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Effect of Macro and Micronutrients on Tomato (cv. Heemshikhar) Performance under Protected Cultivation

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Authors' contributions

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

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ABSTRACT

The investigation entitled "Effect of macro and micronutrients on tomato cv. Heemshikhar perfrormance under protected conditions" was conducted at Polyhouse, School of Agricultural Sciences and Technology, RIMT University, Mandi Gobindgarh, Punjab, during *rabi* 2023-24. The experiment consists of seven treatments viz. T_1 Control, T_2 (NPK 0.5 g + Zinc 50 ppm + Boron 50 ppm /plant), T_3 (NPK 0.5 g + Zinc 100 ppm + Boron 100 ppm /plant),T_4 (NPK 1 g + Zinc 50 ppm + Boron 50 ppm / plant), T_5 (NPK 1 g + Zinc 100 ppm + Boron 100 ppm /plant), T_6 (NPK 1.5 g + Zinc 50 ppm + Boron 50 ppm /plant) and T_7 (NPK 1.5 g + Zinc 100 ppm + Boron 100 ppm /plant).The observations were recorded on growth, flowering, yield and quality traits.Results revealed that growth characters viz., plant height (216.22 cm), number of leaves per plant (31.47), minimum days to 50 per cent flowering (40.58 days) and number of flowers per plant (55.85) was found maximum in Treatment T_7. For the traits number of fruits per cluster (8.22), number of fruits per plant (42.36), fruit length (4.42cm), fruit diameter (5.40cm) and average fruit weight (67.38 g) also recorded

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maximum values with the treatment T_7. Yield characters viz., fruit yield per plant (2.41 kg), fruit yield per plot, (24.10 kg) and per hectare (296.43 q ha^{-1}) recorded under the influence of (NPK 1.5 g + Zinc 100 ppm + Boron 100 ppm /plant). Fruit quality characters viz., TSS (4.57°Brix), pH (4.15), fruit firmness (4.13 kg/cm^2) and dry matter content (5.71%) was also found superior under treatment T_7.

Keywords: Growth; macronutrients; quality; tomato; yield.

1. INTRODUCTION

Tomato (*Solanum lycopersicum*) is one of the most significant vegetable crops from the Solanaceae family, cultivated globally due to its adaptability to diverse climates, high yield potential, and versatility in both fresh consumption and food processing industries. Although primarily a self-pollinating and day-neutral plant, a small degree of cross-pollination can still occur. With a chromosome number of 2n = 24). Tomatoes are believed to have originated along the western coastal plains of South America (Ali et al 2012). Tomatoes thrive in warm climates, with an optimal temperature range between 20–25 °C for best growth, while vibrant red coloration develops ideally at 21–24 °C. They are rich in pigments like β-carotene and lycopene and contribute to vascular health and prevention of scurvy. Nutritionally, tomatoes are valuable, containing calcium (48 mg), vitamin C (27 mg), phosphorus (20 mg), carbohydrates (3.6 g), protein (0.9 g), dietary fibre (0.8 g), iron (0.4 mg), fat (0.2 g), and providing about 20 kilocalories of energy per serving (Kabore et al 2022).

In India, major tomato-producing states include Uttar Pradesh, Karnataka, Maharashtra, Haryana, Punjab, and Bihar. Nationwide, tomatoes are cultivated on approximately 8.49 lakh hectares, and production of 204.25 lakh tones (Food and Agriculture Organization 2023). In Punjab alone, the crop spans about 11.17 thousand hectares with a production output of approximately 2.91 lakh tones (Department of Agriculture & Farmers Welfare, 2025).

Tomato is a widely consumed vegetable known not only for its culinary versatility but also for its significant medicinal properties. It is utilized in a variety of forms, including salads, soups, ketchup, sauces, chutneys, pickles, powders, pastes, juices, and purees. Additionally, whole tomatoes are often canned, and the fruit serves as a key ingredient in beverages such as the cocktail “Bloody Mary.” The distinctive flavour of tomato fruits is influenced by several volatile compounds, particularly ethanol and acetaldehyde.Tomato juice is known to aid digestion by stimulating gastric secretions, purifying the blood, and serving as an intestinal antiseptic. On the global scale, India holds the second position in both the cultivation area and total production of tomatoes. Nutrient amendments are historically used to improve plant productivity. Nitrogen is a major element in protein, nucleic acid, enzymes, and chlorophyll (Javed et al 2022). Lack of nitrogen in tomato causes chlorosis and reduce the total of light engrossed per unit time ultimately reduce the number of photosynthates, leading to both fruit and flower abortion (Shreevastav et al 2022). Lack of phosphorous will show the result in slow stunted growth and reduction in yield and marketable fruits (Lateef et al 2021). Potassium is essential for maintaining osmotic potential in cells. It is summarized in the activation of an enzyme involved in respiration and photosynthesis in the youngest leaves. Micronutrients improve the chemical composition of vegetable crops and are known to acts as catalyst in plants (Karthick et al 2018). Among micronutrients, Zinc and Boron are important for plant nutrition (Aske et al 2017). Boron (B) plays an essential role in the development and growth of new cell in the plant meristem. Boron does not easily move around the plant and therefore, the deficiency appears first in young tissues, growing points, root tips and developing fruits and its deficiency may cause sterility, poor fruit set, small fruit size and ultimately lower yield.Zinc is indispensable for normal growth and development of plants. It is effective for the synthesis of plant hormones like auxin and carbohydrate formation (Pankaj et al 2018). Its deficiency causes interveinal chlorosis of older leaves then leaves turn grey-white and fall prematurely or die.

2. MATERIALS AND METHODS

2.1 Experimental Location

The field experiment was carried out during the Rabi (winter) season of 2023–24 at the Polyhouse facility, School of Agricultural Sciences and Technology, RIMT University, Mandi Gobindgarh, Punjab.

List 1. Physio-chemical properties of soil of the experimental field

Particulars	Value obtained	Method used
Soil pH	7.2	1:2.5 soil water ratio with glass electrode pH meter (Jackson 1973)
Soil EC (ds/m at 25 °C)	0.16 ds/m	1:2.5 soil water suspension with electrode EC meter (Jackson 1973)
Soil organic carbon (%)	0.48 %	Walkley and Black's Rapid titration method (Jackson 1967)
Available N (Kg ha^{-1})	276 Kg ha^{-1}	Alkaline potassium permanganate method (Subbiah & Asija, 1956)
Available P_2O_5 (Kg ha^{-1})	12 Kg ha^{-1}	Olsen's method (Olsen et al 1954)
Available K_2O (Kg ha^{-1})	252 Kg ha^{-1}	Flame photometer method (Jackson 1967)

2.2 Soil Characteristics

Soil samples were collected from different spots randomly from a depth of 15cm depth before laying out the experiment. A representative composite sample was prepared and analysed for various soil characteristics to get information about the nutrient status of the soil.

2.3 Experimental Materials

In the present investigation, the experimental materials comprised of different macro and micronutrients and its various combinations along with tomato cv. Heemshikhar.

2.4 Treatment Detail

Treatments	Treatment combinations
T_1	Control (Distilled water)
T_2	NPK 0.5g + zinc 50 ppm + boron 50 ppm $plant^{-1}$
T_3	NPK 0.5g + zinc 100 ppm + boron 100 ppm $plant^{-1}$
T_4	NPK 1g + zinc 50 ppm + boron 50 ppm $plant^{-1}$
T_5	NPK 1g + zinc 100 ppm + boron 100ppm $plant^{-1}$
T_6	NPK 1.5g + zinc 50 ppm + boron 50 ppm $plant^{-1}$
T_7	NPK 1.5g + zinc 100 ppm + boron 100 ppm $plant^{-1}$

3. RESULTS AND DISCSSION

3.1 Growth Characters

3.1.1 Plant height

The data recorded on plant height of tomato is shown in Table 1, indicates that the maximum plant height 216.22 cm was observed in treatment T_7 (NPK 1.5g + Zinc 100 ppm + Boron 100 ppm per plant). This was followed by treatment T_5 with a height of 207.67 cm, T_6 with 176.56 cm, and T_4 with 166.67 cm while the minimum plant height of tomato was recorded in the control treatment T_1 (142.33 cm). The application of micronutrients viz.,zinc and boron were found to positively influence the plant height. The increase in height was likely due to the foliar application of these micronutrients, as supported by previous studies, such as those by Singh and Tiwari (2013). Zinc aids in auxin synthesis, and in combination with Boron, it plays a crucial role in cell wall formation and cell differentiation in plants (Patil et al 2008).

3.1.2 Number of leaves per plant

The results on the number of leaves per plant arepresented in Table 1, indicating that the highest leaf count (31.47) was recorded in treatment T_7 (NPK 1.5 g + Zinc 100 ppm + Boron 100 ppm per plant). This was followed by T_6 with 30.35 leaves, T_5 with 29.23 leaves, and T_4 with 27.33 leaves per plant while the lowest leaf count was recorded in the control treatment T_1 (18.33). The observed increase in the number of leaves per plant may be attributed to the adequate supply of macro as well as micronutrients through foliar application, which likely provided optimal growing conditions and balanced nutrition (Akand et al., 2016). These findings are consistent with earlier studies on the impact of foliar application of boron and zinc on tomato growth and yield (Harris & Mathuma, 2015).

3.1.3 Number of flowers per plant

The observations recorded on the number of flowers per plant are presented in Table 1. The highest number of flowers per plant (55.85) was recorded in treatment T_7 (NPK 1.5 g + Zinc 100 ppm + Boron 100 ppm per plant), followed by T_6 (50.92), T_5 (45.99), and T_4 (39.63). Among all treatments, T_7 was found to be statistically significant and was considered at par with other higher-performing treatments.The minimum number of flowers per plant (20.00) was recorded in treatment T_1 (Control). This lower flower count may be attributed to the absence of essential nutrients, particularly macronutrients, which are crucial for overall plant growth and reproductive development. Adequate nitrogen availability plays a key role in promoting vegetative growth, accelerating reproductive development, and enhancing protein synthesis, all of which contribute to improved yield parameters (Biswas et al., 2015; Rani & Tripura, 2021).

3.1.4 Days to 50% flowering

The observations on the number of days required to reach 50% flowering are presented in Table 1. Among all treatments, T_7 (NPK 1.5g + Zinc 100 ppm + Boron 100 ppm /plant) recorded the shortest period to reach 50% flowering at 40.58 days, followed by T_6 (41.65 days), T_5 (42.77 days), and T_4(43.86 days). In contrast, the maximum days to 50% flowering was observed in the control group, T_1 (Distilled water), where flowering was recorded at 47.18 days.The earlier flowering observed in nutrient-supplemented treatments can likely be attributed to the balanced availability of essential nutrients, particularly nitrogen, which plays a vital role in promoting cell division and differentiation. However, an excessive nitrogen supply may prolong the vegetative phase, disrupting the carbon-to-nitrogen (C: N) balance and consequently delaying the transition to reproductive growth. These findings are consistent with the results reported by Prativa and Bhattarai (2011).

3.2 Fruit Yield Characters

3.2.1 Number of fruits per cluster

The observations on the number of fruits per cluster are presented in Table 1. The highest number of fruits per cluster **(**8.22) was recorded in Treatment T_7(NPK 1.5g + Zinc 100 ppm + Boron 100 ppm /plant), followed by T_6(7.56), T_5(7.37), and T_4(7.27). This increase in fruit number under nutrient-enriched treatments is likely the result of an adequate supply of essential macronutrients, which play a crucial role in supporting both vegetative and reproductive development. In particular, nitrogen is known to enhance cell division, stimulate protein synthesis, and facilitate overall plant growth, all of which contribute to improved fruit set and higher productivity. These findings are consistent with the reports of (Meenakumari & Shehkar, 2012**)** and (Parmar et al. 2019**)**, who also observed similar trends in tomato yield response to balanced nutrient management.

3.2.2 Number of fruits per plant

The data on the number of fruits per plant are presented in Table 1. The highest fruit count per plant (42.36) was recorded in Treatment T_7, closely followed by T_6(42.15). The lowest number of fruits per plant (25.36) was observed in T_1(Control). The enhanced fruit set under nutrient-enriched treatments can be attributed to the foliar application of essential micronutrients such as boron, zinc, and iron, which are known to play vital roles in supporting physiological and reproductive processes in tomato plants. The application of these elements has been reported to improve overall fruit formation and yield, as documented by Haleema et al. (2018**)**. Similar positive effects on fruit quantity, particularly due to boron, zinc, and iron applications, were also observed by Saky and Sulandjar (2019) in tomato crops.

3.2.3 Fruit Length (cm)

The results for fruit length (cm) are summarized in Table 1. The longest fruits were recorded in Treatment T_7 (NPK 1.5g + Zinc 100 ppm + Boron 100 ppm /plant), with an average length of 4.42 cm. This was followed by T_6 (4.25 cm). The minimum fruit length (3.32 cm) was recorded in the control treatment (T_1). The observed increase in fruit length under nutrient-enriched treatments could be attributed to enhanced photosynthate production and efficient translocation from the leaves to the developing fruits. The higher availability of assimilates likely supported better fruit development, which was facilitated by the overall improved vegetative vigour of the plants. These observations are consistent with the findings reported by Salam et al. (2010).

3.2.4 Fruit diameter (cm)

The data on fruit diameter (cm) are presented in Table 1. The largest fruit diameter (5.40 cm) was observed in Treatment T_7. The minimum fruit diameter (3.10 cm) was recorded in T1 (Control). The increase in fruit diameter under nutrient-rich treatments can be attributed to the enhanced availability of essential macronutrients, particularly nitrogen, which plays a critical role in promoting cell division, protein synthesis, and overall plant growth. These processes collectively contribute to improved fruit development and size. Similar findings were reported by Meena et al. (2014**)**, who highlighted the influence of balanced nutrient supply on fruit diameter in tomatoes.

3.2.5 Fruit weight (g)

The data on average fruit weight (g) are presented in Table 2. The highest average fruit weight (67.38 g) was recorded in Treatment T_7 (NPK 1.5g + Zinc 100 ppm + Boron 100 ppm /plant). In contrast, the lowest average fruit weight (50.24 g) was observed in T_1. The increase in fruit weight under boron and zinc treatments can be attributed to their role in enhancing photosynthate accumulation, which directly influences fruit development. Boron, in particular, facilitates the efficient translocation and storage of assimilates, which contributes to increased fruit mass (Shukla, 2011). Furthermore, the combined application of zinc and boron promotes the synthesis of tryptophan and auxin, both of which are essential for fruit growth, as noted by Wojcik and Wojcik (2003**)**.

3.2.6 Fruit yield per plant (kg)

The results for fruit yield per plant (kg) are presented in Table 2. The highest fruit yield per plant (2.41 kg) was recorded in Treatment T_7 (NPK 1.5g + Zinc 100 ppm + Boron 100 ppm /plant), followed by T_6 (2.26 kg), T_5 (1.97 kg), and T_4 (1.85 kg). The lowest fruit yield per plant (1.26 kg) was observed in T_1 (Control). The increased yield observed under nutrient-enriched treatments can be attributed to improved nutrient uptake and more efficient photosynthetic activity, both of which enhance the accumulation of assimilates in the fruit. This positive relationship between nutrient availability and fruit yield has also been reported by Iguvenc and Badem (2002).

3.2.7 Fruit yield per plot (kg)

The recorded data on fruit yield per plot (kg) are presented in Table 2. The highest fruit yield per plot (24.10 kg) was observed in treatment T_7. The lowest fruit yield per plot (12.60 kg) was recorded in T_1. The observed increase in fruit yield per plot may be attributed to nutrient-supplemented treatments likely resulted from improved vegetative growth and more efficient nutrient uptake, which in turn enhanced the rate of photosynthesis and the accumulation of assimilates. Similar findings were reported by Ali et al. (2012**)**, who highlighted the positive influence of optimal nutrient availability on the overall yield performance of tomato plants.

3.2.8 Fruit yield per hectare (q)

The recorded observations on fruit yield per hectare (q ha^{-1}) are presented in Table 2. The highest fruit yield per hectare (296.43 q ha^{-1}) was achieved in treatmen**t** T_7 (NPK 1.5g + Zinc 100 ppm + Boron 100 ppm /plant). The lowest yield (154.98 q ha^{-1}) was recorded in T_1(Control). The improvement in fruit yield per hectare can be attributed to the combined effect of macro- and micronutrients on vegetative growth, which likely enhanced photosynthetic efficiency and overall plant vigour. These findings are well supported by the studies of Chatterjee et al. (2013**)**, Gulati et al. (2013), and Sulaiman and Sadiq (2020**)**, which also demonstrated that integrated application of NPK, organic manures, and biofertilizers significantly improved growth, yield, and fruit quality in tomato compared to untreated controls.

3.3 Fruit Quality Characters

3.3.1 Total Soluble solids (°Brix)

The data recorded on total soluble solids (°Brix) are presented in Table 2. The maximum total soluble solids content (4.57°Brix) was recorded in Treatment T_7 The minimum TSS value (1.17°Brix) was observed in T_1 (Control). Total soluble solids are a key indicator of fruit quality, as previously noted by Ali et al. (2004). Interestingly, earlier findings by Jyolsna and Mathew (2008) reported that calcium alone did not significantly enhance TSS content, whereas the combined application of calcium and boron resulted in a noticeable improvement. This suggests that the interaction between these two nutrients plays a vital role in enriching the TSS content of tomato fruits.

3.3.2 Fruit pH

The results related to pH values are summarized in Table 2. The highest pH value (4.15) was observed in Treatment T_7 (NPK 1.5g + Zinc 100 ppm + Boron 100 ppm /plant), followed by T_6(4.13) and T_5 (4.11). The pH level of tomato fruit generally increases as the fruit matures, progressing from the mature-green stage to full ripeness. This parameter is mainly influenced by the fruit's acid content, which plays an essential role in both flavour and product safety. According to Anthon et al. (2011), a pH value of 4.4 is considered the upper safety limit, while an ideal target pH is around 4.25 to ensure the product is both safe for consumption and maintains desirable quality. The gradual rise in pH typically coincides with a reduction in titratable acidity, largely due to the decreasing concentration of citric acid the dominant organic acid in tomatoesas the fruit ripens.

3.3.3 Fruit firmness (kg cm^2)

The observations on fruit firmness (kg/cm²) are presented in Table 2. The maximum fruit firmness (4.13 kg/cm²) was recorded in Treatment T_7. The lowest fruit firmness (2.01 kg/cm²) was observed in T_1 (Control). The improved firmness observed in boron-treated fruits can be linked to boron's critical role in enhancing calcium metabolism and promoting cell wall stability. Boron not only contributes to maintaining cell wall integrity but also plays a part in delaying cell wall degradation during fruit ripening, as highlighted by Ryden et al. (2003) and Lester and Grusak(2004). Furthermore, the combined application of calcium and boron has been reported to further enhance fruit firmness, as demonstrated by Smit and Combrink (2005).

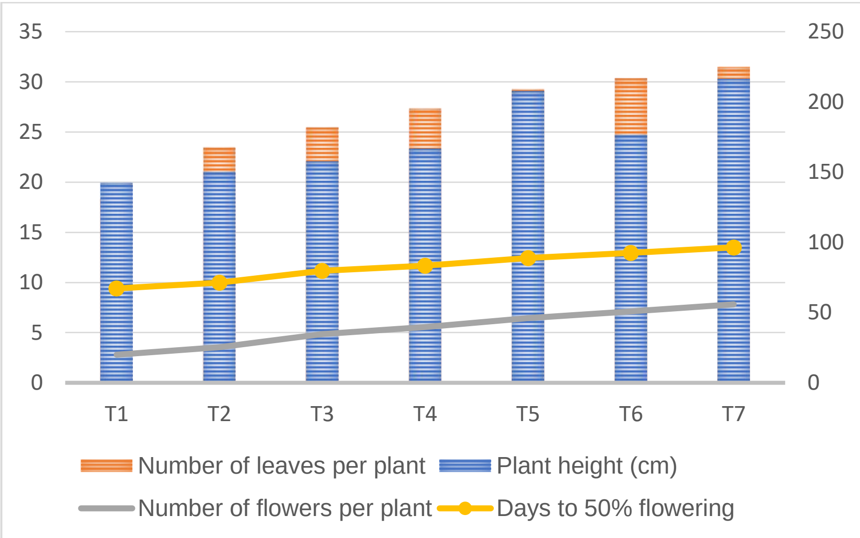

Fig. 1. Effect of macro and micronutrients on growth parameters of tomato

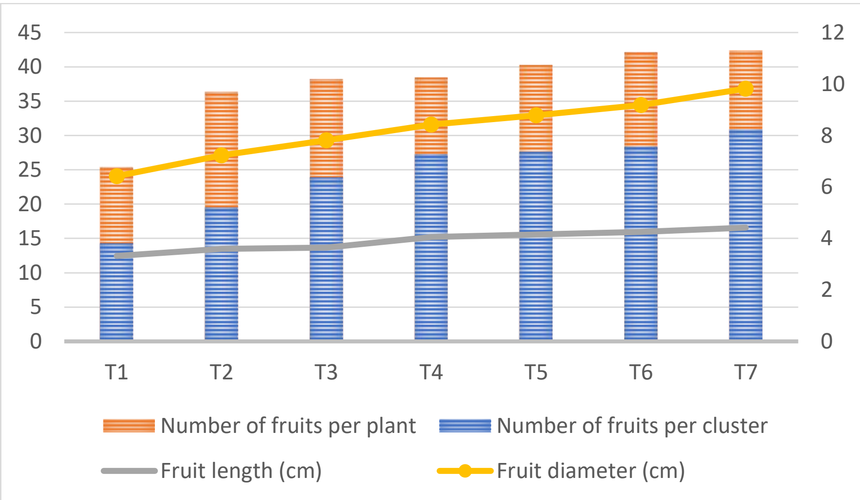

Fig. 2. Effect of macro and micronutrients on fruiting parameters of tomato

Table 1. Effect of foliar applications of nutrients on horticultural traits of tomato cv. Heemshikhar under protected conditions

Treatments	Plant height (cm)	Number of leaves per plant	Number of flowers per plant	Days to 50% flowering	Number of fruits per cluster	Number of fruits per plant	Fruit length (cm)	Fruit diameter (cm)
T_1	142.33	18.33	20.00	47.18	3.80	25.36	3.32	3.10
T_2	150.00	23.42	25.34	46.08	5.20	36.34	3.60	3.63
T_3	157.67	25.43	34.70	44.99	6.37	38.21	3.64	4.17
T_4	166.67	27.33	39.63	43.86	7.27	38.45	4.05	4.37
T_5	207.67	29.23	45.99	42.77	7.37	40.25	4.15	4.63
T_6	176.56	30.35	50.92	41.65	7.56	42.15	4.25	4.93
T_7	216.22	31.47	55.85	40.58	8.22	42.36	4.42	5.40
CD (0.05)	6.98	1.26	2.09	2.35	0.24	1.55	0.24	0.24
SE (±m)	2.26	0.41	0.68	0.76	0.07	0.50	0.07	0.08

Table 2. Effect of foliar applications of nutrients on yield and quality parameters of tomato cv. Heemshikhar under protected conditions

Treatments	Average fruit weight (g)	Fruit yield per plant (kg)	Fruit yield per plot (kg)	Fruit yield per hectare (q)	Total soluble solids (°Brix)	pH	Fruit firmness (kg/cm^2)	Dry matter (%)
T_1	50.24	1.26	12.60	154.98	1.17	4.03	2.01	4.07
T_2	52.36	1.31	13.10	161.13	2.10	4.05	3.26	4.70
T_3	55.28	1.67	16.70	205.41	2.67	4.07	3.33	4.84
T_4	59.74	1.85	18.50	227.55	3.13	4.09	3.52	5.16
T_5	62.29	1.97	19.70	242.31	3.53	4.11	3.68	5.28
T_6	63.14	2.26	22.60	277.98	4.07	4.13	4.00	5.68
T_7	67.38	2.41	24.10	296.43	4.57	4.15	4.13	5.71
CD (0.05)	2.64	0.20	0.93	10.64	0.10	NS	0.13	0.27
SE (±m)	0.85	0.06	0.30	3.45	0.03	NS	0.04	0.08

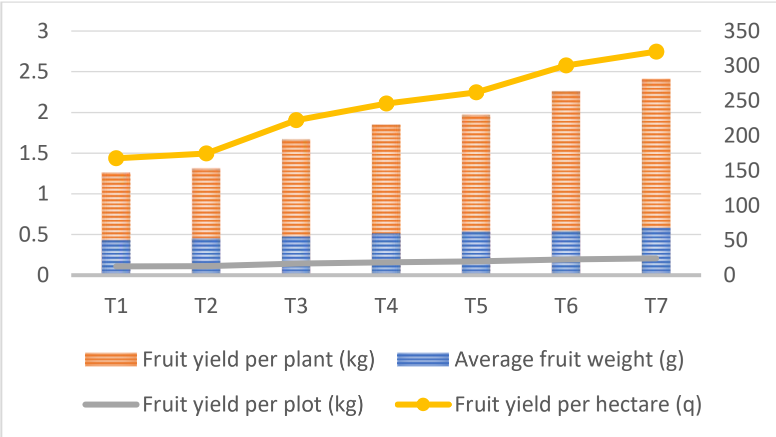

Fig. 3. Effect of macro and micronutrients on yield parameters of tomato

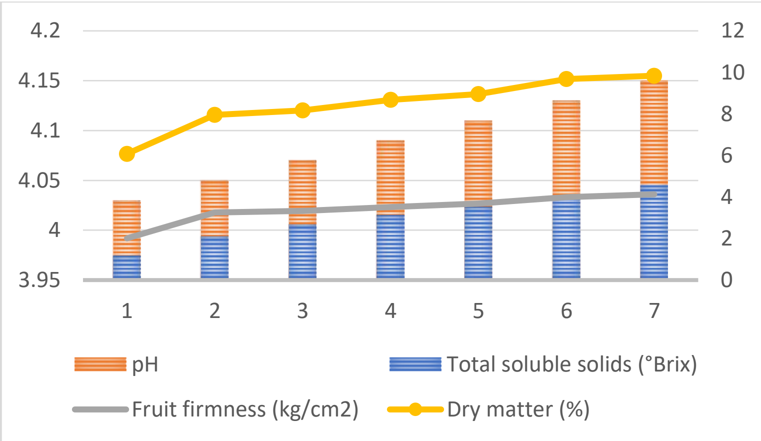

Fig. 4. Effect of macro and micronutrients on quality parameters of tomato

3.3.4 Dry matter (%)

The data pertaining to dry matter content (percentage) are summarized in Table 2. The highest dry matter percentage (5.71%) was observed in treatment T_7. Conversely, the lowest dry matter content (4.07%) was recorded in the control treatment (T_1 1). The enhanced accumulation of dry matter in the shoots can likely be attributed to an increased deposition of photosynthates within the vegetative tissues. Previous studies have shown a positive correlation between the application of micronutrients particularly calcium and zinc and photosynthate accumulation (Thalooth et al., 2006; Verma et al., 2018).

4. CONCLUSION

The study concluded that treatment T_7 (NPK 1.5 g + Zinc 100 ppm + Boron 100 ppm per plant) showed superior performance in tomato growth, flowering, yield, and quality parameters. It recorded the highest plant height, fruit yield (2.41 kg/plant; 234.98 q/ha), and quality traits such as TSS (4.57 °Brix) and firmness (4.13 kg/cm²). Overall, the combined application of macro- and micronutrients in T_7 significantly improved productivity and quality, highlighting the importance of balanced fertilization in tomato cultivation.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

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

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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