{2+}$ content in the soil solution at low N rates promotes N uptake and boosts sugar beet growth at an early stage.

A general trend in decreasing Na, Mn, and Zn contents in leaf samples occurred with increasing N and K concentrations in the nutrient solution (Fig. 1D, F, G). Higher N and K doses suppressed the uptake of Cu and B in leaves (Fig. 1H, I). Increasing N and K decreased the $Na^{+}$ uptake (Fig. 1D) due to the higher availability of N. As a result, N and K applications improved the ability of plants to resist or avoid $Na^{+}$ uptake (Ashraf et al., 2008). Mn supports several biochemical activities while being immobile. This nutrient only moves through the xylem towards the leaves. Once there, its transfer is restricted in the plant (Pasković et al., 2021). In our experiment, leaf tissues accumulated a higher level of Mn than fruits (Fig. 1F). The increased supply of N and K concentrations did not influence the accumulation of all nutrients (except for Cu nutrient) in fruits (Fig. 1A-I). T2 most significantly benefited the Cu concentration in tomatoes, thus leading to high nutritional quality. Tomatoes are rich in ascorbic acid (ascorbic acid) and act as antioxidants in the human body. In this role, ascorbic acid removes free radicals produced during nutrient digestion (Chaudhary et al., 2018). Increasing N and K nutrients resulted in decreased accumulation of ascorbic acid in tomato fruits (Fig. 2A). Similarly, Stefanelli et al. (2010) indicated that increased N feeding improved vegetative growth and led to larger fruits, suggesting that the reduction in ascorbic acid may be partly due to a dilution effect. In contrast, Afzal et al. (2015) found that ascorbic acid contents can be improved significantly via potassium nutrition at high levels.

Total acids and soluble solids are the main components that constitute flavor in tomatoes (Vogel et al., 2010). The present study demonstrated that appropriate N and K doses could increase the total acids. The highest concentration of N and K decreased the total acids in fruits (Fig. 2B). Previous studies indicated that an increased K application to the plant raised the total acid content in fruits (Alva et al., 2006). Furthermore, the total acid in fruits declined as the potassium supply increased (Kumar and Kumar, 2007).

Total soluble solids can be a primary tomato fruit quality index, the general term employed to explain the soluble solids in tomato fruit pulp, comprising about 65% sugar, 13% organic acids, and 12% other minor components (Chen et al., 2014). TSS content was significantly higher in response to higher amounts of K and N in the nutrient solution. El-Nemr et al. (2012) revealed that increasing the K concentrations in the nutrient solution increased the TSS significantly.

An excessive N supply can improve plant growth, broaden shade area, and decrease temperature, thus inducing acid synthesis (Bénard et al., 2009). Optimum K application improves plant photosynthesis and sugar synthesis, thus increasing soluble solids and organic acids in fruit photosynthesis and promoting the synthesis of sugar compounds in plants (Crisosto and Costa, 2008).

In recent years, lycopene has been increasingly utilized in the food industry and pharmaceuticals and is beneficial to human health. (Grabowska et al., 2019). Our results suggested that increasing the N and K supply led to higher levels of lycopene and chlorophyll contents in tomato fruits (Fig. 1), which agrees with the findings of Wang et al. (2015) in that increasing the N fertilizer supply improved the lycopene content in fruit tomatoes. K nutrient may play a unique role in the synthesis of lycopene. This element can affect lycopene synthesis through increased enzymatic activity in carbohydrate metabolism, preparing the necessary substrates for terpenoid synthesis (Serio et al., 2007). Accordingly, appropriate levels of N and K are essential for tomato production, with adequate concentrations of other nutrients to produce fruits of commercial quality.

In the present study, high N and K concentrations provided the most favorable environment for stem diameter growth at the reproductive stage. Tomato fruit yield significantly improved with increasing N and K (N170 + K360 ppm at the vegetative stage and N140 + K260 ppm at the reproductive stage) because an increase in N content improved the physiological growth of the plant and enhanced its uptake of nutrients and water (Drenovsky et al., 2012). Guler and Guzel (1999) investigated fruit yield improvements with increasing levels of N and K, observing that the highest K supply (300 to 450 mg $L^{-1}$) reduced productivity. Increased K concentration in the nutrient solution can distort the nutritional balance of the plant by competing with other nutrients such as Mg and Ca or by increasing the salinity of the medium (Sainju et al., 2003), thus causing nutrient loss by leaching and prompting reductions in plant yield.

## Conclusion

Our study suggested that increasing N and K supply significantly improved total soluble solids content and caused chlorophyll accumulation in tomato fruits. As a result, N and K applications improved fruit quality to some degree. Nutrient concentrations were significantly affected by increasing levels of N and K application. Na, Mn, Ca, and Zn contents decreased in the leaves with the excessive supply of N and K. However, nutrient concentrations in fruits were unaffected by an increased supply of N and K (except for Cu nutrient). T2 was most beneficial in increasing total fruit yield. The best treatment in the present study was N170 + K360 ppm at the vegetative stage and N140 + K260 ppm at the reproductive stage.

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**Conflict of Interest**
The authors indicate no conflict of interest in this work.

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