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Effect of the Major Micronutrients on Quantity and Quality Traits of Broccoli under the Kanpur Region (*Brassica oleracea* var. *Italica* L.)

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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

A field experiment was conducted during Rabi 2024 at the Horticulture Research Farm, Faculty of Agricultural Sciences and Allied Industries, Rama University, Kanpur (U.P.). The experiment was laid out in a Randomized Block Design (RBD) with nine treatments, each replicated three times, based on a one-year trial. The treatments are T1 (Control) T2 Zinc (3kg/ha) T3 Mo (1.5 kg/ha) T4

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Mn (2 kg/ha) T5 Boron (2.5-3 kg) T6 (B+Mo) T7 (B+Mn+Zinc) T8 (Mo+Mn) T9 (B+Mo+Mn+Zinc). Each unit plot measured 4.5 m², with a plant spacing of 60 cm × 45 cm, accommodating a total of 10 plants per plot. The treatments were randomly assigned to plots in each replication. The results revealed that the application of T9 (B + Mo + Mn + Zn) recorded the highest plant growth, yield, and quality attributes of broccoli, significantly outperforming the other treatments. In contrast, the control (T1) recorded the lowest values for growth, yield, and quality parameters. In terms of economics, T9 also recorded the highest gross return, net return (Rs. ha^{-1}), and benefit-cost ratio, indicating its economic viability over other treatments.

Keywords: Molybdenum; boron; yield; quality and broccoli.

1. INTRODUCTION

The category of "protective supplementary food" includes vegetables, as they are rich sources of vitamins and minerals that are essential for the normal functioning of the human metabolic system. Vegetable cultivation is one of the most profitable agricultural enterprises, particularly suitable for small and marginal farmers due to its potential for high yield and quick returns from limited land Among winter vegetables, cole crops hold significant importance. The group is believed to have originated from the wild cabbage known as "colewort" (*Brassica oleracea* var. *sylvestris*). Among all the cole crops, broccoli (*Brassica oleracea* var. *botrytis* L.) is considered one of the most important and popular vegetables. It belongs to the family Cruciferous. The edible part of broccoli, referred to as the curd, is a shortened shoot system comprising pre-floral fleshy apical meristems, forming a convex structure. This curd is generally white in color and may be partially enclosed by inner leaves before exposure.

India ranks as the second-largest producer of vegetables in the world after China, growing a wide variety of crops throughout the country. According to Horticultural Statistics at a Glance (2024–25), India produced approximately 214.56 million tonnes of vegetables, marking a 3.6% increase from 2023–24. Despite this, the country's vegetable productivity remains low compared to developed nations, and current production levels fail to meet national demand, despite a substantial scope for increasing yield per unit area. Moreover, there is considerable potential for the export and processing of vegetables (Parmar et al. 2023).

Currently, only about 40% of the total vegetable requirement in India is being fulfilled. For maintaining a healthy physique, the Indian Council of Medical Research (ICMR) recommends a daily intake of at least 300 grams of vegetables, comprising 50 grams of green leafy vegetables, 200 grams of other vegetables, and 50 grams of roots and tubers. However, actual per capita consumption is only about one-fourth to one-third of this requirement (ICMR, 2023), indicating a significant gap between production and nutritional needs.

In this context, while considerable work has been done on macronutrient management in vegetable crops, information regarding the micronutrient requirements of broccoli particularly boron and molybdenum under the agro-climatic conditions of Eastern Uttar Pradesh is scant. Furthermore, limited research has been carried out on the foliar application of boron, zinc, manganese, and molybdenum on broccoli in this region. Keeping in view the need for enhancing broccoli productivity and quality through proper micronutrient management, the present investigation entitled:

1. To find out the impact of Application of micronutrients on Quantitative attributes of Broccoli.
2. To study the impact of various micronutrients on qualitative attributes of Broccoli.
3. To assess the economics of different treatment combinations.

2. GROWTH ATTRIBUTES

Swiątkiewicz and Sandy (2023) assessed the impact of a 1% foliar zinc spray on broccoli and reported that it resulted in the maximum plant height and plant spread among all treatments.

Singh et al. (2018) conducted a field trial applying foliar sprays of boron (100 ppm) and molybdenum (50 ppm) both individually and in combination with two levels of borax (10 and 20 kg/ha) and sodium molybdate (1 and 2 kg/ha). The combination treatment provided the highest plant height, leaf length, leaf breadth, total plant weight, and curd diameter.

Nagda (2021) examined the effect of boron and molybdenum in cauliflower using similar dosages and reported significant improvements in growth, yield, and quality attributes when these micronutrients were applied both separately and together.

Chaudhari et al. (2023), in an experiment conducted at Navsari Agricultural University (Gujarat), observed that foliar application of Fe (2.0%), Mn (0.5%), Zn (4.0%), Cu (0.3%), B (0.5%), and ammonium molybdate significantly improved plant growth parameters such as plant height (74.93 cm), stalk length (16.59 cm), number of leaves (23.39), and plant spread (N-S: 76.81 cm; E-W: 77.79 cm).

Singh *et al.* (2018) carried out a field trial they applied foliar applications of boron at 100 ppm and molybdenum at 50 ppm both separately and in combination with two levels of borax at 10 and 20 kg/ha and sodium molybdate at 1 and 2 kg/ha. both by itself and in combination.

Provided the plant's maximum height, leaf length, leaf breadth, total plant weight, and curd width.

Nagda, A. (2021) carried out a field study to examine the effects of boron and molybdenum on cauliflower growth, yield, and quality. They applied foliar boron at 100 parts per million and molybdenum at 50 parts per million, both separately and in combination, along with two levels of borax at 10 and 20 kilograms per hectare and sodium molybdate at 1 and 2 kilograms per hectare.

3. YIELD ATTRIBUTES

Mm et al. (2016) observed that foliar application of boron and zinc at 0.5% each significantly increased broccoli yield under the agro-climatic conditions of Peshawar.

Sharma et al. (2018), working with broccoli cultivar Palam Samridhi, found that application of borax @ 15 kg/ha significantly improved primary curd diameter, average curd weight, and total yield.

Kumar et al. (2021) reported that boron spray at 0.5% resulted in the highest curd weight (930.5 g) and marketable yield (310.7 q/ha).

Swain et al. (2015) concluded that application of boron @ 1.5–4.0 kg/ha significantly increased curd size and weight, leading to higher overall yield.

Hassan et al. (2018) found that a foliar combination of borax (0.2%) and $ZnSO_4$ (0.5%) significantly improved leaf length (32.26 cm), total biomass (2849.2 g), and total yield per plot (34.8 kg).

Panda (2024) reported maximum curd diameter (18.41 cm), fresh curd weight (1.24 kg), yield (400.29 q/ha), and dry matter content (11.37%) with ammonium molybdate @ 1 kg/ha applied to soil.

Pankaj et al. (2018) showed that the combined application of B, Mo, Mn, and Zn @ 3:0.5:2:2.5 kg/ha significantly increased the vitamin C content and total soluble solids (TSS) in broccoli cv. Green Magic.

3.1 Quality Attributes

Nagda et al. (2021) found that boric acid (0.5%) gave the lowest TSS, whereas zinc sulfate (0.5%) produced the highest vitamin C content in broccoli.

Shivran et al. (2017) demonstrated that application of zinc @ 30 kg/ha significantly enhanced biochemical quality parameters, especially TSS and ascorbic acid content.

Singh et al. (2018), in a study on Pusa KTS-1 broccoli, reported that boric acid @ 0.4% resulted in the highest TSS content.

Xu et al. (2015) revealed that foliar application of zinc (0.25%) and boron (3.5%) significantly increased vitamin C concentration in broccoli.

3.2 Relative Economics

Singh et al. (2022) reported that foliar application of molybdenum @ 100 ppm resulted in the highest plant height (63.0 cm), number of leaves (16.44), leaf length (49.11 cm), leaf width (16.87 cm), plant spread (52.72 cm^2), and stem diameter (4.24 cm).

3.3 Experimental Site

The field experiment was conducted at the Vegetable Research Farm, Department of Horticulture, Institute of Agricultural Sciences, Rama University, Kanpur (U.P.), during the Rabi season of 2024–2025.

Geographically, the site lies in the central part of the North Gangetic alluvial plains, approximately 20 km southeast of Kanpur Railway Station, situated on the left bank of the river Ganga. The coordinates of the location are 25°10′ N latitude and 83°03′ E longitude, with an altitude of 128.93 meters above mean sea level.

The experimental field is representative of ideal alluvial soils in terms of texture, fertility, and uniformity. Winters in the region are cold and dry, with occasional frost. Temperatures begin to rise from February onwards, continuing up to June, marking the transition from Rabi to summer season.

4. RESULTS AND DISCUSSION

Data on periodic plant height recorded at 15, 30, 45 days after transplanting (DAT), and at harvest are presented in Table 1.

4.1 Crop Growth Characters

4.1.1 Plant height

Perusal of the data revealed that plant height progressively increased with crop age, with a rapid rise during the early growth period, followed by a slower rate of increase at harvest. In general, higher plant height was observed at all growth stages with micronutrient applications. The tallest plants (28.56 cm) were recorded under treatment T9 (B + Mo + Mn + Zn), which was statistically at par with T8 (Mo + Mn) and T6 (B + Mo). The lowest plant height was observed under T1 (Control) at all stages, including harvest.

This significant increase in plant height might be attributed to enhanced cell division and elongation due to boron, improved nutrient uptake, and better root development. The foliar application of micronutrients likely improved physiological processes and nutrient translocation, resulting in enhanced vegetative growth. These findings are in close agreement with those of Moniruzzaman et al. (2007), Singh et al. (2015), Kumar et al. (2013) in broccoli, and Devi et al. (2012) in cabbage.

4.1.2 Number of leaves per plant

Micronutrient applications significantly influenced the number of leaves per plant. At 15 and 30 DAT, the minimum number of leaves was recorded under T1 (Control). At harvest, the number of leaves ranged from 21.25 to 22.14, with the highest number observed in treatment T9 (B + Mo + Mn + Zn), which was statistically at par with T8 (Mo + Mn) and T6 (B + Mo).

The increased number of leaves may be attributed to better availability of essential nutrients during critical growth phases, which enhanced metabolic processes such as sugar metabolism, protein synthesis, and solute translocation. These results are in line with the findings of Gupta et al. (2021) in broccoli.

4.1.3 Leaf length (cm)

Micronutrient treatments also had a significant impact on leaf length at all growth stages (15, 30, 45 DAT, and at harvest), as shown in Table 1 and Fig. 3. Leaf length showed a continuous increase with plant age, ranging from 4.60 to 6.37 cm at early stages, and 7.27 to 10.89 cm by harvest. The maximum leaf length was recorded under T9 (B + Mo + Mn + Zn), which was statistically at par with T8 (Mo + Mn) and T6 (B + Mo). The minimum leaf length was observed under T1 (Control).

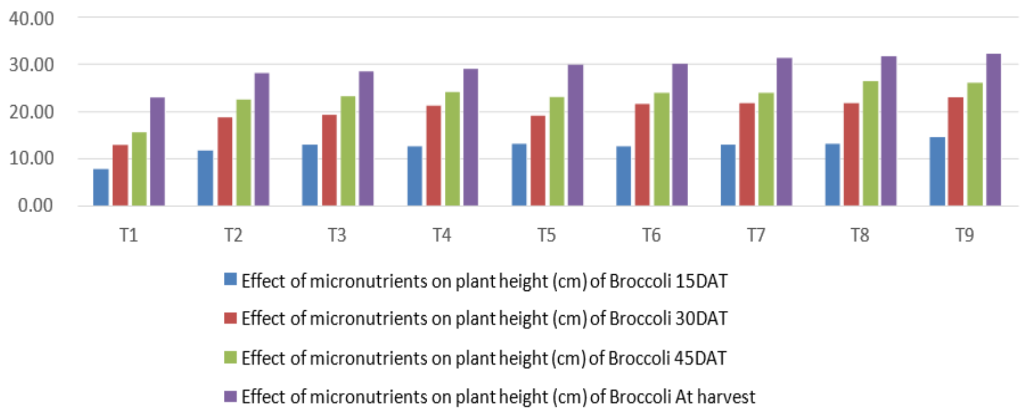

Fig. 1. Effect of micronutrients on plant height (cm) of Broccoli

Table 1. Effect of major micronutrients on growth attributes of Broccoli

	Plant height (cm) of Broccoli				Number of leaves				leaf length of Broccoli				Stem Girth
Treatment	**15 DA T**	**30 DA T**	**45 DA T**	**At harvest**	**15 DA T**	**30 DA T**	**45 DA T**	**At harvest**	**15DA T**	**30 DAT**	**45 DA T**	**At harvest**	
T1	7.67	12.92	15.58	22.75	6.55	13.38	19.52	19.45	4.6	7.27	12.44	14.79	3.697
T2	11.6	18.71	22.35	27.98	7.48	13.62	20.01	20.69	5.26	8.3	14.66	18.08	5.38
T3	12.76	19.19	23.18	28.33	7.66	13.38	19.53	21.02	5.67	8.17	15.39	18.41	5.733
T4	12.55	21.14	24.02	28.82	7.8	13.94	19.32	21.17	5.38	8.96	15.06	18.66	5.487
T5	13.03	19.08	22.94	29.64	6.26	13.86	17.66	21.25	5.29	9.52	13.91	18.92	7.99
T6	12.5	21.59	23.83	29.95	7.55	14.13	18.73	21.27	6.23	10.09	15.83	19.12	6.617
T7	12.9	21.68	23.85	31.11	8.35	14.24	20.49	22.14	5.77	8.6	15.1	19.45	6.57
T8	13.05	21.67	26.24	31.49	8.02	14.36	20.21	22.47	6.37	10.89	16.12	20.05	6.753
T9	14.35	23.01	25.98	32.04	9.41	15.38	22.41	22.78	6.67	11.62	17.52	20.4	7.07
SE±	0.16	0.17	0.18	0.2	0.09	0.19	0.2	0.14	0.15	0.19	0.22	0.19	0.09
CD (P=0.05)	0.47	0.47	0.59	0.56	0.34	0.38	0.46	0.4	0.39	0.49	0.64	0.54	0.24

Table 2. Effect of major micronutrients on yield attributes of Broccoli

Effect of micronutrients on Days required to Head initiation of stem of Broccoli			Effect of micronutrients on diameter of Head (cm) of Broccoli	Effect of Application of micronutrients on curd yield, curd weight and gross weight		
Treatment	**Days to Head Initiation**	**Days to 50% Head Initiation**	**Diameter of Head**	**Gross weight (g)**	**Net curd weight (g)**	**Curd yield (q/ha)**
T1	50	75.89	9.81	885.23	298.19	98.17
T2	45	68.94	11.9	977.84	363.14	132.68
T3	43	64.31	12.1	981.47	374.24	164.43
T4	42	60.99	12.18	968.21	307.55	158.28
T5	42	58.82	12.86	953.09	295.49	148.69
T6	43	56.7	13.59	954.56	256.98	154.89
T7	41	54.04	13.66	975.26	323.46	198.72
T8	40	49.45	13.92	972.32	317.46	190.42
T9	38	45.96	14.74	983.15	376.22	216.69
SE±	1.15	0.26	0.07	0.81	0.62	0.86
CD(P=0.05)	0.41	0.75	0.19	2.37	1.79	2.31

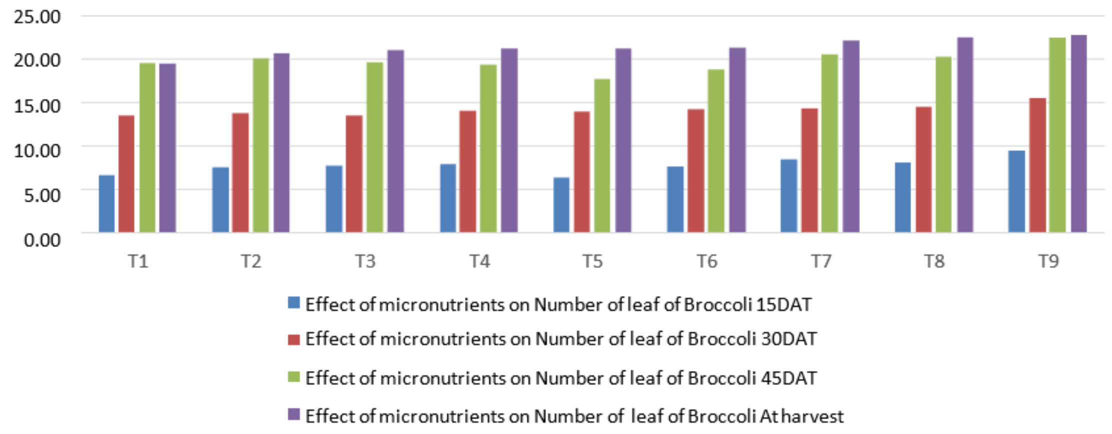

Fig. 2. Effect of micronutrients on number of leaf of Broccoli

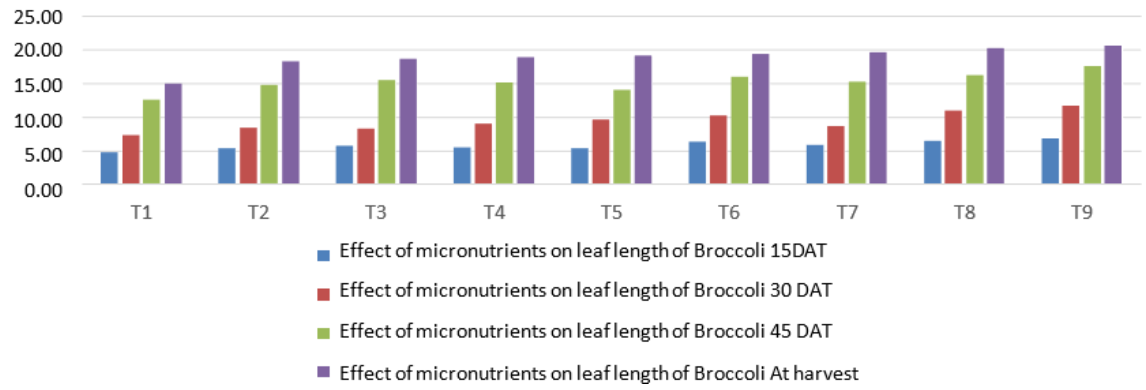

Fig. 3. Effect of micronutrients on leaf length of Broccoli

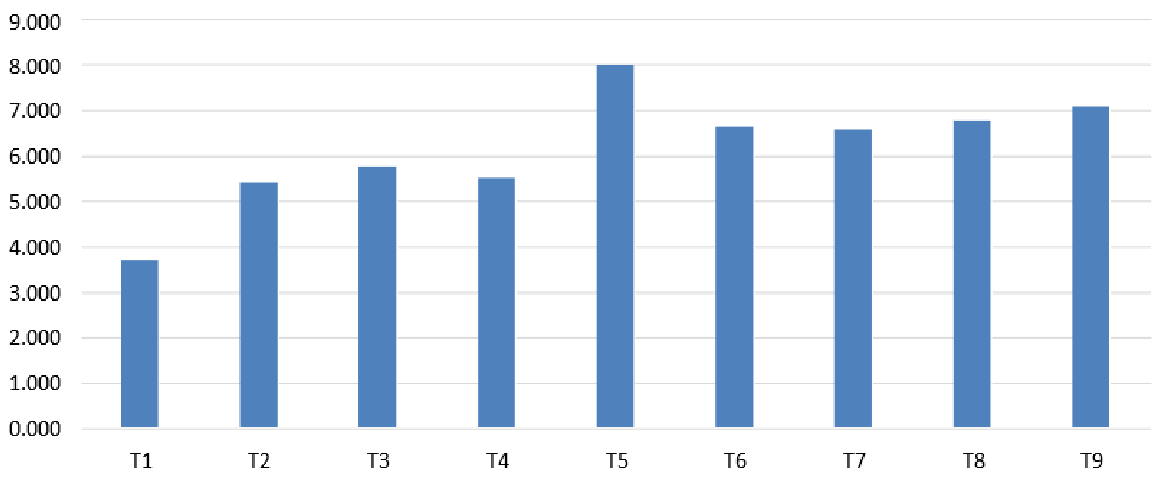

Fig. 4. Effect of micronutrients on Girth of stem of Broccoli Girth

This improvement in leaf size may be due to the enhanced physiological activity, nutrient uptake, and photosynthesis efficiency facilitated by the availability of boron and molybdenum. Similar results were reported by Gupta et al. (2017) in broccoli.

4.1.4 Stem girth (cm)

Data on stem diameter, recorded at various stages and graphically presented in Fig. 4, showed significant differences among treatments (Table 1). The highest stem girth was observed under T9 (B + Mo + Mn + Zn), which was statistically at par with T8 (Mo + Mn) and T7 (B + Mn + Zn), and significantly superior to the remaining treatments. The minimum stem girth was recorded under T1 (Control).

The increase in stem girth under micronutrient applications can be linked to enhanced structural tissue development and better carbohydrate assimilation due to improved nutrient availability and uptake.

4.2 Yield Attributes

4.2.1 Days to head initiation

The data pertaining to the effect of various treatments on days to head initiation are presented in Table 2 and depicted in Fig. 5. The results indicated that micronutrient applications significantly influenced the days required for head initiation. The earliest head initiation (39 days) was observed under treatment T9 (B + Mo + Mn + Zn), which was significantly superior to the other treatments. In contrast, the latest initiation was recorded under T1 (Control).

4.2.2 Days to 50% head initiation

The results on days to 50% head initiation, presented in Table 2 and Fig. 6, revealed that the earliest head maturity (46 days) was recorded under treatment T9 (B + Mo + Mn + Zn), followed by T8 and T6, while the maximum number of days (delayed initiation) was required under T1 (Control).

This advancement in head maturity could be attributed to boron, which facilitates carbohydrate translocation from source to sink (i.e., reproductive tissues), and molybdenum, which enhances photosynthetic activity and metabolic processes. These findings align with those reported by Singh (2015) and Chattopadhyay and Mukhopadhyay (2010) in broccoli.

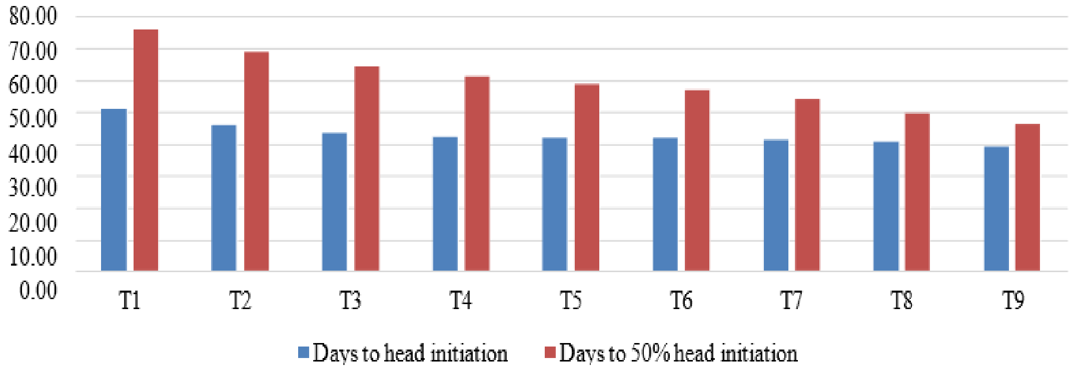

Fig. 5. Effect of micronutrients on Days required to head initiation of stem of Broccoli

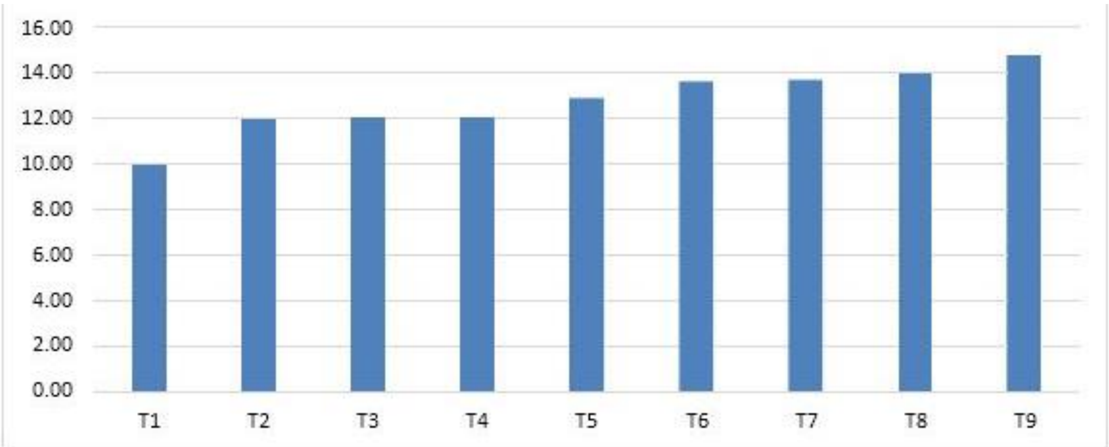

Fig. 6. Effect of micronutrients on diameter of head (cm) of Broccoli diameter of head

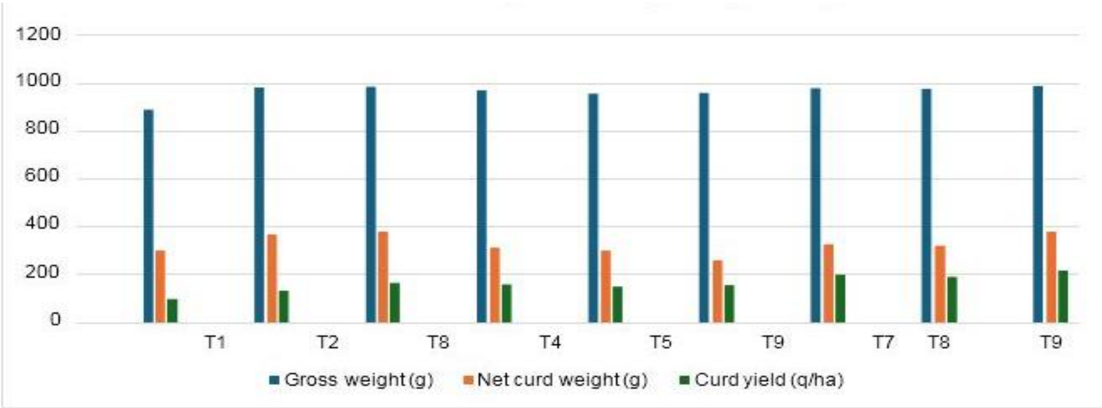

Fig. 7. Effect of micronutrients on curd yield, curd weight and gross weight

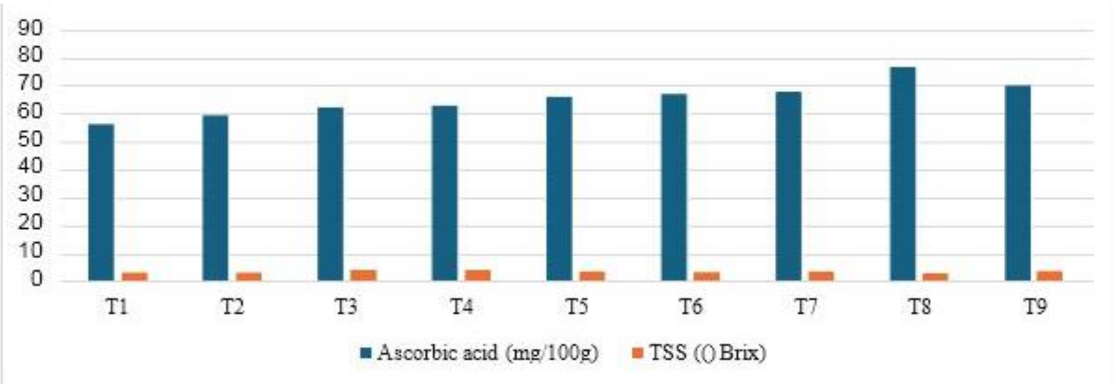

Fig. 8. Ascorbic acid (mg/100g) and TSS (^{0}Brix)

Table 3. Effect of major micronutrients on number of days for marketable maturity, ascorbic acid (mg/100g) and TSS (ºBrix)

Treatment Code	Ascorbic acid (mg/100g)	TSS (^{0}Brix)
T1	56.27	2.89
T2	59.48	2.98
T3	62.28	3.9
T4	62.79	3.98
T5	66.06	3.24
T6	67	3.09
T7	67.8	3.29
T8	76.8	2.68
T9	70.06	3.45
SE±	3.51	3.81
CD(P=0.05)	8.19	10.8

4.2.3 Head diameter (cm)

The effect of micronutrient treatments on head diameter of broccoli is presented in Table 2 and Fig. 6. Significant variation was observed among treatments. The largest head diameter was recorded under T9 (B + Mo + Mn + Zn), followed by T8 and T6. The smallest head diameter was observed under T1 (Control).

4.3 Ascorbic Acid Content (mg/100g)

Data on ascorbic acid content are presented in Table 3. The results indicate a significant increase in ascorbic acid levels with the application of micronutrients. The highest ascorbic acid content (70.06 mg/100g) was recorded under T9 (B + Mo + Mn + Zn), which was statistically at par with T8 (B + Mn + Zn).

The lowest value (56.27 mg/100g) was observed under T1 (Control).

The increase in ascorbic acid content due to micronutrient application may be attributed to improved enzymatic activity, nutrient availability, and metabolic efficiency. These results corroborate the findings of Sharma et al. (2018) in spinach, Guo et al. (2013) in cabbage, Singh (2014) in cauliflower, Thapa et al. (2013), and Thakur (2018) in cabbage.

5. CONCLUSION

Overall, the study concludes that the combined foliar application of B + Mo + Mn + Zn (T9) is most effective in enhancing broccoli growth, earliness, yield, and nutritional quality under the given agro-climatic conditions. The integration of such micronutrient management strategies can be recommended as a vital component of nutrient management in broccoli production for achieving higher productivity and improved quality.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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