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Effect of Zinc and Boron on the Yield and Quality Traits of the Broccoli under the Kanpur Agro Climactic 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 Horticulture Research Farm, The Faculty of Agricultural Sciences and Allied Industries, Rama University, Kanpur (U.P.), conducted an experiment laid out in a Randomized Block Design (RBD) with eight treatments, each replicated three times, based on one year of experimentation. The treatments were as follows: T0: Control, T1: RDF + Zinc foliar application @ 0.5%, T2: RDF + Zinc soil application @ 25 kg/ha, T3: RDF + Zinc soil application @ 25 kg/ha + Zinc foliar application @ 0.5%, T4: RDF + Boron foliar application @ 0.5%, T5: RDF + Boron soil application @ 2 kg/ha, T6: RDF + Boron soil application

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@ 2 kg/ha + Boron foliar application @ 0.5%, T7: RDF + Combined foliar application of Boron @ 0.5% and Zinc @ 0.5%. The unit plot size was 4.5 m². The plant spacing was maintained at 60 cm between rows and 45 cm between plants, with a total of 10 plants in each plot. The treatments were randomly allocated to unit plots in each replication. The results revealed that the application of T7 (RDF + combined foliar application of Boron @ 0.5% and Zinc @ 0.5%) recorded the highest plant growth, yield, and quality of broccoli compared to other treatments. It also achieved the highest gross return, net return (Rs. ha^{-1}), and benefit-cost ratio.

Keywords: Zinc; boron growth; yield; quality; broccoli.

1. INTRODUCTION

"Broccoli (*Brassica oleracea* L. var. *italica*) cv. Phule Ganesh belongs to the genus Brassica and the family Brassicaceae, which includes a wide range of crop plants originally derived from the Mediterranean region and subsequently modified through selection and breeding" (Decoteau, 2000). "Plants in the Cruciferae family bear flowers with four equal-sized petals forming a cross shape, hence the name 'crucifer'. The term Brassica is derived from the Latin word for cabbage" (Lee et al., 2008). Cole crops, widely cultivated in temperate zones, owe their name to the Latin word caulis, meaning stem (Bose, 1993). "The wild ancestor of modern cultivated varieties is Brassica oleracea var. sylvestris. The Mediterranean region is considered the center of origin for cole crops. Vegetables in the Brassicaceae family are rich in glucosinolates and their hydrolysis products, including indoles and isothiocyanates (Browen & Hutchison, 1949). A high intake of these vegetables has been associated with a reduced risk of colon, stomach, and lung cancers" (Lee et al., 2008). "The Brassica genus encompasses a variety of important crops such as broccoli, Brussels sprouts, cauliflower, cabbage, collard greens, kale, kohlrabi, mustard, rutabaga, turnips, bok choy, and Chinese cabbage. Additionally, though not part of the Brassica genus, other cruciferous vegetables include arugula, horseradish, radish, wasabi, and watercress" (Lee et al., 2008). "Micronutrients play specific roles in plant growth and development, and their optimal presence is essential for the completion of a plant's life cycle, culminating in the maturity and harvest of the economic produce. Zinc is an indispensable micronutrient involved in various metabolic processes such as enzyme activation, cell wall development, respiration, photosynthesis, and chlorophyll formation" (Mondal et al., 2023). "Boron is equally vital, contributing to sugar translocation, root elongation, meristematic tissue development, the pyrimidine biosynthetic pathway, and ATPase activity. Foliar application of micronutrients is particularly beneficial during the active growth phase of crops. Both boron (B) and zinc (Zn) are crucial for cell division, nitrogen and carbohydrate metabolism, and water regulation in plants. The application of boron significantly enhances vegetative growth and head yield in broccoli, while zinc supports enzymatic activities, chlorophyll synthesis, and carbohydrate formation, thereby accelerating overall plant growth. Broccoli is also a rich source of sulforaphane, a compound associated with cancer risk reduction. It contains vitamin A (9000 mg/100 g), vitamin B (33 mg/100 g), vitamin C (137 mg/100 g), and minerals such as calcium (1.29%), phosphorus (0.79%), potassium (3.5%), sulfur (1.26%), iron (205 ppm), iodine (1.965 ppm), and copper (24 ppm). Additionally, it provides protein (3.3%), total carbohydrates (5.5%), fat (0.2%), water (89.9%), and energy (36 kcal/100 g) (Thamburaj & Singh, 2003). Globally, the combined area under broccoli and cauliflower cultivation is 1.37 million hectares, with a total production of 25.53 million tonnes. India ranks second in area (0.36 million hectares) and production (9.57 million tonnes) of broccoli" (FAOSTAT, 2021).

2. MATERIALS AND METHODS

The present study, titled "Effect of Zinc and Boron on the Yield and Quality Traits of Broccoli under the Kanpur Agro-Climatic Region (*Brassica oleracea* L. var. *italica*)", was conducted at the Horticulture Research Farm, Faculty of Agricultural Sciences and Allied Industries, Rama University, Kanpur (U.P.), during the Rabi season of 2024. The experimental site is located approximately 25 km from the Kanpur district headquarters (Uttar Pradesh – 208024), positioned at 20°16' North latitude and 80°08' East longitude, in the southwestern plains of Uttar Pradesh. The experiment consisted of eight treatments comprising various combinations and application methods of zinc and boron. It was laid out in a

Randomized Block Design (RBD) with three replications. The treatment details were as follows: T_0: Control, T_1: RDF + Zinc foliar application @ 0.5%, T_2: RDF + Zinc soil application @ 25 kg/ha, T_3: RDF + Zinc soil application @ 25 kg/ha + Zinc foliar application @ 0.5%, T_4: RDF + Boron foliar application @ 0.5%, T_5: RDF + Boron soil application @ 2 kg/ha, T_6: RDF + Boron soil application @ 2 kg/ha + Boron foliar application @ 0.5%, T_7: RDF + Combined foliar application of Boron @ 0.5% and Zinc @ 0.5%. Broccoli seedlings were transplanted in the main field on 15th October 2024 with a spacing of 50 cm × 45 cm. The crop was fertilized with a recommended dose of 150:100:100 kg/ha of N:P_2O_5:K_2O. Healthy, 30-day-old seedlings with two pairs of leaves and a height of 10–15 cm were selected from the nursery. Prior to transplanting, seedling roots were treated with 0.1% carbendazim solution, followed by light irrigation after planting. Data were collected on various growth, yield, and quality parameters, including: Plant height (cm), Number of leaves per plant, Plant spread (cm), Days to first curd formation, Duration from transplanting to harvest (days), Curd diameter (cm), Weight of untrimmed curd (g), Weight of trimmed curd (g), Curd yield per plot (kg), Curd yield (q/ha), Total Soluble Solids (Brix), Ascorbic acid content (mg/100 g edible portion). The collected data were subjected to statistical analysis using Fisher's method of analysis of variance (ANOVA). The F-test was found to be significant and the Critical Difference (CD) at the 5% probability level was calculated for the comparison of treatment means.

3. RESULTS AND DISCUSSION

The findings of the present study, as depicted in Table 1, revealed a significant effect of zinc and boron on plant height (cm), number of leaves per plant, and plant spread (cm) at 15, 30, 45, and 60 days after transplanting (DAT).

3.1 Growth Parameters

3.1.1 Plant height

Foliar and soil application of zinc and boron significantly influenced plant height at all observed stages. The treatment T_7 (RDF + combined foliar application of boron @ 0.5% and zinc @ 0.5%) recorded the highest plant height values of 15.51, 36.44, 47.48, and 55.50 cm at 15, 30, 45, and 60 DAT, respectively. This was followed by T_6 (RDF + boron soil application @ 2 kg/ha + foliar application @ 0.5%). The minimum plant height (11.22, 26.27, 36.17, and 40.67 cm) was observed under T_0 (Control).

3.2 Number of Leaves per Plant

Similar trends were recorded for the number of leaves per plant. The maximum number of leaves (6.47, 14.09, 27.57, and 36.06) at 15, 30, 45, and 60 DAT was observed in T_7, followed by T_6, while the minimum (4.25, 8.78, 18.28, and 27.14) was recorded in T_0.

3.3 Plant Spread

Plant spread was also significantly influenced by micronutrient applications. The widest plant spread (22.10, 46.39, 65.88, and 73.68 cm) was recorded in T_7, followed by T_6, whereas the lowest spread (14.03, 31.46, 46.67, and 57.11 cm) was recorded under the control (T_0). These findings are in line with the results reported by Prasad et al. (2021), Parmar et al. (2023), and Quratul et al. (2021), who observed enhanced vegetative growth in broccoli due to the combined application of zinc and boron. Chowdhury et al. (2019) also found that a 0.5% zinc sulphate application promoted broccoli growth (Muhammad et al., 2018).

3.4 Phenological Parameters

As shown in Table 2, the days to first curd formation and the duration from transplanting to harvesting were significantly influenced by the treatments.

3.5 Days to First Curd Formation

The minimum number of days to first curd formation (44.33 days) was recorded in T_7, which was statistically at par with T_6. The maximum days (56.55) were recorded in T_0.

3.6 Duration from Transplanting to Harvest

The shortest crop duration (63.26 days) was observed in T_7, followed by T_6, T_1, and T_2. The longest duration (73.08 days) was noted under T_0. The reduction in curd initiation and crop duration in T_7 may be attributed to improved uptake and translocation of N, P, and K due to boron, along with enhanced photosynthesis and sugar transport. These findings are supported by Saha et al. (2010), Naher et al. (2014), Singh et al. (2015), Yasir et al. (2016), and Alam et al. (2007).

Table 1. Effect of zinc and boron on the yield and quality traits of the broccoli under the Kanpur agro climactic region *(Brassica oleracea* L. var. *italica)*

S. No.	Treatments Notation	Plant height (cm)				Number of leaves per plant				Plant spread (cm)			
		15 DAT	30 DAT	45 DAT	60 DAT	15 DAT	30 DAT	45 DAT	60 DAT	15 DAT	30 DAT	45 DAT	60 DAT
1	T0	11.22	26.27	36.17	40.67	4.25	8.78	18.28	27.14	14.03	31.46	46.67	57.11
2	T1	15.57	33.26	42.74	50.44	5.28	11.17	24.05	33.05	17.67	42.97	61.25	69.92
3	T2	13.74	31.07	41.22	47.49	4.74	10.28	22.02	30.54	16.89	38.17	57.98	66.59
4	T3	13.93	31.71	42.00	48.88	4.91	10.35	22.25	30.14	16.73	39.16	61.83	69.67
5	T4	13.57	29.66	38.62	45.06	4.47	9.97	21.17	28.77	15.85	36.72	57.35	64.28
6	T5	13.80	30.49	38.61	46.06	4.67	10.21	21.51	29.85	16.12	36.23	57.70	65.91
7	T6	15.15	34.40	45.53	52.89	6.15	12.26	25.36	34.51	21.10	44.53	62.98	71.00
8	T7	15.51	36.44	47.48	55.50	6.47	14.09	27.57	36.06	22.10	46.39	65.88	73.68
	F-Test	S	S	S	S	S	S	S	S	S	S	S	S
	S.Ed (+)	0.761	0.470	0.337	0.469	0.225	0.222	0.449	0.602	1.330	0.706	0.802	0.718
	C.D. at 0.5%	1.632	1.009	0.722	1.005	0.482	0.475	0.963	1.290	2.852	1.514	1.720	1.541

Table 2. Effect of zinc and boron on the yield and quality traits of the broccoli under the Kanpur agro climactic region *(Brassica oleracea* L. var. *italica) (Contd.)*

S. No.	Treatments Notation	Curd diameter (cm)	Weight of untrimmed curd (g)	Weight of trimmed curd (g)	Curd yield per plot (kg)	Curd yield (q ha^{-1})	Total soluble solid (°Brix)	Ascorbic acid (mg / 100 g edible portion)
1	T0	11.07	636.72	334.48	3.34	74.23	3.15	108.37
2	T1	14.21	674.21	409.32	4.09	91.00	4.11	117.04
3	T2	13.37	746.48	359.45	3.59	79.94	3.55	114.34
4	T3	13.93	730.34	363.84	3.64	80.93	3.73	115.17
5	T4	12.69	719.24	346.48	3.46	76.67	3.35	109.88
6	T5	13.26	730.62	355.25	3.55	79.39	3.44	111.04
7	T6	15.02	819.73	418.27	4.18	93.14	4.76	119.66
8	T7	16.21	894.00	428.51	4.29	95.15	5.16	121.40
	F-Test	S	S	S	S	S	S	S
	S.Ed (+)	0.535	3.083	3.308	0.033	0.581	0.051	0.820
	C.D. at 0.5%	1.148	6.612	7.096	0.071	1.247	0.110	1.759

3.7 Yield and Yield Attributes

3.7.1 Curd diameter and weight

The maximum curd diameter (16.21 cm), untrimmed curd weight (894.00 g), and trimmed curd weight (428.51 g) were recorded under T_7. These values were significantly superior to all other treatments, followed by T_6. The lowest values (11.07 cm, 636.72 g, and 334.48 g, respectively) were found under T_0.

3.7.2 Curd yield

T_7 recorded the highest curd yield per plot (4.29 kg) and per hectare (95.12 q/ha), followed by T_6. The lowest curd yield per plot (3.34 kg) and per hectare (74.23 q/ha) were observed under T_0. These results corroborate the findings of Singh et al. (2017), Sidhu et al. (2022), and Mahmoud et al. (2019), who also reported that the combined foliar application of zinc and boron significantly enhanced head weight, diameter, and yield in broccoli. The improvement in yield might be attributed to the synergistic effects of zinc and boron in enhancing plant metabolism and the translocation of sugars and carbohydrates from source to sink.

3.8 Quality Parameters

As per Table 1, the application of zinc and boron significantly influenced the quality traits such as total soluble solids (TSS) and ascorbic acid content.

3.9 Total Soluble Solids (°Brix)

The highest TSS value (5.16°Brix) was recorded under T_7, followed by T_6. The lowest value (3.15°Brix) was noted in T_0.

3.10 Ascorbic Acid Content

Maximum ascorbic acid content (121.40 mg/100 g edible portion) was found in T_7, followed by T_6, while the minimum (108.37 mg/100 g) was recorded in T_0. Boron is absorbed as a neutral molecule and accumulates in broccoli heads. Its combined application with zinc enhanced vegetative growth, improved physical quality, and increased nutritional content, as supported by Mahmoud et al. (2019).

4. CONCLUSION

The present findings clearly indicate that the combined application of NPK at the recommended dose (150:100:100 kg/ha) along with foliar application of boron @ 0.5% and zinc @ 0.5% can be recommended as the optimum treatment for enhancing the growth, yield, and quality of broccoli under the agro-climatic conditions of Kanpur.

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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