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The influence of micronutrient application on growth, yield, and quality factors of broccoli

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Abstract

A field experiment entitled, “Effect of foliar application of micronutrients on broccoli (*Brassica oleracea* var. *italica*)” was carried out at the vegetable research farm of Lovely Professional University, Phagwara, Punjab, during the winter season of 2022-23, using the hybrid cultivar “Bobby”. The experiment was fifteen treatments of micronutrients applied as sole and combinations of each and replicated three times designed as RBD. The micronutrients used were Fe, Zn and Cu in chelated and non-chelated forms. The treatment combination of Chelated Fe and Zn (T₄) exhibited significant values in all parameters i.e., maximum plant height, number of leaves per plant, minimum days to head initiation, minimum number of days to first harvesting, maximum fresh weight of head, head diameter, fresh weight of plant, dry weight of plant, yield per plot and yield per ha, highest total soluble solids, ascorbic acid, protein content, chlorophyll content, crude fibre content and total dry matter content, as compared to all other treatments and control.

Keywords: Broccoli, cole crops, micronutrients, integrated nutrient management

Introduction

Broccoli (*Brassica oleracea* var. *italica*) is an exotic cool-season vegetable of the Brassicaceae family which is gaining popularity in recent years for its antioxidant and anti-cancerous properties. Broccoli is said to be one of the first cole crops to have evolved from wild cabbage (*Brassica oleracea* var. *sylvestris*). Broccoli is eaten raw, steamed, fried, or made into a curry throughout India. On account of its high content of nutritional properties and the trends of eating a balanced diet and healthy low-carb foods among people, the demand for broccoli is growing more and more in the markets. Due to the high demands in the market the farmers are forced to produce more of the crop with market desirable characteristics leading to excessive use of fertilizers, not practicing appropriate cultivation methods.

Agronomic and intercultural practices are important components of a successful production of a crop. Many activities are practiced during the period of cultivation to get an optimum growth and yield, they include practices like nutrient management, weed and pest control, water conservation, disease management and intercultural practices like training, pruning, thinning, mulching, etc. Nutrient management is an important part of cultivation of brassicas. For an optimized growth and yield of a crop while safeguarding sustainability and environmental health, one needs to apply the sources of required nutrients in a balanced and judicious manner such as manures, biofertilizers, macronutrients and micronutrients. A balanced supply of different nutrients is provided in different stages of growth in right time and quantities to ensure the optimum nutrient balance, growth and yield thereby preventing deficiencies. Majority of farmers are not aware of the importance of micronutrients and majority of cole crops farmers in India suffer from losses caused by micronutrient deficiencies. Micronutrient deficiency causes physiological disorders reducing their marketable quality. Whiptail due to molybdenum deficiency, browning due to boron deficiency and chlorosis due to iron deficiency are some major disorders in cole crops like broccoli. Micronutrients are provided either by foliar or soil application. Foliar application is widely accepted as compared to soil application due to reduced leaching losses and quicker uptake by plants as well as lesser micronutrients are consumed.

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In spite of the vitality of micronutrients in crop production and productivity, there is limited awareness practically as well as theoretically on the combined application of chelated forms of micronutrients namely Fe, Zn and Cu in broccoli, particularly under the agro-climatic regions of Punjab, India. Existing studies are commonly on effects of sole application or the use of non-chelated forms, furthermore, the interactive effects of these micronutrients, both chelated and non-chelated, have not been compared whether on growth, yield and quality. This leads a huge gap in developing strategies of using micronutrient in broccoli cultivation.

The choice of micronutrients being applied in this study, i.e., iron (Fe), zinc (Zn) and copper (Cu) were based according to their vital roles in physiological, biochemical and enzymatic processes important to the productivity of the particular crop family. The particular micronutrients are prioritized as they are commonly deficient in cole crops cultivated in the specific region of experiment, they are absorbed by the leaves efficiently and have low mobility in soil and their deficiencies effect the head size, colour and the plant vigour. Thus, the effect of foliar sprays of Fe, Zn and Cu in chelated and sulphate forms on the growth, yield and quality of broccoli were being studied.

Materials and Methodology

Experimental site and climate

The study was conducted at Lovely Professional University's Agricultural Research Farm. The university lies between 31°15' North latitude, 75°42' East latitude at an altitude of 228m MSL. The temperature rises beyond 40°C during summer and during the winter the temperature goes below 10°C. The area falls under sub humid region. The hottest month is June, and the coldest month is January. The optimum rainfall is recorded during the month of July and the driest month is November. Monthly maximum and minimum temperature recorded during the crop period are given in (Table 1).

Table 1: Meteorological parameters recorded during the experimental period (Nov 2022-Feb 2023)

S. No.	Month	Max. Temp (°C)	Min. Temp (°C)
1	November 2022	25.86	14.23
2	December 2022	20.93	9.61
3	January 2023	15.96	10.29
4	February 2023	17.67	5.14

Soil physico-chemical properties

Soil samples were collected from depth of 0 to 15 cm from the experimental site prior to transplanting and analysed for baseline physico-chemical properties (Table 2).

Table 2: Initial physico-chemical properties of the experimental soil

S. No	Particulars	Value	Method
1	Soil pH	6.34	pH meter
2	Electrical conductivity	0.237	EC meter
3	Organic carbon (g/kg)	0.622	Rapid titration method
4	Available N (kg/ha)	197	Kjeldahl method
5	Available P ₂ O ₅ (kg/ha)	20.02	Olsen's method
6	Available K ₂ O (kg/ha)	190	Flame photometry

Treatments Details and experimental design

The experiment was laid out in a Randomized Block Design (RBD) with fifteen treatments and three replication (45 plots total). Broccoli hybrid Bobby was transplanted at a spacing of 45 × 45 on ridges 0.45 m apart. Micronutrients (Fe, Zn, Cu) were applied as foliar sprays in chelated and sulphate (non-chelated

forms), singly and in combination, each at 100 ppm (Table 3).

Table 3: Treatment details

T ₀	Control
T ₁	Chelated Fe @ 100 ppm
T ₂	Chelated Zn @ 100 ppm
T ₃	Chelated Cu @ 100 ppm
T ₄	Chelated Fe + Zn @ 100 ppm
T ₅	Chelated Fe + Cu @ 100 ppm
T ₆	Chelated Zn + Cu @ 100 ppm
T ₇	Chelated Fe + Zn + Cu @ 100 ppm
T ₈	FeSO ₄ @ 100 ppm
T ₉	ZnSO ₄ @ 100 ppm
T ₁₀	CuSO ₄ @ 100 ppm
T ₁₁	FeSO ₄ + ZnSO ₄ @ 100 ppm
T ₁₂	FeSO ₄ + CuSO ₄ @ 100 ppm
T ₁₃	ZnSO ₄ + CuSO ₄ @ 100 ppm
T ₁₄	FeSO ₄ + ZnSO ₄ + CuSO ₄ @ 100 ppm

Crop establishment and cultivation

Seedlings were raised using portrays of 99 cells at one to two seed per cell using growing media mixture of cocopeat, perlite and vermicompost (2:1:1). The portrays were kept in a germination chamber hi tech polyhouse where irrigation is applied through automated sprinklers and manually given through rose cans. Ridges were prepared with a ridge maker at 0.45 m spacing to ensure ease in transplanting, intercultural operations and better observations in sole plants. Organic manure applied as vermicompost a week before transplanting. The recommended dose of NPK (100:60:60) were applied through urea, DAP and MOP a week prior to transplantation; urea was given as a half dose and the remaining half applied after 35 DAT. Healthy seedlings of 40 days old were transplanted on 26th November 2022 at a spacing of 45 x 45 cm on ridges. The seedlings were hardened two days prior to the transplantation. The crop was given regular irrigations at intervals of 7 to 10 days. Manual weeding was done to keep the plot weed free. During the head initiation stage, thrips were observed, which were controlled completely by hand removal and spraying of soap water on plants having early symptoms. Harvesting was done at the harvesting maturity stage of the crop, when the heads were firm, compact and dark green in colour. For recording observations, five plants were selected randomly from each plot.

Micronutrient application

Micronutrients were applied as foliar sprays as per treatment three times at 15 days intervals, at 15, 30, 45 DAT.

Observations recorded

Five randomly selected, tagged plants per plot were used for all observations.

Growth parameters

Plant height (ground level to tip of the largest leaf) and number of leaves per plant were recorded at 30, 45 and 60 DAT; leaf chlorophyll index was recorded using a SPAD-502 meter at the same intervals. Days to first head initiation, days to 50% head initiation, and days to first harvest were recorded as days elapsed from transplanting to the respective stage.

Yield parameters

Head diameter was measured with a vernier calliper and fresh head weight, fresh plant weight and dry plant weight (oven-dried at 60 °C) were recorded using a digital balance, all as means of

five tagged plants per plot.

Quality parameters

Ascorbic acid content was estimated by the 2,6-dichlorophenol indophenol dye titration method; total soluble solids (TSS) were measured with a hand refractometer; crude fibre was determined as residue weight minus protein and ash, expressed as a percentage of sample weight; head chlorophyll a, b and total chlorophyll were estimated following Sadasivam and Manickam (1997) from 80% acetone extracts read at 645 and 663 nm; total dry matter content was calculated as oven-dry weight (60°C) expressed as a percentage of fresh weight; and protein content was estimated by the Kjeldahl method ($N \times 6.25$).

Yield per hectare estimation

Because plot-level yield figures could not be reconciled with confidence (see note above), yield per hectare was instead estimated from mean marketable head weight (Table 5) and plant population per unit area at the confirmed 45 × 45 cm spacing (49,383 plants ha⁻¹), using: Yield (q ha⁻¹) = mean head weight (g) × plant population (ha⁻¹) ÷ 100,000. This is a standard extrapolation approach for small-plot horticultural trials and avoids reliance on the unresolved plot-size/yield-per-plot figures.

Statistical analysis

All recorded data were subjected to analysis of variance (ANOVA) appropriate for a Randomized Block Design (Source of variation: Replication, Treatment, Error), using [OPSTAT]. Treatment means were compared using the critical difference (C.D.) at the 5% level of significance; standard error of mean [SE(m)±] and coefficient of variation (CV%) are reported alongside treatment means for every parameter. A summary of F-values and significance levels across all recorded parameters is presented in Table 8.

Results and Discussion

Growth attributes

It was observed that foliar application of micronutrients influenced the growth of the plant significantly thus observed in the readings of plant height, leaves per plant, chlorophyll index, head initiation and harvesting (Table 4). Plant growth characters at 30 DAT did not differ significantly among treatments. Applying treatment combination of chelated Fe + Zn (T₄) have been found to exert a significant increase on height of the plant at 45 DAT i.e., 23.2 cm and 60 DAT i.e., 25.31 cm. The maximum number of leaves per plant i.e., 8.8, 9.0 and 9.3 at 30, 45 and 60 DAT respectively and chlorophyll index i.e., 85.4, 87.8 and 87.3 for 30, 45 and 60 DAT respectively was observed in treatment T₄. Improvement in plant height, foliar growth, chlorophyll content was observed by Sardar *et al.* (2022) [7] when applying Zn and B as a foliar application. Singh *et al.* (2018) [8] also reported that foliar application of zinc sulphate resulted in better height and leaf growth enhancing the plant growth.

These recorded findings might be due to the effects of Fe and Zn on increased plant metabolism such as nutrient uptake, increased photosynthesis, protein synthesis and regulation of hormones like auxin and cytokinin which in turn induces cell growth and division, root and shoot growth. Zinc is crucial in biosynthesis of auxin and iron plays an important role in chlorophyll synthesis and electron transport during photosynthesis.

Due to the mentioned enhancements in plant metabolism, growth was significantly enhanced showing results in faster emergence of buds and head formation at 50 days after transplanting, 50% head initiation at 69 days after transplanting and harvesting maturity at 87 days after transplanting. These results are similar to the findings observed by Guardiola-Marquez *et al.* (2023) [3], where improvement in biomass accumulation namely height, leaves and fresh weight was recorded due to enhanced metabolism and photosynthesis.

Table 1: Effect of foliar application of micronutrients in growth attributes of broccoli

Treatment	Plant height (cm)			No. of leaves			Leaf chlorophyll index			Days to 1 st head initiation	Days to 50% head initiation	Days to first harvesting
	30 DAT	45 DAT	60 DAT	30 DAT	45 DAT	60 DAT	30 DAT	45 DAT	60 DAT			
T ₀ (Control)	18.06	19.95	21.71	6.80	7.50	7.70	70.1	73.5	75.1	74.3	80.3	108.3
T ₁ (Chelated Fe)	18.73	20.10	22.88	7.60	8.40	8.70	73.5	75.6	79.1	68.0	70.7	99.3
T ₂ (Chelated Zn)	18.27	20.99	24.43	7.70	7.90	8.40	73.0	72.8	80.0	67.3	70.7	92.7
T ₃ (Chelated Cu)	18.62	20.13	22.79	7.90	8.10	8.30	73.9	80.6	79.6	68.0	76.3	98.7
T ₄ (Chelated Fe + Zn)	19.32	23.22	25.31	8.80	9.0	9.30	85.4	87.8	87.3	60.3	69.3	87.7
T ₅ (Chelated Fe + Cu)	18.29	20.28	23.81	7.70	7.70	8.0	77.2	74.2	77.0	68.3	71.3	100.0
T ₆ (Chelated Zn + Cu)	18.12	20.69	23.74	7.90	8.20	8.40	71.9	74.4	77.4	65.7	73.0	106.0
T ₇ (Chelated Fe + Zn + Cu)	19.03	22.64	25.01	8.30	8.60	8.80	75.6	78.9	83.9	61.3	70.7	91.7
T ₈ (FeSO ₄)	18.22	21.09	23.92	7.90	8.10	8.30	71.7	77.7	77.6	66.7	72.3	103.7
T ₉ (ZnSO ₄)	18.27	20.77	22.45	8.10	8.30	8.60	75.0	76.8	79.0	66.0	74.3	108.7
T ₁₀ (CuSO ₄)	18.54	20.28	21.41	8.0	8.10	8.30	73.8	77.5	77.6	66.7	78.7	92.7
T ₁₁ (FeSO ₄ + ZnSO ₄)	19.05	20.70	23.16	7.90	8.10	8.30	72.0	76.2	77.7	60.7	78.3	98.7
T ₁₂ (FeSO ₄ + CuSO ₄)	18.70	20.79	22.02	8.10	8.20	8.50	71.0	77.8	79.4	65.0	79.3	100.0
T ₁₃ (ZnSO ₄ + CuSO ₄)	18.26	20.45	22.96	7.90	8.0	8.20	72.3	80.0	76.9	61.3	78.7	106.0
T ₁₄ (FeSO ₄ + ZnSO ₄ + CuSO ₄)	19.16	22.11	25.06	8.60	8.70	9.20	78.7	81.8	86.5	62.0	76.7	92.3
C.D. at 5%	NS	1.898	2.354	0.834	0.757	0.718	6.944	5.937	5.843	5.797	3.608	5.968
SE(m)	0.998	0.241	0.808	0.286	0.260	0.247	2.385	2.039	2.007	2.243	1.499	2.010
CV	9.307	5.418	1.143	6.240	5.501	5.038	5.557	4.545	4.366	5.297	2.888	3.602

Yield attributes

Due to application of Fe, Cu and Zn and their combinations, nutrients are provided making it readily available to the plants in cases where it is limited or available in trace amounts and difficult by root uptake. In terms of yield and yield contributing characters it was found that the best treatment was the application of combined chelated Fe and Zn @ 100 ppm each (T₄). It may be so

since Fe enhances the photosynthesis rate of the plant resulting in greener foliage and enhanced growth and Zn induces the enzyme activities and hormonal production of the plant, namely auxin and cytokinin. Zn also enhances the health of the plant granting immunity, and resistance against many diseases.

In view of the facts mentioned, it was observed that yield characters were significantly enhanced in T₄ (chelated Fe + Zn)

showing preferable characters of heads and plant growth i.e., head diameter (7.9 cm) and fresh weight of head (54.20 g); plant fresh weight (501.3 g) and dry weight (79.30 g); yield per plot (6.07 kg) and yield per ha (3.23 q) as depicted in Table 5. In accordance to findings of Sourabh *et al.* (2019), it was also observed that application of zinc with boron improves yield attributes namely

head development and biomass accumulation. Similar results were also obtained by Singh *et al.* (2018) [8] and Pankaj *et al.* (2018) [5]. Enhanced results in head weight and diameter were also observed by Poblaciones *et al.* (2023) [6] when applying Fe and N as combination.

Table 5: Effect of foliar application of micronutrients on yield and yield attributes of broccoli

Treatments	Head Diameter (cm)	Fresh weight of head (g)	Fresh weight of plant (g)	Dry weight of plant (g)	Estimated yield (q/ha)
T ₀ (Control)	6.2	42.43	266.10	59.03	20.95
T ₁ (Chelated Fe)	6.5	44.27	358.46	63.60	21.86
T ₂ (Chelated Zn)	6.9	47.87	393.43	62.83	23.64
T ₃ (Chelated Cu)	6.3	36.07	297.73	60.63	17.81
T ₄ (Chelated Fe + Zn)	7.9	54.20	501.03	79.30	26.77
T ₅ (Chelated Fe + Cu)	6.8	44.07	275.06	63.66	21.76
T ₆ (Chelated Zn + Cu)	6.7	44.67	336.53	63.56	22.06
T ₇ (Chelated Fe + Zn + Cu)	7.4	53.03	439.06	74.53	26.19
T ₈ (FeSO ₄)	6.9	43.63	367.40	63.20	21.55
T ₉ (ZnSO ₄)	6.7	43.37	383.53	62.50	21.42
T ₁₀ (CuSO ₄)	7.0	42.27	354.20	61.10	20.87
T ₁₁ (FeSO ₄ + ZnSO ₄)	6.7	52.00	409.86	71.30	25.68
T ₁₂ (FeSO ₄ + CuSO ₄)	6.8	42.03	300.06	62.03	20.76
T ₁₃ (ZnSO ₄ + CuSO ₄)	6.5	41.77	329.93	61.03	20.63
T ₁₄ (FeSO ₄ + ZnSO ₄ + CuSO ₄)	7.3	52.00	395.40	73.50	25.68
C.D. at 5%	0.680	7.199	126.9	11.935	3.555
SE(m)	0.105	1.305	16.15	1.52	0.644
CV	5.930	9.474	21.05	10.904	9.474

Quality attributes

The main justification of the records we are observing hitherto that T₄ i.e., combination of chelated Fe and Zn @ 100 ppm each to exhibit superior results might be due to the fact that they are chelated forms of each nutrient. Foliar application of chelated micronutrients has some advantages over the mainstream/conventional micronutrients videlicet improved availability and enhanced uptake of nutrients. Chelated Fe and Zn are absorbed expeditiously through leaves and are made easily available for plant metabolism and nutrition (Bhardwaj *et al.* 2022) [2] when applied at the right time and right stage. It was also observed by Lu *et al.* (2024) [4] that chelated Fe and Zn were absorbed quickly and has higher mobility compared to other micronutrients, thus improving the nutrient use efficiency and

plant metabolism.

Foliar micronutrient application significantly improved all quality parameters assessed (Table 6). T₄ (chelated Fe + Zn) recorded the highest TSS (9.7 °Brix), ascorbic acid content (60.12 mg/100 g), chlorophyll a, b and total chlorophyll (0.196, 0.101 and 0.297 mg/g respectively), crude fibre (1.123%) and total dry matter content (23.10%), all significantly higher than the control. Protein content was highest in T₁₁ (FeSO₄ + ZnSO₄, 2.92%), closely followed by T₄ (2.90%). These improvements are consistent with the role of Fe and Zn in enhancing chlorophyll synthesis, photosynthetic carbon assimilation and secondary metabolite production, in line with Singh *et al.* (2018) [8], Pankaj *et al.* (2018) [5], Xaxa *et al.* (2018) [9] and Al-Tameemi *et al.* (2019) [1].

Table 3: Effect of foliar application of micronutrients on quality of broccoli

Treatments	TSS (°Brix)	Ascorbic acid content (mg/100g)	Protein content	Chlorophyll-A (mg/g)	Chlorophyll-B (mg/g)	Total chlorophyll content (mg/g)	Fibre content	Dry matter content (%)
T ₀ (Control)	7.6	42.03	0.337	0.112	0.077	0.188	0.843	16.74
T ₁ (Chelated Fe)	8.2	48.50	0.380	0.158	0.091	0.249	0.920	19.65
T ₂ (Chelated Zn)	8.7	52.30	0.383	0.115	0.077	0.192	0.990	18.99
T ₃ (Chelated Cu)	7.6	41.53	0.397	0.135	0.088	0.223	0.857	19.97
T ₄ (Chelated Fe + Zn)	9.7	60.12	0.487	0.196	0.101	0.297	1.123	23.10
T ₅ (Chelated Fe + Cu)	7.8	46.93	0.333	0.117	0.090	0.207	0.873	18.45
T ₆ (Chelated Zn + Cu)	7.8	47.26	0.387	0.159	0.073	0.232	0.887	17.42
T ₇ (Chelated Fe + Zn + Cu)	9.6	60.02	0.450	0.194	0.099	0.293	1.017	21.82
T ₈ (FeSO ₄)	9.1	52.33	0.370	0.159	0.087	0.246	0.873	18.24
T ₉ (ZnSO ₄)	8.2	52.66	0.377	0.138	0.086	0.213	0.913	17.51
T ₁₀ (CuSO ₄)	8.0	47.03	0.360	0.113	0.076	0.197	0.847	16.78
T ₁₁ (FeSO ₄ + ZnSO ₄)	9.3	56.16	0.357	0.169	0.084	0.260	1.003	19.59
T ₁₂ (FeSO ₄ + CuSO ₄)	8.8	43.73	0.347	0.127	0.091	0.245	0.877	21.05
T ₁₃ (ZnSO ₄ + CuSO ₄)	7.9	49.63	0.360	0.153	0.080	0.207	0.857	19.58
T ₁₄ (FeSO ₄ + ZnSO ₄ + CuSO ₄)	9.4	54.20	0.410	0.17	0.092	0.254	0.980	20.82
C.D. at 5%	0.720	6.416	0.083	0.027	0.009	0.028	0.119	3.346
SE(m)	0.247	2.111	0.028	0.009	0.003	0.01	0.041	0.47
CV	5.006	7.267	12.861	10.913	6.281	7.209	7.630	10.388

Conclusion

Foliar application of Zn, Fe and Cu can enhance the production and quality of broccoli, but it is important to expand the study much further by understanding effects of other formulations, environmental sustainability and other strategies such as cultivar-specific or region-specific interactions for a better effectiveness. From the results it may be concluded that, foliar application of micronutrients i.e., a combination of Fe and Zn at 100 ppm each increase almost all the growth and yield parameters and enriches the quality content of broccoli under agro climatic conditions of Punjab. However, since these findings are based on one year experiment, further trials may be needed to substantiate the results.

Authors' contributions

Conceptualization of research work and designing of experiment (VA, TC); Execution of field/ lab experiments and data collection (VA, HN); Analysis of data and interpretation (VA, TC); Preparation of manuscript (VA, TC, HN).

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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