

Influence of Foliar Spray of Mg, Boron, and Zn on Growth and Yield of Broccoli (*Brassica oleracea* var. Marathon)

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ABSTRACT

Broccoli (*Brassica oleracea* var. *italica*) is an important vegetable crop recognized worldwide for its high nutritional value and health-promoting properties. It is a rich source of vitamins, minerals, antioxidants, and dietary fiber, making it an important component of a healthy diet. However, the growth, development, and yield of broccoli can suffer when essential micronutrients are not sufficiently available to plants. Micronutrients such as magnesium, boron, and zinc play important roles in various physiological and biochemical processes, including photosynthesis, enzyme activity, cell division, flowering, and head development. To address micronutrient deficiency and improve broccoli productivity, we conducted a field study in Qalai Janan Khan Village, Behsood District, Nangarhar Province, Afghanistan, during the 2025 fall–winter season. The experiment evaluated the effects of foliar applications of magnesium, boron, and zinc at 100 and 200 ppm, along with an untreated control. The treatments were arranged in a Randomized Complete Block Design (RCBD) with three replications to ensure reliable comparison among treatments. Micronutrient application enhanced vegetative growth, improved plant development, and positively influenced flowering and head formation. Among all treatments, foliar application of zinc at 100 ppm produced the best overall performance, resulting in stronger plant growth, better leaf development, earlier flowering, larger heads, and higher marketable yield. The findings demonstrate that appropriate foliar micronutrient application can improve broccoli productivity under local growing conditions. Overall, foliar application of zinc at 100 ppm was the most effective treatment under the agro-climatic conditions of Nangarhar Province, Afghanistan.

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INTRODUCTION

Broccoli (*Brassica oleracea* var. Marathon) is an important cool-season vegetable crop in the Brassicaceae family. It is closely related to cauliflower, cabbage, kale, and other cole crops. It is cultivated worldwide for its edible green flower heads. It originates from the Mediterranean region and has gained global recognition for its high nutritional value and health-promoting

properties (Thamburaj & Singh, 2015; Singh & Nath, 2012). Broccoli is increasingly considered one of the most beneficial vegetables for human health because of its high content of vitamins, minerals, dietary fiber, and antioxidant compounds (Sardar et al., 2022).

Broccoli contains significant amounts of vitamins A, C, and the B-complex, as well as essential minerals like calcium, phosphorus, potassium, and iron. One hundred (100) g of edible broccoli contains 89.9 g moisture, 3.3 g protein, 5.5 g carbohydrates, 0.2 g fat, 37 kcal energy, and 137 mg vitamin C (Sanwal & Yadav, 2005; Singh & Nath, 2012). Additionally, it is a rich source of bioactive compounds like glucosinolates and sulforaphane, which have antioxidant and anti-carcinogenic properties and may help reduce several chronic disease risks (Singh & Nath, 2012).

Broccoli cultivation is rapidly expanding in several countries as consumer awareness of its functional foods and healthy benefits increases. The leading producers of Broccoli are China, India, the United States, Spain, Italy, and Mexico, where this Cole crop contributes substantially to vegetable production and farm income. Because of its relatively short growth period, high market value, and strong demand, it has become an attractive vegetable for commercial growers worldwide (Siomos et al., 2022).

In Afghanistan, it is still a new vegetable compared with traditional vegetables like cabbage, cauliflower, and spinach. However, consumption is increasing gradually, especially in urban areas; access to quality seed is inadequate, farmers have insufficient technical knowledge, and consumers have limited awareness of its nutritional benefits (FAO, 2022). The country's agro-climatic conditions are suitable for cultivation and production, especially in cooler parts of Afghanistan such as Kabul, Bamyan, Wardak, Ghazni, and some regions of Nangarhar province (MAIL, 2021). Despite favorable conditions, several constraints limit broccoli production, including inadequate irrigation systems, limited access to high-yielding cultivars, insufficient market infrastructure, and weak extension services, which prevent meeting market demand and still require broccoli imports from Iran and Pakistan (Ahmadzai et al., 2020).

Nutrient management, especially micronutrients and their balance, plays a crucial role in broccoli growth, curd formation, yield, quality, and production. Micronutrients such as boron, molybdenum, zinc, manganese, and iron are involved in enzyme activation, chlorophyll synthesis, nutrient transport, and reproductive development; deficiency leads to poor growth, reduced head size, and low production (Kundu & Chamroy, 2020; Pawar & Tambe, 2017).

The micronutrient foliar application is one of the best strategies to improve nutrient uptake and broccoli performance. Foliar feeding allows nutrients to be absorbed directly by leaves, resulting in faster physiological responses than soil application. Studies revealed that foliar application of micronutrients significantly enhances plant height, number of leaves, head diameter, curd weight, and total yield (Mahmoud et al., 2019; Singh et al., 2018). A combination of micronutrients produces better results than a single application because of their

synergistic effects (Pankaj et al., 2018; Parmar et al., 2023). Micronutrients also improve broccoli quality and nutritional components by increasing vitamin C, chlorophyll concentration, antioxidant activity, and TSS (Singh et al., 2017; Kumari et al., 2025). A combination of organic amendments, biofertilizers, and micronutrient application also improves soil health, microbial activity, and long-term production (Chandra & Dash, 2023; Rivera-Martin et al., 2021).

Therefore, enhancing broccoli production in Afghanistan requires a nutrient management adaptation strategy, especially integrating foliar micronutrients to improve yield, quality, and economic returns (El-Mogy et al., 2019; Kaur et al., 2025). Based on this, broccoli is a high-value crop that supports agricultural diversification, increases farmer income, and enhances nutritional security in Afghanistan (FAO, 2022). This investigation aims;

- To assess the effects of magnesium, boron, and zinc concentrations, applied as a foliar spray, on broccoli growth and yield under Nangarhar agro-climatic conditions.

METHODS AND MATERIALS

Research Design

A field experiment was carried out during the fall–winter season of 2025 in Qalai Janan Khan Village, Behsood District, Nangarhar, Afghanistan. The study aimed to evaluate the response of the Marathon broccoli cultivar to foliar application of selected micronutrients. The soil of the experimental site was silty clay, containing 3.04% organic matter, 45.05 ppm P_2O_5 , 319 ppm K, 14.8% $CaCO_3$, 0.24 mS cm^{-1} EC, pH 8.12, and a cation exchange capacity of 21.4 meq $100\ g^{-1}$ soil. Seeds of the broccoli cultivar (Marathon) were sown in a nursery on 25 August 2025, and healthy seedlings were transplanted to the main field on 04 September 2025.

The experiment followed a Randomized Complete Block Design (RCBD) with seven treatments and three replications. The treatments included a control, magnesium at 100 and 200 ppm, boron at 100 and 200 ppm, and zinc at 100 and 200 ppm. Foliar sprays were applied three times at 20, 40, and 60 days after transplanting. The total experimental area covered 216.3 m^2 and consisted of 21 plots. Plants were maintained at 60 cm between rows and 30 cm between plants, with 12 plants per plot.

Data Collection

All plots received the same cultural practices throughout the growing period. We carried out irrigation, weeding, and plant protection measures as needed to ensure healthy crop growth. Growth observations, including plant height, number of leaves, number of branches, and leaf area, were recorded from four randomly selected plants in each plot at 30, 50, and 70 days after transplanting. At harvest, data were collected on curd weight, curd length, curd diameter, curd width, marketable yield, non-marketable yield, and total yield. Yield values were converted to tons per hectare for analysis.

Data Analysis

The recorded data were analyzed using STAR software (version 2.0.1). Treatment means were compared using the Least Significant Difference (LSD) test at the 5% probability level, and the coefficient of variation and F-test values were used to assess result reliability and significance.

FINDINGS

Statistical analysis at the $P < 0.05$ level was performed on various growth and yield parameters measured throughout this investigation. Different micronutrient applications significantly influenced broccoli growth and yield. Various micronutrients affected plant height at both 50 and 70 days after transplanting (DAT), while no significant differences were observed among treatments at 30 DAT. Among the applied treatments, T₄ produced the tallest plants at both 50 & 70 DAT, and T₂, T₃, and T₆ were on par with this treatment. The control produced the smallest plants at both 50 and 70 days after transplanting (Table 1).

Table 1. Effects of foliar spray of Mg, Zn and B on plant height (cm) of Broccoli

Treatments	30 DAT	50 DAT	70 DAT
cnotrol	38.7	44.5 d	53.77 c
Mg 100 ppm	42.43	60.87 a	81.63 a
B 100 ppm	43.07	57.77 ab	79.8 ab
Zn 100 ppm	44.23	61.73 a	81.93 a
Mg 200 ppm	41.4	51.47 c	69.63 b
B 200 ppm	42.2	54.43 bc	72.73 ab
Zn 200 ppm	40.77	57.13 abc	70.47 a
CV(%)	7.98	3.75	5.23
ANOVA	ns	*	*
LSD (0.05)	-	5.9390	10.8926

According to the statistical output, various micronutrient applications significantly influenced branches per plant. Among them, T₄ produced the highest number of branches per plant, and T₂ and T₃ were on par with it (7.33, 6.67, and 7.33, respectively). The control produced the lowest number of branches (4.33) at 50 DAT (Table 2).

Table 2. Effects of foliar spray of Mg, Zn and B on number of Branches per Broccoli plant

Treatments	30 DAT	50 DAT	70 DAT
cnotrol	2.67	4.33 c	9.33 c
Mg 100 ppm	2.67	7.33 a	14.67 a
B 100 ppm	2.67	6.67 ab	13.67 a
Zn 100 ppm	2.67	7.33 a	14.67 a
Mg 200 ppm	2.67	5.33 bc	11.33 b
B 200 ppm	2.67	5 bc	10.33 bc
Zn 200 ppm	2.67	5.33 bc	11 bc
CV(%)	22.41	11.59	5.24
ANOVA	ns	*	*
LSD (0.05)	-	1.9555	1.8181

Based on the statistical analysis results, the number of leaves produced per broccoli plant was significantly influenced by the application of various micronutrients at 30, 50, and 70 DAT. Among the applied treatments, all treatments differed significantly at 30, 50, and 70

days after transplanting (DAT). Among the applied treatments, T₃ produced the most leaves at 70 DAT, while there were no significant differences among treatments without control. At 50 DAT, all treatments differed significantly from the control (Table 3).

Table 3. Effects of foliar spray of Mg, Zn, and B on the number of leaves per Broccoli plant

Treatments	30 DAT	50 DAT	70 DAT
cnotrol	7.33 b	23.33 bc	25.33 b
Mg 100 ppm	9 a	25.67 a	27 ab
B 100 ppm	8.33 ab	25.67 a	28.67 a
Zn 100 ppm	8.67 ab	25.33 ab	27.33 ab
Mg 200 ppm	8.33 ab	21.33 c	27.67 a
B 200 ppm	9 a	21.67 c	28.33 a
Zn 200 ppm	8 ab	23.33 bc	26.67 ab
CV(%)	6.89	3.44	2.59
ANOVA	*	*	*
LSD (0.05)	1.6499	2.3333	2.0207

The statistical analysis showed that different micronutrient applications on broccoli leaf area did not differ significantly at 30 DAT, but did at 50 and 70 DAT. Among the treatments, different micronutrient applications influenced leaf area. No significant differences were observed among T₂, T₃, and T₄; T₄ and T₃ recorded the highest leaf area (25.87). T₅, T₆, and T₇ did not differ significantly from each other. The lowest leaf area was recorded in the control (17.13) (Table 4).

Table 4. Effects of foliar spray of Mg, Zn and B on leaf area of Broccoli plant

Treatments	30 DAT	50 DAT	70 DAT
cnotrol	8.86	15.3 c	17.13 c
Mg 100 ppm	8.53	22.93 ab	25.77 a
B 100 ppm	8.79	23.63 a	25.87 a
Zn 100 ppm	8.83	23.27 ab	25.87 a
Mg 200 ppm	8.75	20.57 ab	22.5 b
B 200 ppm	8.59	20.3 ab	22.9 b
Zn 200 ppm	9.14	19.87b	22.33 b
CV(%)	5.81	5.83	2.56
ANOVA	ns	*	*
LSD (0.05)	-	3.4696	1.6977

Different micronutrient applications influenced broccoli stem girth at both 50 and 70 days after transplanting, but not at 30 DAT. At 50 DAT, all treatments differed significantly, but T₂, T₃, T₄, and T₅ did not differ significantly among themselves, while the control differed significantly from them. At 70 DAT, various micronutrients influenced stem girth; T₄ recorded the highest score (15.15 cm). Among T₅, T₆, and T₇, there were no differences, and the control recorded the lowest score (7.98 cm) (Table 5).

Table 5. Effects of foliar spray of Mg, Zn, and B on stem girth of Broccoli plant

Treatments	30 DAT	50 DAT	70 DAT
cnotrol	4.98	6.03 b	7.98 c
Mg 100 ppm	4.92	11.46 a	14.38 a
B 100 ppm	4.69	12 a	15 a
Zn 100 ppm	4.85	11.88 a	15.15 a
Mg 200 ppm	4.49	11.04 a	13.11 b
B 200 ppm	4.82	11.03 a	12.97 b
Zn 200 ppm	5.19	11.14 a	12.87 b

CV(%)	8.26	6.02	2.93
ANOVA	ns	*	*
LSD (0.05)	-	1.8317	1.0935

Based on the statistical analysis, micronutrient application affected plant spreading; at 30 DAT, there were no significant differences among treatments, while at 50 DAT, there were significant differences among all applied micronutrients. Among them, T₄ exhibited the largest amount of plant spreading (54.83 cm), and the lowest was recorded for the control (34.2 cm). At 70 DAT, differences also existed between treatments and the control, while the other treatments did not differ significantly from each other. T₃ produced the greatest spread, while the control recorded the lowest (51.87 cm), respectively (Table 6).

Table 6. Effects of foliar spray of Mg, Zn, and B on plant spread of broccoli plants

Treatments	30 DAT	50 DAT	70 DAT
control	21.23	34.2 c	51.87 b
Mg 100 ppm	22.48	56.43 a	77.47 a
B 100 ppm	25.53	54.83 a	82.97 a
Zn 100 ppm	23.97	54.53 ab	81.17 a
Mg 200 ppm	24	50.2 b	75.2 a
B 200 ppm	25.75	51.97 ab	76.03 a
Zn 200 ppm	24.41	52.7 ab	76.17 a
CV(%)	7.81	3.12	4.25
ANOVA	ns	*	*
LSD (0.05)	-	4.5250	9.0455

According to the statistical results, different micronutrient treatments significantly influenced the initiation of flowering. Plants treated with T₄ reached first flowering production in only 57.67 days, followed by T₃ (60.67 days) and T₂ (62.67 days). In contrast, T₁ took the longest to reach first flowering production, at 70.33 days. Statistical analysis showed significant differences among treatments, indicating that micronutrient application accelerated flower initiation compared with the control.

The treatments showed significant variation in the number of days required to attain 50% flowering. T₄ recorded the earliest 50% flowering (64.67 days), while T₁ required the most days (77.33 days). Treatments T₂ and T₃ also promoted earlier flowering, requiring 69.67 and 67.67 days, respectively. The results suggest that micronutrient application enhanced flowering development and reduced the time needed to reach the flowering stage (Table 7).

Table 7. Effects of foliar spray of Mg, Zn and B on days to flowering of Broccoli plant

Treatments	0 DAT	50 DAT
control	70.33 a	77.33 a
Mg 100 ppm	62.67 d	69.67 d
B 100 ppm	60.67 e	67.67 e
Zn 100 ppm	57.67 f	64.67 f
Mg 200 ppm	64.67 c	71.67 c
B 200 ppm	65.67 bc	72.67 bc
Zn 200 ppm	66.67 b	73.67 b
CV(%)	0.6814	0.6143
ANOVA	*	*
LSD (0.05)	1.2472	1.2472

Micronutrient treatments significantly affected individual flower weight. The heaviest flowers were obtained from T₄ (495.00 g), followed by T₂ (470.00 g) and T₃ (445.67 g). These treatments were statistically similar to each other but superior to the remaining treatments. T₁ recorded the lowest flower weight (297.67 g). T₅, T₆, and T₇ showed intermediate values, demonstrating the positive contribution of micronutrient application to flower development (Table 8).

Table 8. Effects of foliar spray of Mg, Zn, and B on weight of individual flower of broccoli

Treatments	Weight of individual flower (g)
cnotrol	297.67 c
Mg 100 ppm	470 a
B 100 ppm	445.67 a
Zn 100 ppm	495 a
Mg 200 ppm	380 b
B 200 ppm	374.33 b
Zn 200 ppm	352 b
CV(%)	5.13
ANOVA	*
LSD (0.05)	58.9658

Different micronutrient treatments significantly influenced flower length. T₄ recorded the maximum flower length (18.93 cm), followed closely by T₂ (18.17 cm) and T₃ (17.47 cm), with no significant differences among these treatments. T₁ produced the shortest flowers (12.90 cm). Treatments T₅, T₆, and T₇ exhibited moderate flower lengths, indicating a beneficial effect of micronutrients on floral growth (Table 9).

Table 9. Effects of foliar spray of Mg, Zn, and B on flower length of Broccoli plant

Treatments	Flower length (cm)
cnotrol	12.9 c
Mg 100 ppm	18.17 a
B 100 ppm	17.47 a
Zn 100 ppm	18.93 a
Mg 200 ppm	15.47 b
B 200 ppm	15.3 b
Zn 200 ppm	14.57 bc
CV(%)	3.79
ANOVA	*
LSD (0.05)	1.7453

The results demonstrated significant effects of micronutrient application on flower volume. T₄ produced the highest flower volume (861.33 cm³), followed by T₂ (811.33 cm³) and T₃ (761.00 cm³). These treatments remained statistically similar and outperformed the others. T₁ recorded the lowest flower volume (504.00 cm³). The findings indicate that micronutrient supplementation contributed substantially to improved flower size and development (Table 10).

Table 10. Effects of foliar spray of Mg, Zn and B on flower volume of Broccoli plant

Treatments	Flower volume (cm ³)
cnotrol	504 c
Mg 100 ppm	811.33 a
B 100 ppm	761 a
Zn 100 ppm	861.33 a

Mg 200 ppm	645.33 b
B 200 ppm	635.33 b
Zn 200 ppm	602.33 bc
CV(%)	5.72
ANOVA	*
LSD (0.05)	112.6011

Average flower weight varied significantly among treatments. T₄ had the highest average flower weight (490.00 g), followed by T₂ (465.00 g) and T₃ (440.67 g), which did not differ significantly from each other. T₁ recorded the lowest value (292.67 g). Treatments T₅, T₆, and T₇ produced intermediate average flower weights, reflecting the beneficial role of micro-nutrients in enhancing flower quality (Table 11).

Table 11. Effects of foliar spray of Mg, Zn, and B on flower weight of broccoli plants

Treatments	Flower weight (g)
cnotrol	292.67 c
Mg 100 ppm	465 a
B 100 ppm	440.67 a
Zn 100 ppm	490 a
Mg 200 ppm	374.33 b
B 200 ppm	369.33 b
Zn 200 ppm	347 bc
CV(%)	5.17
ANOVA	*
LSD (0.05)	58.7026

A significant variation in flower yield per hectare was observed due to the application of micronutrients. The highest yield was achieved in T₄, producing 27.27 t ha⁻¹, followed by T₂ (25.90 t ha⁻¹) and T₃ (24.57 t ha⁻¹). These treatments were statistically similar and significantly higher than the control. T₁ recorded the lowest yield (16.27 t ha⁻¹). The improved yields under micronutrient treatments highlight their effectiveness in enhancing overall flower productivity (Table 12).

Table 12. Effects of foliar spray of Mg, Zn, and B on flower yield of Broccoli plant

Treatments	Yield (t ha ⁻¹)
cnotrol	16.27 c
Mg 100 ppm	25.9 a
B 100 ppm	24.57 a
Zn 100 ppm	27.27 a
Mg 200 ppm	20.8 b
B 200 ppm	20.53 b
Zn 200 ppm	19.27 bc
CV(%)	5.11
ANOVA	*
LSD (0.05)	3.2272

DISCUSSION

The results of the present investigation showed that applying micronutrients significantly improved broccoli vegetative growth compared with the control treatment. The effects of micronutrients were reflected in increased plant height, number of branches, number of

leaves, leaf area, stem girth, and plant spread. These enhancements highlight the role of micronutrients in broccoli's physiological and biochemical processes.

The significant increase in plant height under micronutrient treatments, particularly T₄, agrees with Sardar et al. (2022), who reported that foliar application of zinc and boron enhanced plant growth and vigor in broccoli.

The greater number of branches produced under T₂, T₃, and T₄ may be associated with improved nutrient utilization and enhanced meristematic activity. Singh et al. (2017) reported similar findings, observing increased vegetative growth and branching following the combined application of boron, manganese, and zinc in broccoli.

The increase in the number of leaves per plant observed in the micronutrient-treated plants is consistent with Parmar Vijaykumar et al. (2023), who reported that combined application of boron, zinc, and iron significantly improved leaf production and vegetative growth in broccoli.

Leaf area is an important growth parameter because it directly influences plants' photosynthetic capacity. In the present study, T₃ and T₄ treatments recorded the largest leaf area. Netwal et al. (2023) reported similar results, finding that zinc application significantly increased leaf area and chlorophyll content in sprouting broccoli.

Micronutrient application significantly increased stem girth, enhancing cell division and the accumulation of structural carbohydrates in stem tissues. Mahmoud et al. (2019) similarly reported improved vegetative growth and stronger plant structure following combined application of zinc and boron in broccoli.

Micronutrient treatments, particularly T₂, T₃, and T₄, also significantly enhanced plant spread, leading to increased leaf production, branch formation, and greater growth. Singh et al. (2018) reported comparable findings, observing that micronutrient application significantly increased plant spread and vegetative growth in broccoli.

The absence of significant differences among treatments at 30 DAT for most growth parameters suggests that the response to micronutrient application became more evident as plants progressed through their growth stages. Several studies reported similar observations, where micronutrient effects became more pronounced during later vegetative stages as nutrient demand increased. This explains why significant differences among treatments were observed mainly at 50 and 70 DAT.

Overall, T₄'s superior performance across most vegetative growth parameters indicates that balanced micronutrient nutrition played a crucial role in promoting broccoli growth. According to Athokpam et al. (2023), micronutrients such as boron, zinc, iron, manganese, and molybdenum are required in small quantities. However, they are indispensable for plant metabolism, enzyme activity, chlorophyll formation, and nutrient transport. Adequate supply of these nutrients enhances physiological efficiency and promotes vigorous plant growth.

The results of this investigation are consistent with Sardar et al. (2022), who reported that foliar application of zinc and boron significantly enhanced growth, yield, and quality characteristics of broccoli. They observed improvements in plant height, leaf development, head size, chlorophyll content, and nutrient accumulation, which ultimately resulted in increased yield. The present study observed similar results, with micronutrient-treated plants showing superior flowering and productivity compared with untreated plants.

The positive effects of micronutrients recorded in this experiment are also supported by Pawar and Tambe (2017), who found that foliar application of boron and ammonium molybdate significantly increased head weight, head diameter, head volume, number of leaves, and total yield of broccoli. In another study, Pawar and Tambe (2016) reported greater uptake of nitrogen, phosphorus, potassium, boron, molybdenum, and zinc following micronutrient application. Enhanced nutrient absorption may have contributed to the improved flower weight and yield observed in the current investigation.

Similarly, Mahmoud et al. (2019) demonstrated that combined foliar application of zinc and boron improved vegetative growth, head quality, and total yield of broccoli. Their findings suggest that combined micronutrient use can produce a synergistic effect, leading to better crop performance. This observation agrees with the present results, where combined micronutrient treatments consistently outperformed the control.

Singh et al. (2017) further supported these findings, reporting that combined application of boron, manganese, and zinc significantly improved plant height, number of leaves, plant spread, head diameter, head weight, vitamin C content, and yield. The greater flower size and yield recorded under the micronutrient treatments in the present study indicate a similar beneficial effect of balanced micronutrient nutrition on reproductive growth and productivity.

Comparable results were also reported by Singh et al. (2018), who observed that foliar application of zinc sulfate increased plant spread, root growth, and ascorbic acid content, while boric acid application produced the highest curd yield. These improvements were attributed to micronutrients' roles in cell division, carbohydrate metabolism, and nutrient transport, which are essential for flower development and yield formation.

Netwal et al. (2023) also found that zinc application significantly increased plant height, leaf area, chlorophyll content, and curd yield in sprouting broccoli. Their results indicate that zinc enhances photosynthetic activity and biomass production, which may explain the higher flower yield recorded in the present experiment.

The superiority of combined micronutrient treatments observed in this study aligns with the findings of Parmar Vijaykumar et al. (2023), who reported that the combined application of boron, zinc, and iron through foliar sprays produced the highest growth and yield parameters in broccoli. Their study highlighted the importance of balanced micronutrient nutrition, which supports the better performance of T₂, T₃, and T₄ observed in the current investigation.

Recent studies have also emphasized the role of micronutrients in improving broccoli quality attributes. Chandra et al. (2025) reported significant increases in ascorbic acid, total soluble solids, crude protein, and chlorophyll content following micronutrient application. Likewise, Kundu et al. (2025) found that foliar sprays of boron and manganese enhanced plant growth, head weight, head diameter, yield, and quality. These findings suggest that micronutrients contribute not only to higher yields but also to improved nutritional quality of broccoli.

The present results are further supported by Tarafder et al. (2023), who recorded the highest marketable yield and economic returns from the combined application of boron, zinc, and molybdenum. Similarly, Kaur et al. (2025) concluded that combined foliar application of boron and zinc was more effective than individual applications in improving broccoli growth and yield parameters. These reports reinforce the importance of micronutrient combinations in achieving optimum crop performance.

The beneficial effects observed in the present study can be explained by micronutrients' essential functions in plant metabolism. According to Athokpam et al. (2023) and Kundu and Chamroy (2020), micronutrients such as boron, zinc, iron, manganese, and molybdenum play vital roles in chlorophyll synthesis, enzyme activation, nutrient regulation, reproductive development, and assimilate translocation. Adequate availability of these nutrients promotes vigorous vegetative growth and enhances the development of reproductive structures, resulting in higher yields.

Overall, the findings of the present investigation, together with previous research, demonstrate that micronutrient application is an effective approach to improving broccoli growth and yield.

CONCLUSION

This study indicated that foliar application of micronutrients positively influenced the growth, flowering, and yield of broccoli under the agro-climatic conditions of Nangarhar. Treated plants showed improved vegetative development, earlier flowering, and higher yield than untreated plants. Among these treatments, T₄ showed the most favorable results for both growth and yield components. The findings suggest that balanced micronutrient application through foliar spraying can effectively enhance broccoli productivity and quality. Similar investigations may contribute to more sustainable and profitable broccoli production in the region.

Author Contributions

- Abdul Rahman Azami: Conceptualization, methodology, investigation, data collection, data analysis, and writing original draft.
- Mohammad Nasim Ayobi: Methodology, investigation, data collection, and writing—review and editing.

- Rahmat Gul Hassanzai: Supervision, validation, project administration, and writing—review and editing.
- All authors read and approved the final manuscript.

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Conflict of Interest Statement

The authors confirm that there are no conflicts of interest in any aspect of this paper.

Data Availability Statement

All data generated and analyzed in this study are presented within the article. Any additional information can be obtained from the corresponding author upon reasonable request.

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