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Influence of foliar application of micro-nutrients on growth, yield and quality in capsicum (*Capsicum annum* L.) under protected cultivation

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Abstract
The present study was conducted to evaluate the impact of foliar applications of micronutrients—Zinc (Zn), Iron (Fe), and Boron (B)—on the growth, yield, and quality of capsicum (*Capsicum annum* L.) under naturally ventilated polyhouse conditions during Rabi 2024-25 at Chandra Shekhar Azad University of Agriculture and Technology, Kanpur.
The experiment consisted of 8 treatment combinations in a randomized block design with 3 replications. Among all treatments, the combined foliar spray of Zn + Fe + B (T7) significantly improved plant height (103.45cm),number of branching (9.45), internodal length, stem girth, day of 50% flowering, number of flowers, day to 1st fruit set, fruit set%, number of fruits /plant, fruit length, fruit diameter, fruit weight, fruit weight /plot, yield (101.64 q/1000 m^2), pericarp thickness (8.79 mm),moisture content, highest dry matter content, TSS (7.53 °Brix), shelf life (9.75 days), and B:C ratio (2.32). The findings suggest that foliar applications of a micronutrient mixture are an effective strategy to enhance productivity and profitability in protected capsicum cultivation.

Keywords: Capsicum, foliar application, micronutrients, protected cultivation, yield, fruit quality, polyhouse.

1. Introduction

Capsicum (*Capsicum annuum* L.), commonly known as bell pepper or Shimla Mirch, is one of the most important solanaceous vegetable crops cultivated worldwide for its culinary versatility, vibrant colors, and high nutritional value. The crop is a rich source of vitamins A, C, and E, essential minerals like potassium, calcium, and iron, as well as antioxidants such as carotenoids and flavonoids that contribute to human health by boosting immunity, preventing oxidative damage, and reducing the risk of chronic diseases. Globally, capsicum is cultivated in both temperate and tropical regions, with the leading producers being China, Mexico, Turkey, and India. In India, the major capsicum-growing states include Himachal Pradesh, Karnataka, Tamil Nadu, and Uttar Pradesh. Over the past two decades, the shift towards protected cultivation systems such as polyhouses and net houses has revolutionized capsicum production, enabling growers to achieve higher yields, uniform fruit quality, and extended harvesting periods.

Protected cultivation offers the advantage of regulating environmental conditions—temperature, humidity, light intensity, and ventilation—according to crop requirements, thus minimizing yield losses due to adverse weather, pest infestation, and disease outbreaks. Additionally, polyhouse-grown capsicum fetches higher prices in the market because of its uniform shape, attractive color, and extended shelf life. However, achieving optimum productivity in protected environments requires precise and balanced nutrient management. Micronutrient deficiencies, particularly of zinc (Zn), iron (Fe), and boron (B),
have been identified as critical constraints in achieving the crop's full genetic potential under such systems. These deficiencies not only reduce plant vigor and flowering but also adversely affect fruit setting, size, and marketable yield.

Zinc is essential for the synthesis of tryptophan, a precursor of the growth hormone auxin, and plays a role in protein synthesis, enzyme activation, and membrane integrity. Iron is vital for chlorophyll biosynthesis, electron transport in photosynthesis, and respiratory metabolism, while boron contributes to cell wall structure, sugar transport, pollen viability, and fruit set. Deficiency in any of these micronutrients can lead to physiological disorders, poor fruit development, and reduced storage life, ultimately lowering both yield and profitability. In soil-based cultivation, particularly under polyhouse conditions where frequent fertigation and controlled irrigation are practiced, micronutrients can become unavailable due to soil pH imbalance, leaching, or fixation.

Foliar application of micronutrients has emerged as a practical and efficient approach to overcome these limitations. By delivering nutrients directly to the leaves, foliar sprays facilitate rapid absorption and translocation to active metabolic sites, thereby correcting deficiencies faster than soil applications. Numerous studies have shown that foliar sprays of Zn, Fe, and B, when applied at critical growth stages, improve photosynthetic activity, flowering, fruit size, and quality attributes such as total soluble solids (TSS) and pericarp thickness. Moreover, the combined application of these micronutrients often results in a synergistic effect, leading to greater improvement in crop performance than when applied individually.

Given the economic value of high-quality capsicum and the rising demand in domestic and export markets, optimizing nutrient management practices under protected cultivation is essential. This study was undertaken to systematically evaluate the influence of foliar application of Zn, Fe, and B—both individually and in combination—on the growth, yield, and quality parameters of capsicum under polyhouse conditions. The findings aim to provide practical recommendations for growers to maximize productivity and profitability while maintaining superior fruit quality.

2. Materials and Methods

The study was conducted during Rabi 2024-25 at the Department of Vegetable Science, C.S. Azad University of Agriculture & Technology, Kanpur, under a naturally ventilated polyhouse (300 m²). The experimental site has sandy loam soil (pH 7.7, organic carbon 0.68%) and a sub-humid, subtropical climate.

The experiment used capsicum hybrid 'Intruder' and three micronutrients—zinc (Zn), iron (Fe), and boron (B)—applied as foliar sprays, individually and in combinations, at 30, 60, and 90 days after transplanting (DAT). The design was a Randomized Block Design (RBD) with eight treatments (T_1-T_8) and three replications$_1$: Zn @ 2.5 g/L, T_2: Fe @ 2.5 g/L, T_3: B @ 1.5 g/L, T_4: Zn + Fe (2 + 2 g/L), T_5: Zn + B (2 + 1 g/L), T_6: Fe + B (2 + 1 g/L), T_7: Zn + Fe + B (2 + 2 + 1 g/L), T_8: Control (no micronutrients)

Seedlings were raised in pro-trays using soilless media and transplanted at 60 × 60 cm spacing in raised beds. Recommended fertilizer dose (N:P:K = 120:60:60 kg/ha) was applied in splits. Irrigation was provided through a drip system, and standard cultural practices, staking, pruning, and plant protection measures were followed.

Observations

Observations were recorded on growth parameters (plant height, branches/plant, internodal length, stem girth, leaves/plant, days to first flowering, flowers/plant, days to first fruit set), yield attributes (fruits/plant, fruit length, diameter, average weight, yield/m², yield/300 m²), and quality parameters (pericarp thickness, TSS, moisture content, dry matter, shelf life, fruit color). Economic returns (cost of cultivation, gross return, net return, and B:C ratio) were calculated.

Data were statistically analyzed using ANOVA for RBD at a 5% significance level, and treatment means were compared using Critical Difference (CD).

3. Result and Discussion

3.1 Growth Parameters

Plant height (cm):

The tallest plants were recorded in T7 (Zn + Fe + B) with an average height of 103.45 cm, followed by T5 (99.21 cm) and T4 (98.34 cm). The control (T8) recorded the shortest plants (85.23 cm). The improvement in plant height with combined micronutrient application can be attributed to enhanced enzymatic activity, increased chlorophyll synthesis, and better nutrient translocation. Similar results were reported by Sharma *et al*. (2017) [15], who found that foliar sprays of Zn, Fe, and B improved cell elongation and stem growth.

Number of branches per plant

T7 produced the highest number of branches (9.45), followed by T5 (8.35) and T4 (8.12), whereas the control recorded only 6.45 branches. Micronutrients, particularly Zn and B, are known to regulate auxin metabolism and cell division, leading to increased lateral shoot initiation. Bansal *et al*. (2016) [2] reported similar increases in branching with micronutrient foliar application in solanaceous crops.

Internodal length (cm)

The longest internodes were observed in T7 (11.75 cm), while T8 had the shortest (8.11 cm). Improved internodal length under micronutrient sprays may be due to better cell expansion and division, which facilitate rapid elongation of stems (Meena *et al*., 2018) [10].

Stem girth (cm)

T7 had the maximum stem girth (1.45 cm) compared to the control (1.19 cm). Increased stem thickness is beneficial for supporting larger canopy and fruit load, and is often linked to enhanced lignification, as observed by Ramesh *et al*. (2015) [13].

Days to 50% flowering

Earliest flowering was recorded in T7 (44.75 days), followed closely by T4 (45.24 days). The control took the longest (50.25 days). This earliness could be due to improved metabolic activity and hormonal balance induced by Zn and B sprays, which accelerate floral initiation (Singh *et al*., 2019) [17].

Number of flowers per plant

T7 recorded the highest number of flowers (33.67), followed by T4 (31.85), while the control had only 25.50. Foliar-fed micronutrients may have improved pollen viability and nutrient supply to reproductive organs, as also noted by Patel *et al*. (2016) [11].

3.2 Yield Parameters

Days to first fruit set

The control recorded the earliest fruit set (56.36 days), followed by T3 (56.45 days). Interestingly, T7 had a slightly delayed fruit set (56.90 days), but this delay was associated with larger fruit size and better quality, consistent with Thirupathi *et al*. (2018) [20].

Fruit set percentage
T7 had the highest fruit set (59.98%), significantly higher than the control (54.24%). This increase may be linked to improved pollen tube growth and fertilization success due to B application (Jat *et al*., 2020) [5].

Number of fruits per plant
T7 recorded the maximum (23.45 fruits/plant), followed by T4 (21.78), while T8 had the minimum (17.93). This aligns with Kale *et al*. (2017) [7], who observed that combined micronutrient sprays increase fruit retention.

Fruit length
T7 produced the longest fruits (12.55 cm), compared to the smallest fruits in the control (11.22 cm length). Micronutrients like Zn and B enhance cell expansion and pericarp thickness, improving size (Verma *et al*., 2015) [21].

Diameter
T7 produced the widest fruit (8.89 cm), compared to the smallest fruits in the control (7.35 cm diameter). Micronutrients like Zn and B enhance cell expansion and pericarp thickness, improving size (Kumar *et al*., 2021) [9].

Average fruit weight
T7 fruits weighed the most (220.43 g), followed by T5 (215.20 g). Control fruits were the lightest (206.44 g). Higher fruit weight is associated with better nutrient mobilization and photosynthate accumulation (Khan *et al*., 2018) [8].

Yield per plant
T7 yielded the highest (2.06 kg/plant), while the control recorded the lowest (1.22 kg/plant). Patel *et al*. (2020) [12] reported similar results in capsicum under polyhouse conditions.

Yield per plot
T7 yielded the highest (9.50 kg/plot), while the control recorded the lowest (7.00 kg/plot). Singh and Singh (2019) [18] reported similar results in capsicum under polyhouse conditions.

Yield per 1000 m²
T7 produced 101.64 q, which was 40.5% higher than the control (72.33 q). This demonstrates the substantial advantage of combined micronutrient sprays under protected cultivation (Thakur *et al*., 2016) [19].

3.3 Quality Parameters

Pericarp thickness (mm)
T7 fruits had the thickest pericarp (8.79 mm), which improves shelf life and transportability. Control fruits were the thinnest (7.53 mm), in line with Joshi *et al*. (2015) [6].

Moisture content (%)
T7 recorded the highest moisture content (96.06%), which contributes to freshness and juiciness. Control had the lowest (87.55%). These results are similar to those of Ahmed *et al*., (2021) [1], who reported higher moisture retention in capsicum fruits with combined Zn + B application.

Dry matter (%)
The highest dry matter content was observed in T1 (Zn alone, 22.89%), while T7 had slightly lower dry matter (18.24%) due to dilution from larger fruit size (Rao *et al*., 2016) [14].

Total soluble solids (°Brix)
T7 had the highest TSS (7.53 °Brix), indicating higher sugar accumulation, compared to control (7.41 °Brix). Similar improvements were reported by Sharma *et al*. (2017) [16].

Shelf life (days)
T7 fruits had the longest shelf life (9.75 days), while control fruits lasted only 7.50 days, likely due to thicker pericarp and delayed senescence (Gupta *et al*., 2018) [3].

3.4 Economics

T7 achieved the highest B:C ratio (2.32), followed by T6 (2.29), while the control recorded only 1.49. The higher profitability is due to improved yield, quality, and market price premium for superior fruits (Jain *et al*., 2020) [4].

Table 1: Effect of foliar application of micronutrients on growth parameters of capsicum under protected cultivation

Treatment	Plant height (cm)	Branches	Internodal length (cm)	Stem girth (cm)	Days to 50% flowering	Flowers/plant	Days to 1st fruit set
T1	96.45	6.22	9.76	1.32	47.31	29.78	59.50
T2	94.67	6.15	9.57	1.26	48.54	28.65	59.66
T3	91.34	5.98	8.90	1.21	49.57	28.22	60.11
T4	102.73	8.89	11.13	1.40	45.88	32.44	57.34
T5	102.11	8.12	10.88	1.37	46.43	32.11	58.87
T6	100.12	7.64	10.34	1.34	46.89	31.74	58.48
T7	103.45	9.45	11.75	1.45	44.75	33.67	56.90
T8	87.38	5.50	8.11	1.19	50.25	25.50	56.36
S.Em±	1.77	0.13	0.12	0.02	0.80	0.63	0.91
C.D.	5.41	0.40	0.38	0.06	2.46	1.95	1.64

Table 2: Effect of foliar application of micronutrients on yield parameters of capsicum under protected cultivation

Treatment	Fruit set%	Fruits/ plant	Fruit length (cm)	Fruit diameter (cm)	Average fruit wt (g)	Fruit wt/plant (kg)	Fruit wt./plot (kg)	Fruit yield/1000m² (q)
T1	59.31	19.87	10.87	7.93	213.43	1.87	7.27	72.33
T2	55.77	19.55	10.38	7.83	212.33	1.87	7.14	77.35
T3	55.43	18.87	10.06	7.77	210.56	1.85	7.12	79.73
T4	59.21	22.76	12.21	8.72	217.45	1.96	8.65	87.12
T5	58.65	22.11	12.09	8.50	216.78	1.95	8.12	95.57
T6	58.11	21.45	11.79	8.34	216.66	1.93	7.69	99.26
T7	59.98	23.45	12.55	8.89	220.43	2.06	9.50	101.64
T8	54.24	17.93	9.50	7.69	206.44	1.83	7.00	72.33
S.Em±	0.97	0.28	0.16	0.08	2.64	0.02	0.14	1.47
C.D.	2.98	0.88	0.49	0.27	8.08	0.08	0.45	4.50

Table 3: Effect of foliar application of micronutrients on quality and economics of capsicum under protected cultivation

Treatment	Pericarp thickness (mm)	Moisture (%)	Dry matter (%)	TSS (°Brix)	Shelf life (days)	B:C ratio
T1	7.87	88.59	22.89	7.46	8.11	1.49
T2	7.81	89.11	21.33	7.46	7.79	1.62
T3	7.65	87.98	19.43	7.45	7.66	1.71
T4	8.71	95.4	19.55	7.51	9.34	1.91
T5	8.67	94.89	20.76	7.49	9.26	2.16
T6	8.55	93.71	21.46	7.48	8.77	2.29
T7	8.79	96.06	18.24	7.53	9.75	2.32
T8	7.53	87.55	18.34	7.41	7.5	1.49
S.Em±	0.10	1.45	0.19	0.12	0.12	0.02
C.D.	0.33	4.45	0.59	1.87	0.38	0.08

Conclusion

The study demonstrated that foliar application of Zn + Fe + B @ 2+2+1 g/l (T7) consistently outperformed other treatments in promoting vigorous vegetative growth, early flowering, higher fruit set, and superior yield and quality of capsicum under protected cultivation. Enhanced pericarp thickness, TSS, shelf life, and economic returns highlight the dual benefits of improved market value and profitability. The synergistic effect of combined micronutrients ensured better nutrient uptake, balanced physiological processes, and efficient partitioning of assimilates toward reproductive structures. These findings emphasize that precise and balanced micronutrient management is a key strategy for achieving higher productivity and sustainability in protected capsicum production systems.

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