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Impact of Foliar Application of Zinc and Zinc Oxide Nanoparticles on Growth, Yield, Nutrient Uptake and Quality of Tomato

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Abstract: Appropriate foliar application of zinc (Zn) and zinc oxide nanoparticles (ZnO-NPs) is important for the proper growth and yield of tomato. However, the effects of foliar application of Zn and ZnO-NPs were not well-studied on tomato production. A pot experiment was conducted at glasshouse (8D) conditions under the Faculty of Agriculture, Universiti Putra Malaysia (UPM) to evaluate the effectiveness of Zn and ZnO-NPs on growth, yield, nutrient uptake, and fruit quality of tomatoes and to compare between the Zn nutrient and ZnO-NPs. Treatment combinations were 14 viz. T_1 = 0 (control), T_2 = 1500 ppm (mg/L) Zn nutrient, T_3 = 2000 ppm (mg/L) Zn nutrient, T_4 = 2500 ppm (mg/L) Zn nutrient, T_5 = 75 ppm ZnO nanoparticle, T_6 = 100 ppm ZnO nanoparticle, and T_7 = 125 ppm ZnO nanoparticle along with two tomato varieties. The experimental design was a split plot with four replications. Results indicated that foliar application of 100 ppm ZnO-NPs performed best in terms of growth parameters, physiological traits, yield attributes, yield, and quality traits of tomatoes. The same treatment (100 ppm ZnO-NPs) contributed to attain the highest nutrient uptake. Recovery use efficiency of Zn was highest with foliar application of 75 ppm ZnO-NPs. The highest yield increment (200%) over control was from foliar sprayed with 100 ppm ZnO-NPs. Comparing the two varieties, MARDI Tomato-3 (MT3) showed better than MARDI Tomato-1 (MT1). As is appears from the results, foliar application of zinc oxide nanoparticles was more efficient than conventional zinc fertilizer. Therefore, the foliar sprayed with 100 ppm ZnO-NPs can be suggested to improve quantity and quality of tomato in glasshouse soil conditions.

Keywords: *Solanum lycopersicum*; ZnO-NPs; quality; use efficiency

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1. Introduction

Tomato (*Solanum lycopersicum* L.) is a good source of phytochemicals and nutrients such as lycopene, potassium, magnesium, calcium, iron, folate, and vitamin C [1]. It provides other antioxidants such as beta-carotene and phenolic compounds, as well as protein, flavonoids, hydroxycinnamic acid, chlorogenic, homovanillic acid, and ferulic acid that help in preventing cancer and degenerative diseases [1,2].

Tomato crop production is hampered due to the lack of proper management practices including micronutrients such as zinc. Hence, introduction of appropriate practices of Zn including macro and other micronutrients plays an important role for tomato yield maximization and quality improvement. The Zn helps in increased fruit yield, fruit set, number of fruits per plant, fruit length and diameter, dry weight of fruits, number of seeds per fruit, and fruit yield per plant [3]. Zinc is used extensively as a component of treating solution in current agriculture. Foliar application of micronutrients is the most efficient and safe method, and it is preferable to soil treatments since it quickly ensures improvement of plant growth, yield, and quality [3,4].

Reducing the particle size of the droplets can assist in preventing the buildup of spraying materials such as nanoparticles (NPs), which have a distinctive size between 1 and 100 nm [5]; this can be achieved through nanotechnology, an emerging technology that has the potential to revolutionize every branch of agricultural research activities for benefit of productivity, food, and nutritional security in future [6]. The ZnO-NPs involved in growth characteristics, photosynthesis, yield, and biomass production improve the efficiency of nutrient uptake and nutrient content in edible plant parts and increase the contents of sugar, total nitrogen, and protein in many crops [7–10]. This nanoparticle is confirmed to reduce Zn deficiency in plants [11].

Currently, several studies have been performed to check the effect of zinc fertilizer and zinc oxide nanoparticles in various plants such as eggplant, wheat, onions, and peanut including tomatoes. However, no systematic research trial has been conducted in a comparative way on the effect of zinc fertilizer and zinc oxide nanoparticles on productivity, quality improvement, nutrient uptake, and nutrient use efficiency in tomatoes. Since larger concentration of zinc oxide nanoparticles may hamper the crop productivities such as with tomato, choosing the right dosage of zinc oxide nanoparticles for tomatoes plants is essential. Now, it is crucial to maintain soil health for improving the yield and quality of crops without soil deterioration and environmental and economic hazard of excess fertilizer approach. In the above circumstances, it is essential to evaluate the appropriate dosages of zinc fertilizer and zinc oxide nanoparticles for yield maximization, quality improvement, and nutrient uptake and use efficiency of tomatoes and also compare between zinc fertilizer and zinc oxide nanoparticles under glasshouse conditions.

2. Materials and Methods

2.1. Experimental Site, Treatment and Design

The pot experiment under glasshouse (8D) conditions was conducted at the Agro-Tech Unit, Ladang 15, Faculty of Agriculture, Universiti Putra Malaysia (UPM), Serdang, Selangor from March 2021 to August 2021. The site was in the lowland of Malaysia at 2°59′22.6″ N latitude and 101°42′82.2″ E longitude. The soil of the study area belongs to the Bungor soil series of Ultisols [12]. The texture of the collected soil (0–20 cm depth) was sandy clay loam. The average daytime temperatures of the site were 32.69 °C (35.65 °C inside the glasshouse), and relative humidity averaged 86.08% (81.84% inside the glasshouse), reflecting high ambient temperature and high humidity. The 14 treatment combinations were comprising seven levels of Zn fertilizer and zinc oxide nanoparticles (ZnO-NPs) such as T_1 = Control (0), T_2 = 1500 ppm(mg/L) Zn nutrient, T_3 = 2000 ppm(mg/L) Zn nutrient, T_4 = 2500 ppm(mg/L)Zn nutrient, T_5 = 75 ppm(mg/L) ZnO nanoparticle, T_6 = 100 ppm (mg/L) ZnO nanoparticle, and T_7 = 125 ppm(mg/L) ZnO nanoparticle along with two tomato varieties, MT-1 and MT-3. The experiment was laid out in split plot design with four replications. The varieties were considered as main plot, and Zn nutrient doses (Zn fertilizer and zinc oxide nanoparticles) were as sub-plot.

2.2. Plant and Planting Materials

The seeds of two high-yielding tomatoes varieties, MT-1 and MT-3, released by the Malaysian Agricultural Research and Development Institute (MARDI), were used in the study. The released MT-1 and MT-3 varieties are suitable for the cultivation in the lowland area of Malaysia year-round. The seeds were germinated in a total of 4 germination trays using a medium of peat moss and bio-soil (3:1). Seeds were sown in germination trays on 5 March 2021. After emergence, developing seedlings were watered thrice weekly. Twenty-five-day-old strongest and healthiest seedlings were uprooted from the germination trays and were put by hand on 30 March 2021 in black poly bags (18″ × 18″) with 32 holes to allow for drainage. Each poly bag contained 20 kg of soil media. Tomato seedlings followed the spacing of 60 cm between each plant and 75 cm between each row.

The texture and nutrient statuses of initial soil samples were analyzed by the standard methods and the properties are presented in Table 1.

Table 1. Initial soil physical and chemical properties of the experimental pot.

Properties and Unit	Value
% Sand	46.35
% Silt	21.48
% Clay	32.17
pH	6.52 ± 0.409
Total C (%)	2.44 ± 0.179
Total N (%)	0.18 ± 0.022
Total S (%)	0.05 ± 0.011
Available P (mg//kg)	9.39 ± 0.61
Potassium (mg/kg)	140.25 ± 10.091
Calcium (mg/kg)	775 ± 58.248
Magnesium (mg/kg)	85.35 ± 6.284
Boron (mg/kg)	2.4 ± 0.189
Zinc (mg/kg)	10.7 ± 0.718

2.3. Synthesis Method of Zinc Oxide Nanoparticles (ZnO-NPs)

The 2 mL of 0.01% Poly Vinyl Alcohol (PVA) solution was added to 1 M of zinc sulfate heptahydrate solution, after which 2 M of sodium hydroxide was added dropwise and slowly. The resulting solution was then stirred for almost 18 h. A significant amount of white precipitate formed after 18 h. Then, it was filtered, cleaned with distilled water, and dried in a muffle furnace for two hours at a temperature of 100 °C. After being ground into a fine powder, it was finally calcined for three hours at 450 °C. According to Mohan and co-workers [13], the structural and morphological properties of ZnO were examined by using XRD and FESEM.

2.4. Agronomic Practices

Three types of fertilizer as a blanket dose were applied in a liquid form. These fertilizers were applied to tomatoes plants at seedling (initial) stage for two weeks, vegetative stage for three weeks, and fruiting stage for five weeks. The initial liquid fertilizer was prepared by addition of 20g fertilizer in 20 L water following the composition of N (13%), P (40%), K (13%), B (0.01%), Cu (0.003%), Fe (0.025%), Mn (0.013%), Mo (0.0018%), and Zn (0.004%) nutrients. The initial liquid fertilizer was applied to each tomato plant at the rate of 250 mL twice in a week at seedling stage. The second liquid solution was prepared by addition of 20g fertilizer in 20 L water followed by the composition of N (13%), P (40%), K (13%), B (0.01%), Cu (0.003%), Fe (0.025%), Mn (0.013%), Mo (0.0018%), and Zn (0.004%), and it was given twice in a week to each tomato plant at the rate of 300 mL in the vegetative stage. The third liquid solution was prepared by addition of 35 g fertilizer in 20 L water followed by the composition of N (13%), P (7%), K (20%), Ca (8%), Mg (2%), B (0.025%), Cu (0.01%), Fe (0.085%), Mn (0.045%), Mo (0.0038%), and Zn (0.025%), and it was applied twice in a week at the rate of 500 mL in the fruiting stage.

Treatment-wise, three splits of zinc foliar applications were performed to three different plant growth stages. Spray materials of Zn fertilizer were prepared in a total amount of about 750 milliliters of water, which was divided in 3 equal parts—250 mL + 250 mL + 250 mL of solution. The first spray of 250 mL solution was completed to each plant before flower initiation, the second spray (250 mL) was applied to each plant in the fruit set when it reached marble size, and the third spray (250 mL) was applied 20 days after the second spray to the single plant. The source of Zn fertilizer was zinc chelate (AgEDTA-Zn-14%). Similarly, as per treatment, three splits of ZnO-NPs were foliar-sprayed to three different plant growth stages. Spray materials of ZnO-NPs were prepared in a total amount of about 1000 milliliters of water, which was split into 3 parts—300 mL + 300 mL + 400 mL of solution. The first spray of 300 mL ZnO-NPs solution was applied to each plant before flower initiation, the second spray (300 mL) was applied to each plant in the fruit set when it reached marble size, and the third spray (400 mL) was applied 20 days after the second spray to the single plant.

Tomatoes plants were vertically staked using plastic sticks to avoid the plant wounding and damaging the roots. Weeding and irrigation was performed as per requirement. Diseases and insects were not observed during the study.

2.5. Data Collection of Growth, Yield and Yield Parameters

Plant height, number of primary branches per plant, and number of fruits per plant were determined. A leaf area meter (LI-3000, Li-COR, Lincoln, NE, USA) was used for calculating the leaf area represented as cm^2. Until the last commercial harvest of tomato fruits, total fruit weight per plant (kg) was recorded according to the method of Cox [14]. The fruit weight kg per plant was converted into t/ha. Leaf chlorophyll content was measured by a soil–plant analysis development (SPAD) chlorophyll meter (Konica Minolta, model SPAD-502 plus, Tokyo, Japan) from each plant of each treatment at vegetative, flowering, and mature stages. The SPAD readings were collected from mid-ribs of fully expanded individual leaves in each plant. Tomato fruits were harvested during the second week of June (15 June) 2021 to the end of July (31 July) 2021. Five fruit samples from each plant were collected to record fruit length, fruit diameter, and individual fruit weight.

2.6. Data Collecton of Photosynthetic Parameters

The data of gross photosynthetic rate (PN), leaf stomatal conductance (gs), and transpiration rates were measured by a portable gas-exchange system LI-6400 (LI-COR, Lincoln, NE, USA) from 5-week-old plant leaves of each treatment in the morning.

2.7. Determination of Quality Parameters

Fresh and matured uniform tomato samples were collected from each treatment plant, brought to the laboratory and preserved by freezing at -30 °C, and held for fruit quality analysis. Tomato fruit samples were to determine total soluble solid (TSS), fruit firmness, titratable acidity (TA), ascorbic acid, lycopene, total phenolic content (TPC), and DPPH radical scavenging assay.

Total soluble solid (TSS) was measured by using fresh fruit juice dropped on the digital pocket refractometer's glass lens (model PAL1, ATAGOTM Tokyo Tech, Minato city, Japan), and results were expressed in °Brix according to an accepted method [15].

A Universal Testing Machine (Model 5543, load frame, Instron Corp., University Avenue Norwood, Norwood, MA, USA) with a 6 mm diameter cylindrical probe at a speed of 20 mm per min and an Instron Merlin software, version M12-13664-EN were used to measure the firmness of the tomato fruits. A reading in Newton (N) was recorded for each sample [16].

Titration techniques were used to determine the titratable acidity. Approximately 10 g of tomato fruit pulp tissue were homogenized and filtered using cotton wool after being blended with 20 mL of distilled water in a kitchen blender (MX-799S, Panasonic). In response to the appearance of a pink color, two drops of phenolphthalein indicator (1% dye) were added to a 5-mL titrate. This was followed by a 0.1 N sodium hydroxide (NaOH) titration up to the endpoint (pH 8.1). According to the procedures of Mohammadi-Aylar et al. [17], the volume of titrating added was noted, and the results were expressed as the percentage of citric acid per 100 g fresh weight.

$$\text{Titratable acidity (\%)} = \frac{\text{Titer vol. (mL)} \times \text{normality NaOH}(0.1) \times \text{vol. made up (20 mL)} \times 64\ \text{g(equivalent wt. of citric acid)} \times 100}{\text{Wt. of sample (5 g)} \times \text{vol. of sample for titration (5 mL)} \times 1000} \quad (1)$$

2,6-Dichlorophenol-indophenol (DCPIP) dye was used in direct colorimetric methods to measure ascorbic acid [18]. To make a volume of 40 mL, 2 g of tomato samples were combined with 20 mL of metaphosphoric acid, HPO_3 (2%) and extracted. The samples were then filtered with cotton wool, and the volume was then diluted with additional HPO_3 (2%). The aliquot (0.5 mL) was combined with 3 mL of HPO_3 (2%) and 2 mL of dye solution, and the absorbance at 518 nm wavelength was measured immediately using a UV spectrophotometer (Spectrophotometer-1510, Thermo Fisher Scientific, Vantaa, Finland). The amount of ascorbic acid in tomato fruit, expressed as mg/g fresh weight, was found using the standard curve.

$$\text{AA (in mg/g FM)} = \frac{\text{Cppm} \times \text{V}}{\text{W}} \tag{2}$$

Here, Cppm = Conc. of sample soln. as ppm computed from the standard curve, V = Final vol. made up in liter (0.04 L), W = Fresh wt. of the samples (g).

Following slightly modified techniques developed by Nagata and Yamashita, the fruit lycopene was determined following to the method of Nagata, et al. [19]. A mixture of 10 to 20 mL of acetone and hexane (acetone:hexane = 4:6) was used to dissolve about 1 g of sample. Using a mortar and pestle, the pigments were extracted, homogenized, and the supernatant was automatically separated. A UV spectrophotometer was used to measure the optical density at 663, 645, 505, and 453 nm. The amount of lycopene was calculated using the below equation

$$\text{Lycopene (mg/100 g)} = -0.0458A_{663} + 0.204A_{645} + 0.372A_{505} - 0.0806A_{453} \tag{3}$$

A_{663}, A_{645}, A_{505}, and A_{453} are the absorbance at 663 nm, 645 nm, 505 nm, and 453 nm of each other. Data obtained as mg/100 mL were further converted as data mg/100 g × sample, volume = data mg/100 g.

Total phenolic content (TPC) and DPPH radical scavenging assay: Using a pestle and mortar, a 3-g weight tomato sample was ground. The ground sample was added to an 8 mL dark-colored tube filled with 80% (*v*/*v*) methanol, and the tube was then mounted on an orbital shaker and shaken for an hour at 180 rpm. The mixture was then filtered using No. 1 Whatman filter paper, and the supernatant was prepared for 2,2- diphenyl-1-picrylhydrazyl (DPPH) and Total Phenolic Content (TPC) analysis. Up until it was used for the experiment, the supernatant was kept in the chiller. The procedure was applied in accordance with Addai et al. [20], with a few minor modifications. Total phenolic content (TPC) was measured by the procedures outlined by Musa et al. [21] that after mixing 150 mL of the supernatant with 750 mL of 10% Folin–Ciocalteu reagent (FCR), the mixture was incubated for five minutes. After that, 600 L of sodium carbonate at 7.5% (*w*/*v*) was added. The mixture was then incubated once more in the dark for an additional 30 min. A UV spectrophotometer was used to measure the absorbance at a wavelength of 765 nm after 30 min of incubation. The results were given in milligrams of gallic acid equivalents for every 100 g of fresh sample (mg GA/100 g FW).

The DPPH (2,2-diphenyl-1-picrylhydrazyl) free radical scavenging techniques described by Musa et al. [21] were used to measure the antioxidant activity. To create the stock solution, 40 mg of DPPH was dissolved in 100 mL of 80% methanol, which was then chilled until needed. About 1 mL of the supernatant was combined with 1 mL of 1 mM DPPH, and the mixture was incubated for 30 min in the dark. The UV spectrophotometer was used to measure the absorbance at 517 nm immediately the following incubation, and the following equation was used to calculate the percentage of antioxidant activity:

$$\text{DPPH scavenging activity (\%)} = \frac{(A_{\text{blank}} - A_{\text{Sample}})}{A_{\text{blank}}} \times 100 \tag{4}$$

where A is for absorbance.

2.8. Plant Samples Analysis

Determination of N, P, K, S, Mg, B, Fe, and Zn Content in Leaves and Fruits

Above-ground plant parts such as leaves from each treatment plant were collected and air- as well as sundried for 3 days, and then they were oven-dried at 60 °C for 72 h and ground to pass through a 1 mm sieve. Tomato fruit samples from each treatment plant were washed and sliced into round or triangular shapes for 5 days of air- and sun-drying, then they were oven-dried and ground to pass through a 1 mm sieve. Each sample of dry leaves and fruit was preserved in plastic bottles. Dry samples of tomato fruits and leaves were taken and Leco's TruMac CNS analyzer was used to calculate the total amounts of carbon, nitrogen, and sulfur. In brief, 0.2–0.3 g of the dry sample was placed in a ceramic boat and burned at 1350 °C with helium, compressed air, and 99.999% pure oxygen. C, N, and S were identified by the analyzer as CO_2, NO_2, and SO_2 gases, respectively. On a percentage basis (%), the total C and N contents were recorded.

One gram of the oven-dried sample was taken and put in a crucible cup to create ash in a muffle furnace made of carbolite (AAF1100) at 300 °C for an hour. After cooling the sample, the temperature was raised to 550 °C for 8–9 h. Following the addition of 2 mL of concentrated HCl and a few drops of distilled water, the sample was dried by being placed on a hot plate for 15 to 20 min in the fume hood chamber. The sample was once more cooled down before 10 mL of 20% HNO_3 was added to it, and it was kept in the water bath for an hour with the crucible cap covered. The sample was then carefully cleaned and made up to a volume of 100 mL before filtering through Whatman filter paper no. 2 into a volumetric flask. Then, standard solution was made. Phosphorus, K, Mg, B, Fe, and Zn content in the solution was measured by an ICP-Optical Emission Spectrometer (Perkin Elmer, Optima 8300, PerkinElmer Corporation, Norwalk, CT, USA).

2.9. Soil Sample Analysis

Particle size of the initial soil was determined by hydrometer method [22]. Initial soil pH was determined by glass electrode pH meter using a soil–water ratio of 1:2.5 [23]. A soil sample-filled paper bag was placed in the oven at 70 °C for 72 h to dry until it reached a constant weight. The soil sample was crushed and sieved with a 4 mm sieve after drying. Leco's TruMac CNS analyzer was used to calculate the total amounts of carbon, nitrogen, and sulphur. Potassium, Ca, Mg, B, and Zn content in the soil was measured by the similar procedure of ICP-Optical Emission Spectrometer (Perkin Elmer, Optima 8300, PerkinElmer Corporation, Norwalk, CT, USA).

2.10. Calculation of Nutrient Uptake

The following formula [24] was used to calculate the nutrient uptake by multiplying the plant part's dry weight (oven dry weight) by the nutrient content:

$$\text{Nutrient uptake} = \frac{\text{Nutrient concentration } (\%) \times \text{ Dry weight } (\text{g})}{100} \tag{5}$$

2.11. Calculation of Apparent Nutrient Recovery Efficiency (ANR)

The apparent nutrient recovery efficiency (ANR) was calculated on a dry-weight basis according to Baligar et al. [25], and the equation is as follows:

$$\text{ANR} = \frac{\text{Nutrient uptake}(\text{mg/plant}) - \text{ control value}}{\text{Applied nutrient } (\text{mg/plant})} \times 100 \tag{6}$$

2.12. Relative Data in Percentage

For each element, the relative data of the value were presented as percentages relative to the control [26].

$$\text{Relative data } (\%) = \frac{\text{Treatment value} - \text{control value}}{\text{control value}} \times 100 \tag{7}$$

2.13. Statistical Analysis

Data for growth, yield and yield-contributing characters, quality traits, nutrient content, and nutrient uptake were subjected to statistical analysis of ANOVA using SAS software (version 9.4). Means of all data were compared using the Tukey's HSD test with a significance level of 0.05 ($p \leq 0.05$).

3. Results and Discussion

Results of the present experiment are presented, and only significant results for explanation are discussed. Foliar application of different levels of Zn fertilizers and zinc oxide nanoparticles (ZnO-NPs) affected the maximum characteristics of tomatoes.

3.1. Growth Parameters of Tomato

The plant height, number of primary branches per plant, and leaf area of two varieties of tomatoes were significantly influenced by the foliar application of Zn fertilizers and zinc oxide nanoparticles (ZnO-NPs) (Table 2). The highest plant height (135 cm) was observed in T_6 (100 ppm ZnO nanoparticles) treatment, which was an 18% increase over control, and this treatment was similar to most of the treatments. However, decreased plant height (117 cm) was achieved in increased application of 0.25% zinc fertilizer (T_4). However, minimum plant height (114 cm) was in T_1 (control) treatment. Zinc oxide nanoparticles might be more effective to develop the plant growth such as plant height due to the release of demanding nutrients for crop [8]. Sun et al. [27] reported that foliar spraying with 100 mg/L ZnO-NPs obtained the maximum plant height. The tomato plants treated with 50 ppm of ZnO-NPs exhibited highest shoot length increment (30.1%) over control [28]. It has been reported that the application of ZnO-NPs at 100 ppm resulted the 16% increase in plant height compared to control treatment in wheat [11]. In the study, increased number of primary branches per plant (18.5) was in T_6 (100 ppm ZnO nanoparticles) comparable with T_7 (125 ppm ZnO nanoparticles) and T_5 (75 ppm ZnO nanoparticles) treatments. Foliar application of increased dose of Zn fertilizer (0.25%) tended to decrease the number of primary branches per plant. The lowest number of primary branches per plant (8.50) was from control treatment (T_1). The ZnO-NPs contributed significantly to enhance the tomato shoot growth, chlorophyll content, and photosynthetic efficiency [29]. Similar viewed verified by Faizan et al. [28] that ZnO-NPs cooperate with meristematic cells and metabolic flows that promote growth characteristics. In the case of leaf area, the increased leaf area (25.45 cm^2) was obtained from the plant receiving 100 ppm ZnO nanoparticles (T_6) followed by the plant getting 125 ppm ZnO nanoparticles (T_7). The lowest result (13.08 cm^2) was in control treatment (T_1). Zinc oxide nanoparticles are a very effective source of Zn because they are essential for normal plant growth and development as carbohydrates and protein metabolism and help with auxin synthesis, which ultimately enhances cell wall development and cell differentiation of plants [30]. The maximum leaf area (24.1%) was observed by the application of 50 ppm ZnO-NPs over control [7,28].

3.2. Physiological Characters

Physiological traits such as photosynthetic and transpiration rates exhibited significant variation between tomato varieties, but others such as leaf chlorophyll content and stomatal conductance were insignificant (Table 3). Regarding two varieties, the significantly highest photosynthetic rate (24.5 $\mu mol/m^2/s$) was achieved in the V_2 = MT3 variety and the minimum was (23.6 $\mu mol/m^2/s$) in the V_1 = MT1 variety. Significantly, an increased transpiration rate was also found (12.4 $mmol/m^2/s$) in the V_2 = MT3 variety, and lesser was in the V_1 = MT1 variety. The above photosynthetic rate and transpiration rate variation might be related to the varietal divergence. However, the physiological growth performances are dependent mainly on their morphological and physiological process during the growth period, which are controlled by the interaction of both genetic make-up and the environmental conditions [31]. Furthermore, the variety V_2 = MT3 had a higher capacity of nutrient uptake than the V_1 = MT1 variety. The reports by Olaniyi et al. [32] indicated that UC82B was higher in the physiological growth attributes of tomato than other varieties evaluated.

The physiological parameters such as the leaf chlorophyll content, photosynthetic rate, stomatal conductivity, and transpiration rate of two varieties of tomatoes were significantly influenced by the foliar application of Zn fertilizers and zinc oxide nanoparticles (ZnO-NPs) (Table 3). The highest chlorophyll content (51.6 SPAD) in leaves was measured from T_6 (100 ppm ZnO nanoparticles) which was statistically similar to T_7 (125 ppm ZnO nanoparticles) treatment. However, decreased chlorophyll content was recorded from an increased dose of zinc at 0.25% Zn fertilizer comparable with the control treatment (T_1). Sun et al. [27] reported that the improved amount of chlorophyll in tomato leaves were from foliar sprayed with 100 ppm ZnO-NPs. The foliar spraying of 50 ppm ZnO-NPs indicated 32.1% increment of chlorophyll over control [28]. In the case of photosynthetic rate, the maximum photosynthetic rate (30.8 μmol/m^2/s) was from T_6 (100 ppm ZnO nanoparticles) followed by T_7 (125 ppm ZnO nanoparticles) treatment. Photosynthetic rate was increased by 61.7% in T_6 over control. Results also indicate that decreased photosynthetic rate was correlated with increased dose of zinc 0.25% (T_4), which was 67.4% lower than the maximum result. This highest result might be due to the better role of zinc oxide nanoparticles. Similar assessment verified by Sofy et al. [33] that zinc oxide nanoparticles resulted in the highest photosynthetic rate of tomatoes. The significant effect of foliar spray at 50 ppm ZnO-NPs increased the net photosynthetic rate by 33% over control [28]. Application of ZnO-NPs at 100 mg/L improved photosynthetic rate by 58% compared to control in wheat plant [11].

Table 2. Effect of zinc fertilizer and zinc oxide nanoparticles on growth parameters of two selected tomato varieties.

Treatment	Plant Height (cm)	No. of Primary Branch/Plant	Leaf Area (cm^2)
V_1 = MT1	123 a ± 2.31	13.1 a ± 0.75	18.1 a ± 0.93
V_2 = MT3	125 a ± 2.13	13.7 a ± 0.76	19.1 a ± 0.98
Level of significance	ns	ns	ns
MSD value	5.09	1.16	1.01
CV (%)	8.42	14.5	8.36
T_1	114 c ± 2.85	8.50 d ± 0.46	13.1 d ± 0.41
T_2	124 abc ± 2.84	14.0 bc ± 0.71	19.1 c ± 0.50
T_3	121 abc ± 3.63	11.0 cd ± 0.60	14.8 d ± 0.47
T_4	117 bc ± 3.02	9.38 d ± 0.60	12.7 d ± 0.33
T_5	127 abc ± 3.95	16.0 ab ± 0.76	22.1 b ± 0.66
T_6	135 a ± 4.28	18.5 a ± 0.71	25.4 a ± 0.66
T_7	131 ab ± 3.73	16.5 ab ± 0.65	23.1 ab ± 0.76
Level of significance	**	**	**
MSD value	16.37	3.05	2.43
CV (%)	8.42	14.57	8.36
Interaction (V*T) significance	ns	ns	ns

Means in a column that include the same letters are not statistically different at the 5% level using Tukey's HSD test. MSD = Minimum significant difference, CV = Coefficient of variation, T_1 = 0, T_2 = 1500 ppm Zn nutrient, T_3 = 2000 ppm Zn nutrient, T_4 = 2500 ppm Zn nutrient, T_5 = 75 ppm ZnO nanoparticle, T_6 = 100 ppm ZnO nanoparticle and T_7 = 125 ppm ZnO nanoparticle, Varieties = Main plot, Zn doses = Sub plot; Note: ns-not significant at $p > 0.05$, * significant at $p \leq 0.05$ and ** significant at $p \leq 0.01$; ±standard error (n = 4); (as ANOVA).

In our study, foliar sprayed with 100 ppm ZnO nanoparticles (T_6) significantly increased stomatal conductance (1.13 mol/m^2/s), which was identical to the T_7 (125 ppm ZnO nanoparticles) and T_5 (75 ppm ZnO nanoparticles) treatment. Results indicate that the highest dose of 0.25% zinc nutrient decreased the value of stomatal conductance. Tomato plant can be fed through foliar application with ZnO-NPs, resulting in good physiological growth [34]. The ZnO NPs might have helped to increase the stomatal conductance. A similar view corroborated by Munir et al. [11] in wheat plant demonstrated that foliar application of ZnO NPs at 100 mg/L improved stomatal conductance by 102% compared to control. Regarding transpiration rate, a significantly augmented transpiration rate (16.1 mmol/m^2/s) was from T_6 (100 ppm ZnO nanoparticles), and it was about 80 percent higher than control treatment (T_1). Zinc plays a vital role in the synthesis of carbonic anhydrase enzyme, which helps in transport of CO_2 in photosynthesis [35]. Application of ZnO-NPs at 100 mg/L improved transpiration rate by 62% compared to control in wheat plant [11].

Table 3. Effect of zinc fertilizer and zinc oxide nanoparticles on physiological growth traits of two selected tomatoes varieties.

Treatment	Chlorophyll Content in Leaf (SPAD)	Photosynthetic Rate (μmol/m^2/s)	Stomatal Conductance (mol/m^2/s)	Transpiration Rate (mmol/m^2/s)
V_1 = MT1	40.8 a ± 1.33	23.6 b ± 0.91	0.83 a ± 0.05	12.0 b ± 0.51
V_2 = MT3	41.8 a ± 1.33	24.5 a ± 0.96	0.87 a ± 0.04	12.4 a ± 0.52
Level of significance	ns	*	ns	*
MSD value	1.30	0.86	0.08	0.33
CV (%)	8.41	9.38	10.4	11.2
T_1	34.5 e ± 0.97	19.1 e ± 0.64	0.54 d ± 0.02	8.96 d ± 0.37
T_2	40.6 cd ± 1.01	23.8 cd ± 0.72	0.90 bc ± 0.03	13.1 bc ± 0.48
T_3	37.8 de ± 1.02	21.3 de ± 0.77	0.80 c ± 0.03	11.4 c ± 0.30
T_4	33.0 e ± 0.95	18.4 e ± 0.59	0.55 d ± 0.02	9.08 d ± 0.32
T_5	44.6 bc ± 1.15	27.1 bc ± 0.75	1.00 ab ± 0.03	13.1 bc ± 0.49
T_6	51.6 a ± 1.31	30.8 a ± 0.97	1.13 a ± 0.04	16.1 a ± 0.63
T_7	47.0 ab ± 1.24	28.1 ab ± 0.95	1.06 a ± 0.04	13.9 b ± 0.44
Level of significance	**	**	**	**
MSD value	5.43	3.53	0.14	2.15
CV (%)	8.41	9.38	10.41	11.26
Interaction (V*T) significance	ns	ns	ns	ns

Means in a column that include the same letters are not statistically different at the 5% level using Tukey's HSD test. MSD = Minimum significant difference, CV = Coefficient of variation, T_1 = 0, T_2 = 1500 ppm Zn nutrient, T_3 = 2000 ppm Zn nutrient, T_4 = 2500 ppm Zn nutrient, T_5 = 75 ppm ZnO nanoparticle, T_6 = 100 ppm ZnO nanoparticle and T_7 = 125 ppm ZnO nanoparticle, Varieties = Main plot, Zn doses = Sub plot; Note: ns—not significant at $p > 0.05$, * significant at $p \leq 0.05$ and ** significant at $p \leq 0.01$; ±standard error (n = 4); (as ANOVA).

3.3. Yield and Yield-Contributing Characters

Only tomato yield like fruit yield per hectare displayed a significant difference between two tomato varieties, but fruit length and diameter, individual fruit weight, number of fruits per plant, and fruit yield per plant were insignificant (Table 4). Significantly, the increased fruit yield of tomato (26.7 t/ha) was from the V_2 = MT3 variety, and lowest was from the V_1 = MT1 variety. The superior varietal response from V_2 = MT3 might be due to contribution of genetic variance and higher nutrient uptake capacity [36]. In the study, the variety V_2 = MT3 was calculated at 2.41% yield increment over the V_1 = MT1 variety. This yield increment of variety V_2 = MT3 might be attributed to confirmation of a higher number of fruits per plant. A similar statement was also outlined by Quddus et al. [36] and Razzaque et al. [37] in mung bean varieties.

Tomato yield per plant and per hectare and yield contributing characteristics such as fruit length and diameter, individual fruit weight, and number of fruits per plant were significantly influenced by the foliar application of zinc fertilizers and zinc oxide nanoparticles (Table 4). Regarding fruit length, the increased fruit length (4.73 cm) of tomatoes was achieved in T_6 (100 ppm ZnO nanoparticles) comparable with T_7 (125 ppm ZnO nanoparticles), T_2 (0.15% zinc fertilizer), and T_5 (75 ppm ZnO nanoparticles) treatments. On the other hand, a higher dose of zinc nutrient (0.25%) had gradually reduced the fruit length. The lowest fruit length (3.10 cm) was in the control treatment (T_1). In case of fruit diameter, the biggest fruit diameter (4.13 cm) was obtained from T_6 (100 ppm ZnO nanoparticles), which was statistically similar to T_7 (125 ppm ZnO nanoparticles), T_2 (0.15% zinc fertilizer), and T_5 (75 ppm ZnO nanoparticles) treatments. The minor fruit diameter (3.02 cm) was in control treatment (T_1). Fruit size, meaning fruit length and diameter, have special significance not only due to being components of yield, but they also determine the time of harvesting and better acceptance of fruits by stakeholders in the field and the market. However, Zn nutrient plays an important role for controlling the fruit quality such as fruit size. Zinc is necessary for the metabolism of RNA, as well as for the stimulation of the synthesis of carbohydrates, proteins, and DNA, as well as for fruit set, fruit length, and diameter [38]. The study indicated that a zinc oxide nanoparticle was the best way to achieve higher fruit size. A similar statement corroborated by Kumar et al. [39] indicated that ZnO-NPs @ 150 ppm with FeO-NPs was the best in terms of highest fruit length and diameter. Individual fruit weight is a very influential character of crop yield and genetically controlled. Agronomic practice and environment also imposed its appearance. In the study, the heaviest fruit (48.1 g) was in T_6 (100 ppm ZnO nanoparticles), which statistically resemble T_7 (125 ppm ZnO nanoparticles) and T_2 (0.15% zinc fertilizer), and higher dose of Zn fertilizer hampered the fruit weight. The higher fruit weight increment (94.4%) over control was recorded from T_6 treatment. The lightest fruit (24.7 g) was found in the control treatment (T_1). The ZnO nanoparticles might be involved in biochemical and enzymatic activities to the higher mobilization of photosynthates for developing the higher size of tomato fruit and heavy weight [5,39]. The findings of the study agree with the previous findings of Prasad et al. [40] in peanut. Number of fruits per plant is the most variable component and the most noticeable yield trait, which exhibited best correlation with tomato fruit yield [41]. Maximum number of fruits/plant (38.4) was recorded from T_6 (100 ppm ZnO nanoparticles), which was statistically similar to T_7 (125 ppm ZnO nanoparticles), T_2 (0.15% zinc fertilizer), and T_5 (75 ppm ZnO nanoparticles) treatments. The greatest percent increment (54.3%) of fruits per plant over control was also calculated from T_6 (100 ppm ZnO nanoparticles). The minimum number of fruits per plant (24.9) was from the control treatment (T_1). Zinc is crucial for plant nutrition and is considered as a fundamental component of several enzyme systems [42]. It is attributed to growth regulation, protein synthesis, energy production, enzyme activation, gene expression, phytohormone activity, photosynthesis, carbohydrate metabolism, fruit production, and defense against disease [43]. The result of fruits per plant in the study was confirmed by the findings of Faizan et al. [28], which indicated that the percent increment of number of fruits per plant over control was higher (21.1%) in foliar spraying at 50 ppm ZnO-NPs. The treatment containing ZnO NPs @ 150 ppm with FeO NPs was estimated the best in terms of the highest number of fruits per plant [39,40]. In the case of fruit yield per plant, the highest fruit yield (1.85 kg/plant) was obtained from T_6 (100 ppm ZnO nanoparticles), comparable to T_7 (125 ppm ZnO nanoparticles) and T_2 (0.15% zinc fertilizer) treatment. Regarding the fruit yield as tons per hectare, significantly increased fruit yield of tomatoes (36.9 t/ha) was from same T_6 treatment and lesser was from control treatment (T_1). Further increase in Zn fertilizer (0.25% Zn) tended to decrease the fruit yield of tomatoes. Results seemed to show that ZnO-NPs were more effective than conventional Zn fertilizer and moderate dose increased the productivity. A similar observation was corroborated by Wei Du et al. [44] in wheat. Tomato fruit yield more depends on the number of fruits per plant, fruit size, and fruit weight. The increment of fruit yield over control varied from 46.3 to 200% across the treatments. Among the various ZnO-NP concentrations, foliar spraying at 50 ppm produced the best results in terms of fruit production (19.4%), which increased over control [28]. The above result indicates that Zn foliar application may have promoted the photosynthesis process and translocation of photosynthetic products to the plant body as well as fruits or seed [45]. Tomato plant can be fed through foliar applications of ZnO-NPs to promote growth, flowering, fruit set, and marketable output by increasing photosynthesis [3,34,40]. Zinc with nanoscale ZnO @ 125 ppm resulted in an increase in shoot growth and pod production of peanut. Foliar application of nanoscale ZnO resulted in high zinc uptake by the leaf and kernel when compared to chelated zinc sulfate [40].

Table 4. Effect of zinc fertilizer and zinc oxide nanoparticles on the yield and yield attributes of two selected tomato varieties.

Treatment	Fruit Length (cm)	Fruit Diameter (cm)	Individual Fruit Weight (g)	No. of Fruits/Plant	Yield/Plant (kg)	Fruit Yield (t/ha)
V_1 = MT1	4.05 a ± 0.12	3.59 a ± 0.09	38.1 a ± 1.66	33.4 a ± 1.06	1.31 a ± 0.09	26.1 b ± 1.74
V_2 = MT3	4.12 a ± 0.12	3.65 a ± 0.09	38.6 a ± 1.63	33.8 a ± 1.03	1.34 a ± 0.08	26.7 a ± 1.72
Level of significance	ns	ns	ns	ns	ns	*
MSD value	0.38	0.21	0.67	1.86	0.08	0.40
CV (%)	9.18	9.21	9.92	10.54	16.44	10.07
T_1	3.10 d ± 0.09	3.02 d ± 0.08	24.7 e ± 0.68	24.9 c ± 0.79	0.62 e ± 0.03	12.3 g ± 0.63
T_2	4.43 ab ± 0.14	3.87 ab ± 0.13	43.5 ab ± 1.42	36.2 a ± 1.16	1.58 ab ± 0.08	31.6 c ± 1.50
T_3	3.90 bc ± 0.12	3.45 bcd ± 0.09	35.8 cd ± 1.48	33.2 ab ± 1.31	1.19 cd ± 0.06	23.8 e ± 1.28
T_4	3.60 cd ± 0.12	3.23 cd ± 0.15	30.4 de ± 0.92	29.6 bc ± 1.13	0.90 de ± 0.05	18.0 f ± 0.93
T_5	4.23 ab ± 0.11	3.73 abc ± 0.11	40.4 bc ± 1.15	35.7 a ± 1.18	1.45 bc ± 0.07	28.9 d ± 1.46
T_6	4.73 a ± 0.14	4.13 a ± 0.12	48.1 a ± 1.59	38.4 a ± 1.40	1.85 a ± 0.10	36.9 a ± 1.77
T_7	4.63 a ± 0.15	3.93 ab ± 0.12	45.6 ab ± 1.33	37.0 a ± 1.24	1.69 ab ± 0.08	33.7 b ± 1.77
Level of significance	**	**	**	**	**	**
MSD value	0.59	0.52	5.94	5.52	0.34	2.09
CV (%)	9.18	9.21	9.92	10.54	16.44	10.07
Interaction (V*T) significance	ns	ns	ns	ns	ns	ns

Means in a column that include the same letters are not statistically different at the 5% level using Tukey's HSD test. MSD = Minimum significant difference, CV = Coefficient of variation, T_1 = 0, T_2 = 1500 ppm Zn nutrient, T_3 = 2000 ppm Zn nutrient, T_4 = 2500 ppm Zn nutrient, T_5 = 75 ppm ZnO nanoparticle, T_6 = 100 ppm ZnO nanoparticle and T_7 = 125 ppm ZnO nanoparticle, Varieties = Main plot, Zn doses = Sub plot; Note: ns—not significant at $p > 0.05$, * significant at $p \leq 0.05$ and ** significant at $p \leq 0.01$; ±standard error (n = 4); (as ANOVA).

3.4. Quality Parameters

The total soluble solid (TSS), fruit firmness, and titratable acidity of tomatoes were significantly influenced by foliar spraying of Zn fertilizer and zinc oxide nanoparticles (Table 5). The most total soluble solid (9.05 ^{0}Brix) was attained from T_6 (100 ppm ZnO nanoparticles) comparable with most of the treatments except T_4 (0.25% zinc fertilizer) and T_1 (control). The lowest (7.05 ^{0}Brix) was from T_1 (control) treatment. Zinc plays a key role in plants with enzymatic activities, protein synthesis, and gene expression, and Zn is also involved in quality improvement of tomato fruits [35]. However, Sun et al. [27] reported that the tomato plants were sprayed with ZnO NPs at 100 ppm increased the sugar, starch, and glucose ultimately increased the TSS content. The application of phytonanoparticles at 50 ppm enhanced the total soluble solids by 26.92% over control [46]. In the experiment, the highest fruit firmness (17.3 N) was determined from T_6 (100 ppm ZnO nanoparticles), which was statistically similar to T_7 (125 ppm ZnO nanoparticles) and T_2 (0.15% zinc fertilizer) treatment. The highest increment of tomato firmness (48.4%) was obtained from the same T_6 treatment. The lowest firmness (11.7 N) was from T_1 (control) treatment. Subedi and Walsh [47] reported that fruit firmness of tomatoes is an important quality parameter closely associated with the ripening stage. The ripening stage can be considered the best-tasting tomatoes, but these fruits are more fragile and can become easily damaged; thus, it is better to harvest them earlier in order to extend their shelf-life and ensure they are safe from handling damage [48]. Zinc nutrition contributed significantly to improve the tomato fruit firmness and shelf life [49]. In the trial, titratable acidity in fruits significantly decreased with increasing ZnO-NPs, while the control treatment increased (0.82%) the titratable acidity. The result of titratable acidity was shown to be inconsistent among the treatments (Table 5).

Table 5. Effect of zinc fertilizer and zinc oxide nanoparticles on total soluble solid, firmness, and titratable acidity of two selected tomatoes varieties.

Treatment	TSS (^{0}Brix)	Firmness (N)	Titratable Acidity (%)
V_1 = MT1	8.16 a ± 0.20	14.7 a ± 0.41	0.63 a ± 0.03
V_2 = MT3	8.23 a ± 0.19	14.8 a ± 0.40	0.65 a ± 0.03
Level of significance	ns	ns	ns
MSD value	0.83	1.39	0.03
CV (%)	9.99	7.89	7.59
T_1	7.05 c ± 0.20	11.7 e ± 0.34	0.82 a ± 0.02
T_2	8.50 ab ± 0.39	15.6 abc ± 0.46	0.57 cd ± 0.02
T_3	8.00 abc ± 0.27	14.2 cd ± 0.37	0.70 b ± 0.02
T_4	7.55 bc ± 0.25	13.0 de ± 0.34	0.78 a ± 0.02
T_5	8.38 ab ± 0.28	15.3 bc ± 0.43	0.62 c ± 0.02
T_6	9.05 a ± 0.32	17.3 a ± 0.43	0.48 e ± 0.02
T_7	8.85 a ± 0.30	16.3 ab ± 0.43	0.50 de ± 0.02
Level of significance	**	**	**
MSD value	1.28	1.82	0.08
CV (%)	9.99	7.89	7.59
Interaction (V*T) significance	ns	ns	ns

Means in a column that include the same letters are not statistically different at the 5% level using Tukey's HSD test. MSD = Minimum significant difference, CV = Coefficient of variation, T_1 = 0, T_2 = 1500 ppm Zn nutrient, T_3 = 2000 ppm Zn nutrient, T_4 = 2500 ppm Zn nutrient, T_5 = 75 ppm ZnO nanoparticle, T_6 = 100 ppm ZnO nanoparticle and T_7 = 125 ppm ZnO nanoparticle, Varieties = Main plot, Zn doses = Sub plot; Note: ns—not significant at $p > 0.05$, * significant at $p \leq 0.05$ and ** significant at $p \leq 0.01$; ±standard error (n = 4); (as ANOVA).

The ascorbic acid, lycopene content, total phenolic content (TPC), and 2, 2-Diphenyl-1-picrylhydrazyl (DPPH) of tomatoes were significantly influenced by foliar spraying of Zn fertilizer and zinc oxide nanoparticles (Table 6). The highest amount of ascorbic acid (22.1 mg/100 g) was recorded from T_6 (100 ppm ZnO nanoparticles) followed by T_7 (125 ppm ZnO nanoparticles) and T_2 (0.15% zinc fertilizer) treatment. However, the decreased amount of fruit ascorbic acid (15 mg/100 g) was noted from increased dose of zinc (0.25% Zn) fertilizer (T_4). The control treatment (T_1) had minimum ascorbic acid (12 mg/100 g). In the study, the highest lycopene content (248 µg/100 g) was from T_7 (125 ppm ZnO nanoparticles), which was similar to the treatment T_6 (100 ppm ZnO nanoparticles), T_2 (0.15% zinc fertilizer), and T_5 (75 ppm ZnO nanoparticles). However, an increased dose of zinc foliar application (0.25% Zn) caused a decline in the lycopene content. The lowest lycopene content (136 µg/100 mL) was from the control treatment. The quality results of this trial are in agreement with the findings of a number of former research activities involving other crops [27,46]. The plants treated with foliar spraying 100 ppm ZnO nanoparticles had a 113.1% rise in fruits' ascorbic acid and lycopene content [50]. Ascorbic acid and lycopene contents in tomato fruits were comparatively greater in ZnO-NPs-treated plants than that of Zn fertilizer-treated plants. Faizan et al. [28] reported that foliar application at 50 ppm ZnO-NPs increased fruit lycopene content (23%) over control. Foliar application of 100 ppm ZnO-NPs exhibited significant improvement of the ascorbic acid and lycopene, photosynthetic characteristics, and enzymatic activities [33]. Zinc applied as a nano fertilizer in the form of ZnO-NPs can increase the cherry tomato yield [42]. The increased TPC (0.48 mg/g) was from T_6 (100 ppm ZnO nanoparticles) similar to the treatments T_7 (125 ppm ZnO nanoparticles) and T_2 (0.15% zinc fertilizer). The lowest TPC (0.28 mg/g) was from T_1 (control). In case of DPPH, an increased DPPH (58.4%) was found in T_6 (100 ppm ZnO nanoparticles), statistically similar to T_7 (125 ppm ZnO nanoparticles), T_2

(0.15% zinc fertilizer), and T_5 (75 ppm ZnO nanoparticles) treatment. The minimum DPPH (34.5%) was in the control treatment (T_1).

Table 6. Effect of zinc fertilizer and zinc oxide nanoparticles on the quality parameters of two selected tomatoes varieties.

Treatment	Ascorbic Acid (mg/100 g)	Lycopene Content (µg/100 g)	TPC (mg/g)	DPPH (%)
V_1 = MT1	18.1 a ± 0.69	206 a ± 8.81	0.38 a ± 0.02	48.6 a ± 1.68
V_2 = MT3	18.3 a ± 0.69	212 a ± 8.59	0.39 a ± 0.02	49.2 a ± 1.66
Level of significance	ns	ns	ns	ns
MSD value	1.81	11.62	0.06	2.63
CV (%)	9.23	10.49	13.24	10.02
T_1	12.0 e ± 0.32	136 c ± 5.72	0.28 e ± 0.01	34.5 d ± 0.80
T_2	20.0 abc ± 0.60	239 a ± 8.25	0.42 abc ± 0.02	53.0 ab ± 1.60
T_3	18.2 c ± 0.57	192 b ± 6.60	0.37 cd ± 0.02	47.9 bc ± 1.57
T_4	15.0 d ± 0.43	171 b ± 6.22	0.32 de ± 0.01	41.8 cd ± 1.29
T_5	19.3 bc ± 0.58	232 a ± 8.71	0.40 bc ± 0.02	51.2 ab ± 1.73
T_6	22.1 a ± 0.65	246 a ± 9.43	0.48 a ± 0.02	58.4 a ± 2.05
T_7	20.9 ab ± 0.61	248 a ± 9.02	0.45 ab ± 0.02	55.5 ab ± 1.46
Level of significance	**	**	**	**
MSD value	2.63	34.32	0.08	7.65
CV (%)	9.23	10.49	13.24	10.02
Interaction (V*T) significance	ns	ns	ns	ns

Means in a column that include the same letters are not statistically different at the 5% level using Tukey's HSD test. MSD = Minimum significant difference, CV = Coefficient of variation, T_1 = 0, T_2 = 1500 ppm Zn nutrient, T_3 = 2000 ppm Zn nutrient, T_4 = 2500 ppm Zn nutrient, T_5 = 75 ppm ZnO nanoparticle, T_6 = 100 ppm ZnO nanoparticle and T_7 = 125 ppm ZnO nanoparticle, Varieties = Main plot, Zn doses = Sub plot; Note: ns—not significant at $p > 0.05$, * significant at $p \leq 0.05$ and ** significant at $p \leq 0.01$; ±standard error (n = 4); (as ANOVA).

3.5. Nutrient Contents in Leaves

Varietal effects on sulfur and magnesium content in leaves between two tomatoes varieties exhibited significant but nitrogen, phosphorus, potassium, boron, iron, and zinc content in leaves showed insignificant (Tables 7 and 8). Significantly, the highest sulfur (10.74 g/kg) and magnesium content (5.56 g/kg) was estimated from the V_2 = MT3 variety and both were lowest from V_1 = MT1 variety. The content of sulfur and magnesium in leaves of the V_2 = MT3 variety is higher due to higher S and Mg uptake capacity, which is governed by contribution of hereditary modification and environmental condition [48,51].

Table 7. Effect of zinc fertilizer and zinc oxide nanoparticles on nitrogen, phosphorus, potassium, sulfur, and magnesium content in leaves of two selected tomato varieties.

Treatment	Nitrogen (N) Content (g/kg)	Phosphorus (P) Content (g/kg)	Potassium (K) Content (g/kg)	Sulfur (S) Content (g/kg)	Magnesium (Mg) Content (g/kg)
V_1 = MT1	23.2 a ± 0.89	10.6 a ± 0.39	20.8 a ± 0.93	10.4 b ± 0.39	5.35 b ± 0.22
V_2 = MT3	23.6 a ± 0.89	10.9 a ± 0.39	21.6 a ± 0.90	10.7 a ± 0.40	5.56 a ± 0.21
Level of significance	ns	ns	ns	*	*
MSD value	1.65	0.56	0.88	0.16	0.18
CV (%)	7.97	8.54	7.84	8.24	7.17
T_1	14.3 d ± 0.38	6.85 c ± 0.17	12.4 e ± 0.31	6.87 f ± 0.27	3.53 d ± 0.10
T_2	25.3 b ± 0.67	10.3 b ± 0.27	27.4 a ± 0.68	12.6 a ± 0.50	7.02 a ± 0.18
T_3	29.1 a ± 0.80	12.4 a ± 0.35	22.7 bc ± 0.61	11.3 c ± 0.46	6.09 b ± 0.16
T_4	26.2 ab ± 0.68	11.9 a ± 0.32	19.7 d ± 0.71	10.2 e ± 0.41	4.93 c ± 0.16

Table 7. *Cont.*

Treatment	Nitrogen (N) Content (g/kg)	Phosphorus (P) Content (g/kg)	Potassium (K) Content (g/kg)	Sulfur (S) Content (g/kg)	Magnesium (Mg) Content (g/kg)
T_5	22.3 c ± 0.56	10.1 b ± 0.27	25. ab ± 0.74	10.5 de ± 0.42	6.23 b ± 0.16
T_6	24.2 bc ± 0.68	11.4 ab ± 0.58	22.4 c ± 0.56	11.7 b ± 0.47	5.29 c ± 0.15
T_7	22.2 c ± 0.64	12.4 a ± 0.38	18.8 d ± 0.48	10.8 d ± 0.47	5.10 c ± 0.14
Level of significance	**	**	**	**	**
MSD value	2.91	1.44	2.60	0.37	0.61
CV (%)	7.97	8.54	7.84	8.24	7.17
Interaction (V*T) significance	ns	ns	ns	ns	ns

Means in a column that include the same letters are not statistically different at the 5% level using Tukey's HSD test. MSD = Minimum significant difference, CV = Coefficient of variation, T_1 = 0, T_2 = 1500 ppm Zn nutrient, T_3 = 2000 ppm Zn nutrient, T_4 = 2500 ppm Zn nutrient, T_5 = 75 ppm ZnO nanoparticle, T_6 = 100 ppm ZnO nanoparticle and T_7 = 125 ppm ZnO nanoparticle, Varieties = Main plot, Zn doses = Sub plot; Note: ns—not significant at $p > 0.05$, * significant at $p \leq 0.05$ and ** significant at $p \leq 0.01$; ±standard error (n = 4); (as ANOVA).

Table 8. Effect of zinc fertilizer and zinc oxide nanoparticles on boron, iron, and zinc content in leaves of two selected tomatoes varieties.

Treatment	Boron Content (mg/kg)	Iron Content (mg/kg)	Zinc Content (mg/kg)
V_1 = MT1	51.4 a ± 2.02	81.3 a ± 2.61	488 a ± 39.28
V_2 = MT3	52.3 a ± 2.02	83.3 a ± 2.97	497 a ± 39.93
Level of significance	ns	ns	ns
MSD value	3.29	6.38	31.91
CV (%)	7.97	7.64	8.02
T_1	36.7 d ± 1.05	112 a ± 2.84	21.2 d ± 0.57
T_2	58.7 b ± 1.50	87.8 b ± 2.51	547 bc ± 15.83
T_3	66 a ± 1.77	77.9 cd ± 1.94	573 b ± 14.11
T_4	61.9 ab ± 1.69	68.9 d ± 1.68	700 a ± 16.12
T_5	43.2 cd ± 0.99	83.1 bc ± 2.23	498 c ± 11.81
T_6	49 c ± 1.24	76.8 cd ± 2.14	506 c ± 11.95
T_7	47.5 c ± 1.16	71.5 d ± 1.88	604 b ± 16.18
Level of significance	**	**	**
MSD value	6.45	9.85	61.77
CV (%)	7.97	7.64	8.02
Interaction (V*T) significance	ns	ns	ns

Means in a column that include the same letters are not statistically different at the 5% level using Tukey's HSD test. MSD = Minimum significant difference, CV = Coefficient of variation, T_1 = 0, T_2 = 1500 ppm Zn nutrient, T_3 = 2000 ppm Zn nutrient, T_4 = 2500 ppm Zn nutrient, T_5 = 75 ppm ZnO nanoparticle, T_6 = 100 ppm ZnO nanoparticle and T_7 = 125 ppm ZnO nanoparticle, Varieties = Main plot, Zn doses = Sub plot; Note: ns—not significant at $p > 0.05$, * significant at $p \leq 0.05$ and ** significant at $p \leq 0.01$; ±standard error (n = 4); (as ANOVA).

The foliar application of zinc fertilizer and zinc oxide nanoparticles affected the nitrogen (N), phosphorus (P), potassium (K), sulfur (S), magnesium (Mg), boron (B), iron (Fe), and zinc (Zn) content in tomato leaves (Tables 7 and 8). The increased nitrogen content in leaves (29.1 g/kg) was obtained from T_3 (0.20% zinc fertilizer) alike with T_4 (0.25% zinc fertilizer) treatment. The minimum content was from T_1 (control) treatment. The most phosphorus content in leaves (12.4 g/kg) was from T_7 (125 ppm ZnO nanoparticles), closely comparable with T_3 (0.20% zinc fertilizer), T_4 (0.25% zinc fertilizer), and T_6 (100 ppm ZnO nanoparticles). Zinc is the important constituent of several enzymes, which regulate various metabolic reactions in the plant, and is also essential for auxin and protein synthesis and to help higher absorption of N and P by plant [52]. The maximum potassium content

(27.4 g/kg) was from the T_2 (0.15% zinc fertilizer) treatment, which was similar to T_5 (75 ppm ZnO nanoparticles). The lowest (12.4 g/kg) was from the control treatment. The significantly increased sulfur content in leaves (12.6 g/kg) was also achieved from T_2 (0.15% zinc fertilizer) and lesser sulfur content (6.87 g/kg) was from T_1 (control) treatment. Maximum magnesium content in leaves (7.02 g/kg) was also found in T_2 (0.15% zinc fertilizer), which was significantly different with other treatments. The minimum result (3.53 g/kg) was exposed in T_1 (control) treatment. All nutrient content values in the study were shown to be inconsistent across the treatments. Similar explanations have been stated in previous studies involving different crops, where micronutrients such as Zn were publicized to have influenced the nutrient contents such as K, S, and Mg [45,53,54]. Agrawal et al. [55] also recorded maximum accumulation of NPKS, copper, and iron with Zn application in tomato.

In the experiment, the highest boron content in leaves (66.05 mg/kg) was recorded from T_3 (0.20% zinc fertilizer) comparable with T_4 (0.25% zinc fertilizer) treatment (Table 8). The lowest boron content in leaves (36.7 mg/kg) was from T_1 (control) treatment. Maximum iron content in leaves (112 mg/kg) was estimated from T_1 treatment and minimum iron content (68.9 mg/kg) was from T_4 treatment, which was statistically similar to T_7 (125 ppm ZnO nanoparticles). Regarding Zn content, significantly, the highest content of Zn in leaves (700 mg/kg) was from T_4 (0.25% zinc fertilizer) and the lowest result (21.2 mg/kg) was from T_1 (control) treatment. The improved B and Zn content in leaves of tomato varieties was exhibited only in receiving of Zn foliar fertilizers. Comparable results were corroborated by some earlier studies in different crops, where the application of micronutrients such as Zn influenced the content of B and Zn [45,56,57]. On the other hand, Zn foliar application might reduce the iron accumulation in plants. Similar observation were outlined by Ibiang et al. [58] in tomato. The result is in agreement with the findings of Haydon et al. [59] and Briat et al. [60] in other crops that Zn causes physiological Fe deficiency.

3.6. Nutrient Contents in Fruits

Varietal effects on sulfur content in fruits of two tomato varieties demonstrated significant variation, but nitrogen, phosphorus, potassium, magnesium, boron, iron, and zinc content in fruit showed insignificant effects (Tables 9 and 10). Significantly, the highest sulfur content (9.44 g/kg) (5.56 g/kg) was assessed from the V_2 = MT3 variety, and the lowest was from V_1 = MT1 variety. The content of sulfur in fruits of the V_2 = MT3 variety is higher due to higher S absorption capacity and the role of genetic variation and ecological adjustment [48].

The nitrogen, phosphorus, potassium, sulfur, and magnesium contents in fruits of two tomato varieties influenced significantly by the foliar spraying of Zn fertilizers and zinc oxide nanoparticles (Table 9). The increased nitrogen amount in fruits (25.8 g/kg) was obtained from T_7 (125 ppm ZnO nanoparticles), which was statistically similar to T_6 (100 ppm ZnO nanoparticles) and T_5 (75 ppm ZnO nanoparticles) treatments. The lesser nitrogen content (14.2 g/kg) was from the T_1 (control) treatment. In the study, maximum phosphorus content in fruits (12.1 g/kg) was found in T_3 (0.20% zinc fertilizer), which was similar to T_4 (0.25% zinc fertilizer) treatment. The lowest phosphorus content in fruits (5.00 g/kg) was in T_1 (control) treatment. The utmost potassium content in fruits (23.7 g/kg) was attained from T_2 (0.15% zinc fertilizer) comparable with T_5 (75 ppm ZnO nanoparticles) treatment. The lowest result (10.9 g/kg) was in T_1 (control) treatment. Significantly the topmost sulfur content in fruits (11.2 g/kg) was found in T_2 (0.15% zinc fertilizer) and the bottommost content (5.35 g/kg) was in control T_1 (control). The maximum magnesium content in fruits (2.39 g/kg) was also found in T_2 (0.15% zinc fertilizer), which was statistically similar to most of the treatments except control. However, the increment was most 49.4% in the same T_2 treatment over control. Comparable explanations were outlined in former studies concerning dissimilar crops, where micronutrients like Zn were revealed to have increased the nutrient contents such as N, P, K, S, and Mg [45,53,54].

Table 9. Effect of zinc fertilizer and zinc oxide nanoparticles on nitrogen, phosphorus, potassium, sulfur, and magnesium content in fruits of two selected tomatoes varieties.

Treatment	Nitrogen Content (g/kg)	Phosphorus Content (g/kg)	Potassium Content (g/kg)	Sulfur Content (g/kg)	Magnesium Content (g/kg)
V_1 = MT1	21.8 a ± 0.78	9.54 a ± 0.44	17.9 a ± 0.76	9.17 b ± 0.39	2.13 a ± 0.05
V_2 = MT3	22.2 a ± 0.78	10. a ± 0.46	18.7 a ± 0.81	9.44 a ± 0.39	2.18 a ± 0.06
Level of significance	ns	ns	ns	*	ns
MSD value	1.37	0.53	0.96	0.16	0.08
CV (%)	8.66	7.87	8.43	8.96	7.58
T_1	14.2 e ± 0.43	5.00 e ± 0.15	10.9 f ± 0.27	5.35 d ± 0.22	1.60 b ± 0.04
T_2	20.0 d ± 0.54	10.1 cd ± 0.39	23.7 a ± 0.67	11.2 a ± 0.45	2.39 a ± 0.06
T_3	22.8 bcd ± 0.59	12.1 a ± 0.34	19.5 bc ± 0.58	10.1 b ± 0.39	2.28 a ± 0.06
T_4	22.0 cd ± 0.59	11.6 ab ± 0.35	16.9 de ± 0.47	9.15 c ± 0.37	2.15 a ± 0.05
T_5	24.0 abc ± 0.70	8.90 d ± 0.23	21.6 ab ± 0.68	9.33 c ± 0.38	2.20 a ± 0.06
T_6	25.3 ab ± 0.79	9.95 cd ± 0.31	19.1 cd ± 0.52	10.4 b ± 0.42	2.34 a ± 0.06
T_7	25.8 a ± 0.69	10.9 bc ± 0.30	16.2 e ± 0.44	9.55 c ± 0.43	2.17 a ± 0.06
Level of significance	**	**	**	**	**
MSD value	2.98	1.20	2.41	0.43	0.26
CV (%)	8.66	7.87	8.43	*	7.58
Interaction (V*T) significance	ns	ns	ns	ns	ns

Means in a column that include the same letters are not statistically different at the 5% level using Tukey's HSD test. MSD = Minimum significant difference, CV = Coefficient of variation, T_1 = 0, T_2 = 1500 ppm Zn nutrient, T_3 = 2000 ppm Zn nutrient, T_4 = 2500 ppm Zn nutrient, T_5 = 75 ppm ZnO nanoparticle, T_6 = 100 ppm ZnO nanoparticle and T_7 = 125 ppm ZnO nanoparticle, Varieties = Main plot, Zn doses = Sub plot; Note: ns—not significant at $p > 0.05$, * significant at $p \leq 0.05$ and ** significant at $p \leq 0.01$; ±standard error (n = 4); (as ANOVA).

Table 10. Effect of zinc fertilizer and zinc oxide nanoparticles on boron, iron, and zinc content in fruits of two selected tomatoes varieties.

Treatment	Boron Content (mg/kg)	Iron Content (mg/kg)	Zinc Content (mg/kg)
V_1 = MT1	24.3 a ± 1.26	78.9 a ± 2.23	35.4 a ± 1.60
V_2 = MT3	24.9 a ± 1.27	78.8 a ± 2.33	36.6 a ± 1.67
Level of significance	ns	ns	ns
MSD value	0.84	4.40	1.53
CV (%)	8.75	8.53	7.05
T_1	11.8 f ± 0.34	99.1 a ± 2.51	19.5 d ± 0.47
T_2	30.1ab ± 0.86	81.6 bc ± 2.20	29.1 c ± 0.71
T_3	32.3 a ± 0.93	76.5 bcd ± 1.93	37.1 b ± 0.84
T_4	28.1 bc ± 0.88	71.5 cd ± 2.03	40.7 b ± 1.15
T_5	21.3 e ± 0.58	86.2 b ± 2.45	40.1b ± 0.97
T_6	23.4 de ± 0.66	68.1 d ± 2.06	40.9 b ± 1.00
T_7	25.4 cd ± 0.69	69.2 d ± 2.33	45.1 a ± 1.10
Level of significance	**	**	**
MSD value	3.37	10.50	3.97
CV (%)	8.75	8.53	7.05
Interaction (V*T) significance	ns	ns	ns

Means in a column that include the same letters are not statistically different at the 5% level using Tukey's HSD test. MSD = Minimum significant difference, CV = Coefficient of variation, T_1 = 0, T_2 = 1500 ppm Zn nutrient, T_3 = 2000 ppm Zn nutrient, T_4 = 2500 ppm Zn nutrient, T_5 = 75 ppm ZnO nanoparticle, T_6 = 100 ppm ZnO nanoparticle and T_7 = 125 ppm ZnO nanoparticle, Varieties = Main plot, Zn doses = Sub plot; Note: ns—not significant at $p > 0.05$, * significant at $p \leq 0.05$ and ** significant at $p \leq 0.01$; ±standard error (n = 4); (as ANOVA).

Different levels of Zn fertilizers and zinc oxide nanoparticles affected the boron, iron, and zinc content in two varieties of tomatoes (Table 10). The highest boron content in fruit (32.3 mg/kg) was obtained from T_3 (0.20% zinc fertilizer), which was statistically similar to T_2 (0.15% zinc fertilizer) treatment. The lowest boron content (11.8 mg/kg) was from T_1 (control) treatment. Sufficient application of zinc in the plant can reduce the harmful effect of boron deficiency; however, the appropriate zinc dose increased the boron accumulation in plants [61]. In the experiment, the maximum iron content in fruits (99.1 mg/kg) was obtained from T_1 (control), which was significant with other treatments, and the minimum iron content in fruits (68.1 mg/kg) was found in T_6 (100 ppm ZnO nanoparticles). Imtiaz et al. [62] reported that Zn application had an adverse effect on Fe concentration in plant tissue. The lower concentration of zinc represented the significantly higher Fe concentrations in shoots than the higher concentration of Zn in plants. Significantly, the most zinc content in fruits (45.1 mg/kg) was estimated from T_7 (125 ppm ZnO nanoparticles), and the minimum result (19.5 mg/kg) was from T_1 (control) treatment. The foliar application of zinc had a great influence on the leaves and fruits of tomatoes. The highest dose of zinc application had shown the highest concentration of zinc in leaves and fruits. The concentration of zinc increased linearly in leaves and fruits with the increasing doses of zinc as foliar spraying. This result was similar to the result of Kaya and Higgs [63].

3.7. Effect of Nutrient Uptake by Leaves

Varietal effects on N, P, K, S, B, and Zn uptake by leaves revealed significant variation between two tomatoes varieties (Table 11). Zinc uptake was shown to be insignificant in leaves. Significantly, the maximum uptake of N (2.62 g/plant), P (1.22 g/plant), K (2.42 g/plant), S (1.20 g/plant), Mg (0.62 g/plant), and B (5.72 mg/plant) was obtained from V_2 = MT3 variety and lowest uptake of all nutrients were from the V_1 = MT1 variety. These variations in nutrient uptakes might be related to the varietal yield variation, which means the V_2 = MT3 variety achieved a comparatively higher yield than the variety V1 = MT1. The variety V_2 = MT3 has a higher nutrient uptake capacity due to the role of genetic variation and ecological adjustment [48].

The foliar application of zinc fertilizer and zinc oxide nanoparticles affected the uptake of N, P, K, S, Mg, B, and Zn by tomato leaves (Table 11). The highest nitrogen uptake by leaves (3.16 g/plant) was achieved in T_6 (100 ppm ZnO nanoparticles), which was similar to T_2, T_3, and T_7 treatments. The lowest nitrogen uptake (0.91g/plant) was found in T_1 (control). The maximum phosphorus uptake by leaves (1.59 g/plant) was obtained from T_7 (125 ppm ZnO nanoparticles) comparable with T_6 (100 ppm ZnO nanoparticles) treatment. The minimum phosphorus uptake (0.43 g/plant) was from T_1 (control). The most potassium uptake (3.20 g/plant) was from T_2 (0.15% zinc fertilizer), which was statistically similar to T_6 (100 ppm ZnO nanoparticles) and T_5 (75 ppm ZnO nanoparticles) treatments. The lowest potassium uptake (0.78 g/plant) was from T_1 (control). The maximum sulfur uptake in leaves (1.53 g/plant) was found in T_6 (100 ppm ZnO nanoparticles), which was similar to T_2 (0.15% Zn fertilizer) and T_7 (125 ppm ZnO nanoparticles) treatment. The minimum uptake (0.43 g/plant) was in T_1 (control) treatment. Regarding magnesium, the highest Mg uptake by leaves (0.82 g/plant) was recorded from T_2 (0.15% Zn) comparable with T_5 and T_6 treatments. The minimum Mg uptake (0.22 g/plant) was from T_1 (control) treatment (Table 11).

Zinc fertilizers and zinc oxide nanoparticles affected the uptake of boron and zinc by leaves of two varieties of tomatoes (Table 11). The highest boron uptake in leaves (6.87 mg/plant) was recorded from T_2 (0.15% zinc fertilizer) alike with T_3, T_6, and T_7 treatments. The lowest boron uptake (2.32 mg/plant) was from T_1 (control) treatment. The maximum zinc uptake in leaves (77.8 mg/plant) was obtained from T_7 (125 ppm ZnO nanoparticles), which was significantly different from other treatments but comparable with T_6 treatment. The minimum zinc uptake (1.34 mg/plant) was in T_1 (control) treatment.

Table 11. Effect of zinc fertilizer and zinc oxide nanoparticles on nitrogen, phosphorus, potassium, sulfur, boron, and zinc uptake by leaves of two selected tomatoes varieties.

Treatment	Nitrogen Uptake (g/Plant)	Phosphorus Uptake (g/Plant)	Potassium Uptake (g/Plant)	Sulfur Uptake (g/Plant)	Magnesium Uptake (g/Plant)	Boron Uptake (mg/Plant)	Zinc Uptake (mg/Plant)
V_1 = MT1	2.44 b ± 0.14	1.12 b ± 0.07	2.21 b ± 0.15	1.10 b ± 0.07	0.56 b ± 0.04	5.33 b ± 0.29	53.0 a ± 4.51
V_2 = MT3	2.62 a ± 0.15	1.22 a ± 0.08	2.42 a ± 0.16	1.20 a ± 0.08	0.62 a ± 0.04	5.72 a ± 0.32	57.2 a ± 4.90
Level of significance	*	*	*	*	*	*	ns
MSD value	0.31	0.04	0.03	0.03	0.02	0.15	17.55
CV (%)	14.9	15.8	13.6	7.74	15.4	14.1	14.08
T_1	0.91 c ± 0.03	0.43 d ± 0.02	0.78 e ± 0.03	0.43 d ± 0.02	0.22 d ± 0.01	2.32 d ± 0.07	1.34 c ± 0.05
T_2	2.97 ab ± 0.15	1.21 bc ± 0.06	3.20 a ± 0.13	1.47 a ± 0.08	0.82 a ± 0.04	6.87 a ± 0.30	64.1 b ± 3.97
T_3	2.85 ab ± 0.14	1.21 bc ± 0.06	2.22 cd ± 0.09	1.11 b ± 0.06	0.60 b ± 0.03	6.46 ab ± 0.30	56.0 b ± 3.06
T_4	2.39 b ± 0.12	1.09 c ± 0.05	1.80 d ± 0.11	0.93 c ± 0.05	0.45 c ± 0.02	5.64 bc ± 0.26	63.8 b ± 3.60
T_5	2.55 b ± 0.12	1.16 c ± 0.06	2.86 ab ± 0.12	1.20 b ± 0.06	0.71 ab ± 0.04	4.93 c ± 0.21	56.9 b ± 3.04
T_6	3.16 a ± 0.13	1.48 ab ± 0.10	2.91 ab ± 0.11	1.53 a ± 0.08	0.69 ab ± 0.03	6.39 ab ± 0.27	65.9 ab ± 2.95
T_7	2.86 ab ± 0.15	1.59 a ± 0.08	2.43 bc ± 0.12	1.40 a ± 0.08	0.66 b ± 0.03	6.12 abc ± 0.27	77.8 a ± 4.53
Level of significance	**	**	**	**	**	**	**
MSD value	0.59	0.29	0.49	0.14	0.14	1.21	12.12
CV (%)	14.9	15.8	13.6	7.74	15.4	14.1	14.08
Interaction (V*T) significance	ns	ns	ns	ns	ns	ns	ns

Means in a column that include the same letters are not statistically different at the 5% level using Tukey's HSD test. MSD = Minimum significant difference, CV = Coefficient of variation, T_1 = 0, T_2 = 1500 ppm Zn nutrient, T_3 = 2000 ppm Zn nutrient, T_4 = 2500 ppm Zn nutrient, T_5 = 75 ppm ZnO nanoparticle, T_6 = 100 ppm ZnO nanoparticle and T_7 = 125 ppm ZnO nanoparticle, Varieties = Main plot, Zn doses = Sub plot; Note: ns—not significant at $p > 0.05$, * significant at $p \leq 0.05$ and ** significant at $p \leq 0.01$; ±standard error (n = 4); (as ANOVA).

3.8. Effect of Nutrient Uptake by Fruits

Varietal effects on N, P, K, S, B, and Zn uptake by fruits showed significant between two tomatoes varieties (Table 12). Significantly the most uptake of N (2.58 g/plant), P (1.16 g/plant), K (2.15 g/plant), S (1.10 g/plant), Mg (0.25 g/plant), B (2.87 mg/plant), and Zn (4.29 mg/plant) was attained from the V_2 = MT3 variety, and the lowest uptake of all nutrients were from V_1 = MT1 variety. These variations in nutrient uptakes might be correlated with the difference of yield between two varieties. The variety V_2 = MT3 has a higher nutrient uptake capacity due to the role of genetic variation and ecological adjustment [48].

The nutrients such N, P, K, S, and Mg uptake by fruits of two tomato varieties significantly influenced by the foliar application of Zn fertilizers and zinc oxide nanoparticles (Table 12). Significantly, the maximum nitrogen uptake by fruits (3.95 g/plant) was obtained from T_6 (100 ppm ZnO nanoparticles), and the minimum (0.61 g/plant) was from T_1 (control) treatment. Grzebisz et al. [64] reported that foliar Zn application enhances the nitrogen uptake, and accumulation by crops resulted in an increase of the crop yield. In the study, the significantly highest phosphorus uptake by fruits (1.66 g/plant) was from T_7 (125 ppm ZnO nanoparticles), and the lowest uptake (0.21 g/plant) was from T_1 (control) treatment. In the case of potassium, the upmost potassium uptake by fruits (2.94 g/plant) was from T_2 (0.15% zinc fertilizer), which was similar to T_6 (100 ppm ZnO nanoparticles) treatment. The lowest potassium uptake by fruits (0.46 g/plant) was from T_1 (control). Regarding S and Mg uptake, the highest sulfur and magnesium uptake by fruits (1.53 g/plant and 0.34 g/plant) was obtained from T_6 (100 ppm ZnO nanoparticles), comparable with T_7 (125 ppm ZnO nanoparticles) treatment. Both S and Mg uptakes by fruits were lowest from T_1 (control) treatment. Similar outcomes have been described in former studies concerning diverse crops, where micronutrients such as Zn are exhibited to have increased the uptake of N, P, K, S, and Mg [45,53,65].

The effect Zn fertilizers and zinc oxide nanoparticles affected the B and Zn uptake by fruits of two varieties of tomatoes (Table 12). The maximum boron uptake by fruits (3.89 mg/plant) was obtained from T_7 (125 ppm ZnO nanoparticles), which was statistically identical to T_2 (0.15% zinc fertilizer) treatment. The minimum boron uptake (0.50 mg/plant) was from T_1 (control) treatment. Concerning Zn uptake, significantly highest zinc uptake by fruits (6.88 mg/plant) was recorded from T_7 (125 ppm ZnO nanoparticles) and the lowest was T_1 (control) treatment. The results of B and Zn uptakes are in agreement with the findings of Almendros et al. [42] in tomato and Khan et al. [5].

Table 12. Effect of zinc fertilizer and zinc oxide nanoparticles on nitrogen, phosphorus, potassium, sulfur, magnesium, boron, and zinc uptake by fruits of two selected tomatoes varieties.

Treatment	Nitrogen Uptake (g/Plant)	Phosphorus Uptake (g/Plant)	Potassium Uptake (g/Plant)	Sulfur Uptake (g/Plant)	Magnesium Uptake (g/Plant)	Boron Uptake (mg/Plant)	Zinc Uptake (mg/Plant)
V_1 = MT1	2.52 b ± 0.20	1.09 b ± 0.08	2.07 b ± 0.17	1.06 b ± 0.09	0.24 b ± 0.02	2.80 b ± 0.22	4.11 b ± 0.34
V_2 = MT3	2.58 a ± 0.22	1.16 a ± 0.09	2.15 a ± 0.17	1.10 a ± 0.09	0.25 a ± 0.09	2.87 a ± 0.22	4.29 a ± 0.39
Level of significance	*	*	*	*	*	*	*
MSD value	0.03	0.02	0.04	0.02	0.01	0.03	0.03
CV (%)	9.11	8.50	9.96	10.6	14.5	9.62	9.33
T_1	0.61 f ± 0.03	0.21 f ± 0.01	0.46 e ± 0.03	0.23 e ± 0.02	0.07 d ± 0.01	0.50 e ± 0.03	0.83 f ± 0.04
T_2	2.48 d ± 0.09	1.25 c ± 0.05	2.94 a ± 0.10	1.39 b ± 0.07	0.30 ab ± 0.02	3.72 a ± 0.14	3.60 de ± 0.13
T_3	2.42 d ± 0.10	1.29 c ± 0.05	2.07 c ± 0.08	1.07 c ± 0.06	0.24 b ± 0.01	3.42 b ± 0.13	3.93 d ± 0.15
T_4	1.79 e ± 0.07	0.94 e ± 0.04	1.38 d ± 0.05	0.74 d ± 0.04	0.18 c ± 0.01	2.29 d ± 0.09	3.32 e ± 0.16
T_5	2.92 c ± 0.12	1.08 d ± 0.04	2.63 b ± 0.10	1.13 c ± 0.06	0.27 b ± 0.02	2.59 c ± 0.11	4.86 c ± 0.20
T_6	3.95 a ± 0.20	1.46 b ± 0.06	2.81 a ± 0.10	1.53 a ± 0.08	0.34 a ± 0.02	3.44 b ± 0.12	5.99 b ± 0.22
T_7	3.72 b ± 0.13	1.66 a ± 0.09	2.49 b ± 0.14	1.46 ab ± 0.11	0.33 a ± 0.02	3.89 a ± 0.20	6.88 a ± 0.35
Level of significance	**	**	**	**	**	**	**
MSD value	0.20	0.10	0.16	0.13	0.06	0.20	0.35
CV (%)	9.11	8.50	9.96	10.6	14.5	9.62	9.33
Interaction (V*T) significance	ns	ns	ns	ns	ns	ns	ns

Means in a column that include the same letters are not statistically different at the 5% level using Tukey's HSD test. MSD = Minimum significant difference, CV = Coefficient of variation, T_1 = 0, T_2 = 1500 ppm Zn nutrient, T_3 = 2000 ppm Zn nutrient, T_4 = 2500 ppm Zn nutrient, T_5 = 75 ppm ZnO nanoparticle, T_6 = 100 ppm ZnO nanoparticle and T_7 = 125 ppm ZnO nanoparticle, Varieties = Main plot, Zn doses = Sub plot; Note: ns—not significant at $p > 0.05$, * significant at $p \leq 0.05$ and ** significant at $p \leq 0.01$; ±standard error (n = 4); (as ANOVA).

3.9. Apparent Zinc Recovery Efficiency of Tomato

Zinc fertilizers and ZnO-NPs foliar application affected nutrient use efficiency as with apparent zinc recovery efficiency of tomato (Figure 1). The highest apparent Zn recovery efficiency (5.37%) was obtained from application of 75 ppm ZnO-NPs (T_5) that was comparable with T_6 and T_7 treatments. The lowest was from 0.25% Zn (T_4) treatment. There was an increasing trend in apparent Zn recovery efficiency with decreased application of Zn nutrient. However, nutrient use efficiency generally declined with increase of nutrient like Zn supply [66]. Nutrient absorption power of tomato might depend on utilization of biological levels and varied recovery of the applied nutrients. The inconsistency result of apparent nutrient recovery is attributed to the growing environment, seasonal variability, and fertilizer management that affect yield of crops [25]. Apparent Zn recovery efficiency was high due to high consumption of Zn by tomato at 75 ppm ZnO-NPs. It has been documented that effects of NUE on crops varied due to the rate of added fertilizer and environmental factors. Quddus et al. [36] reported similar a view in tomato.

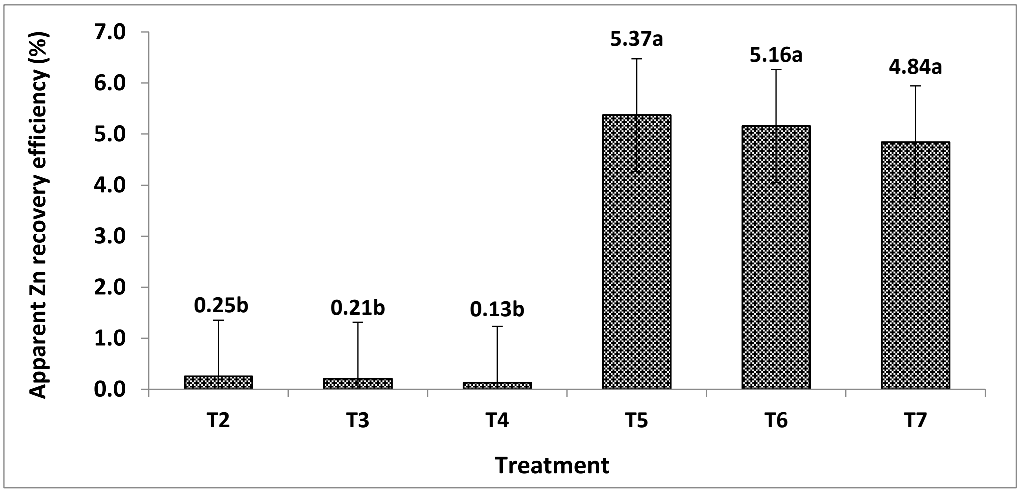

Figure 1. Effect of zinc fertilizer and zinc oxide nanoparticles on apparent zinc recovery efficiency of tomato in soil condition. Means followed by common letter(s) are not significantly different from each other at 5% level of significance. Note: T_2 = 1500 ppm Zn nutrient, T_3 = 2000 ppm Zn nutrient, T_4 = 2500 ppm Zn nutrient, T_5 = 75 ppm ZnO nanoparticle, T_6 = 100 ppm ZnO nanoparticle, and T_7 = 125 ppm ZnO nanoparticle.

4. Conclusions

The aforesaid results and discussion indicated that foliar sprayed of 100 ppm ZnO-NPs performed better on the basis of tomatoes' growth characters, physiological traits, yield attributes, and quality traits. The similar treatment (100 ppm ZnO-NPs) facilitated the production of more fruits per plant and maximum fruit yield. The foliar sprayed with 100 ppm ZnO-NPs exhibited the highest yield increment over control and maximum nutrient uptake by tomatoes. The varietal result directed that the MARDI Tomato-3 (MT3) variety was comparatively better than that of MARDI Tomato-1 (MT1). The results also indicated that the foliar application of zinc oxide nanoparticles was more efficient than the conventional zinc fertilizer application. Therefore, the foliar spray of 100 ppm ZnO-NPs can be recommended for maximum productivity and quality improvement of tomatoes in glasshouse soil conditions.

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