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Optimizing foliar micronutrient nutrition for enhanced morphophysiological traits and pod quality in okra [*Abelmoschus esculentus* (L.) Moench]

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Abstract
The experiment was conducted during summer, 2024 at the Regional Horticultural Research Station, Navsari Agricultural University, Navsari, and Gujarat. The experiment was laid out in a Randomized Block Design with three replications and nine treatments, *i.e.* T_1 - Ammonium molybdate @ 0.1%, T_2 - Boric acid @ 0.2%, T_3 - Zinc sulphate @ 0.5%, T_4 - Copper sulphate @ 0.5%, T_5 - Ferrous sulphate @ 0.5%, T_6 - Manganese sulphate @ 0.5%, T_7 - General grade-IV @ 1.5%, T_8 - General grade-IV @ 1.5% + T_3 and T_9 - Control (no spray). Foliar applications of micronutrients were given at 25 DAS and 40 DAS using a knapsack sprayer during morning hours. The effect of foliar application of micronutrients was found significant on growth and quality parameters of okra. Among all the treatments T_8, recorded maximum plant height (66.41 cm and 90.29 cm) at 60 DAS and at final harvest, respectively; internodal length (5.50 cm), stem girth (5.97 cm), Ascorbic acid content (16.14 mg/100g) and chlorophyll content (2.84 mg/100g).

Keywords: Okra, foliar application, growth, micronutrients, quality

Introduction
Okra [*Abelmoschus esculentus* (L.) Moench] is known as lady's finger or bhindi. It belongs to Malvaceae family. It is a popular tropical and subtropical vegetable crop. Among the four main species of the genus, *A. esculentus* and *A. caillei* are cultivated for their fruits, *A. manihot* for its leaves and *A. moschatus* for its seeds. *Abelmoschus esculentus* is the only one that is commercially cultivated. Okra known by various regional names such as Bhindi (Hindi), Dhenras (Bengali), Vendai (Tamil) and Bendekayi (Kannada). It is commercially grown in India, Turkey, Iran, West Africa, Bangladesh, Pakistan, Burma, Japan, Malaysia, Brazil, Ghana, Ethiopia, Cyprus and the southern United States (Chauhan, 1972) [7]. India is leading producer and cultivator of okra contributing almost 72 % of total okra production in the world.

Micronutrients are crucial for growth of plants; proper balance of all essential nutrients is necessary for healthy development and optimal yield. The micronutrients essential for healthy plant growth are Boron (B), Zinc (Zn), Manganese (Mn), Iron (Fe), Copper (Cu), Molybdenum (Mo) and Chlorine (Cl). Although these elements are required in minimal amount, they play a significant role in various physiological and biochemical processes within plants (Rab and Haq, 2012) [23]. Applying foliar nutrients with a blend of multiple nutrients for balanced plant nutrition is seen as efficient and sustainable vegetable farming. This method of fertilizer application serves as a valuable addition to nutrient delivery to plants (Fageria *et al*., 2009) [11]. Furthermore, foliar fertilization not only enhances crop yield and quality but also helps to prevent the issue of leaching in soil and encourage a rapid response from plants.

Materials and Methods
The experiment was carried out in E-6 Block during summer, 2024 at Vegetable Research Farm, Regional Horticultural Research Station (RHRS), Navsari Agricultural University, and Navsari. The experiment was laid out in randomized block design (RBD) with three replications and nine micronutrient treatments, *i.e.* T_1 - Ammonium molybdate @ 0.1 % , T_2 - Boric acid @ 0.2 %, T_3 - Zinc sulphate @ 0.5 %, T_4 - Copper sulphate @ 0.5 %, T_5 - Ferrous sulphate @ 0.5 %, T_6 - Manganese sulphate @ 0.5 %, T_7 - General grade – IV (Fe-2.0, Mn-0.5, Zn-4.0, Cu-0.3 and B-0.5) @ 1.5 %, T_8 - General grade - IV @ 1.5 % + T_3 and T_9 - Control (No spray). The treatments were applied twice by foliar application at 25 DAS and 40 DAS.

The experiment was carried out using the GNO-1 (Purna Rakshak) variety with spacing of 45 cm × 30 cm. The recommended dose of fertilizers 100:50:50 kg NPK kg/ ha and farmyard manure (10 t/ha) was applied to the experimental plots. Out of recommended dose of fertilizers half dose of nitrogen and full dose of phosphorus and potash applied before sowing as basal dose and remaining half dose of nitrogen was applied at 45 DAS and 60 DAS in two equal split doses by top dressing method.

Plant growth parameters such as plant height (cm), internodal length (cm), stem girth (cm) recorded from tagged five plants in each treatment of all replications. The titrimetric method described by Ranganna (1979) was adopted to estimate ascorbic acid (vitamin - c) content mg per 100g of okra pulp. The chlorophyll content of okra (*Abelmoschus esculentus*) fruit pulp was determined after extraction with ethanol, using a procedure described by Arnon (1949) [3]. The laboratory work was carried out in the Department of NRM (Natural Resource Management) of ASPEE College of Horticulture, NAU, Navsari. The standard method of analysis of variance technique appropriate to the randomized block design (RBD) as described by Panse and Sukhatme (1985) [22] was used.

Result and Discussion

The effect of foliar application of micronutrients on growth and quality attributes of okra such as plant height, internodal length, stem girth, ascorbic acid content and chlorophyll content is summarized in table 1. The data illustrate that all growth and quality parameters were significantly influenced by foliar application of different micronutrients. Applying General grade – IV with zinc sulphate (T_8) significantly improved growth and quality attributes by enhancing key physiological and biochemical processes because micronutrients like Zn, B, Fe, Cu, Mo and Mn are vital for enzyme activation, photosynthesis and protein synthesis also foliar application ensures better absorption, leading to increased growth and quality.

The higher plant height (66.41 cm and 90.29 cm) at 60 DAS and at final harvest), respectively was recorded in treatment T_8 (General grade – IV @ 1.5% + Zinc sulphate @ 0.5%). The plant height achieved under T_8 was found to be statistically at par with treatment T_7 (General grade – IV @ 1.5%) and T_3 (Zinc sulphate @ 0.5%). The lower plant height 51.97 cm at 60 DAS and 65.80 cm at harvest, was observed in the control (T_9). Effect of foliar sprays of different micronutrients found significant on internodal length (cm), indicating the effectiveness of these treatments in influencing internodal length. The maximum internodal length (5.50 cm) was noted in treatment T_8 (General grade – IV @ 1.5% + Zinc sulphate @ 0.5%), which was at par with T_7 (General grade – IV @ 1.5 %) and T_3 (Zinc sulphate @ 0.5 %). Whereas, the minimum internodal length (4.12 cm) was recorded in treatment T_9 (no spray). Effect of foliar application of micronutrients found significant on stem girth (cm). The maximum stem girth (5.97 cm) was noted in the treatment T_8 (General grade – IV @ 1.5% + Zinc sulphate @ 0.5%) which was statistically at par with T_7 (General grade – IV @ 1.5 %) and T_3 (Zinc sulphate @ 0.5 %), respectively. Ascorbic acid content/vitamin C content was significantly influenced by different foliar spray treatments of micronutrient found. The highest vitamin C content (16.14 mg/100g) was noted with T_8 (General grade – IV @ 1.5% + Zinc sulphate @ 0.5%). Whereas, lowest vitamin C content (11.82 mg/100g) found in T_9 (no spray). The results showed that various foliar spray of micronutrient had a substantial impact on the chlorophyll content. T_8 (General grade – IV @ 1.5% + Zinc sulphate @ 0.5%) had the highest chlorophyll concentration (2.84 mg/100g). While T_9 (no spray) had the lowest chlorophyll concentration (1.71 mg/100g).

The increased height of the okra linked with the involvement of zinc in the production of auxins, while boron is associated with the formation of cell walls and the differentiation of cells, they participate in cell division, hormone production and photosynthesis, which together lead to greater stem elongation and an overall increase in plant height. Higher plant height observed by foliar application of micronutrients was in close conformity with the findings of Mehraj *et al*. (2015), Kumar *et al*. (2020), Rahman *et al*. (2020), Arya *et al*. (2021), Maliha *et al*. (2022) and Ayobi *et al*. (2022) [4, 5, 16, 17, 19, 24] in okra and Sathiyamurthy *et al*. (2017) [27] in tomato.

Applying micronutrients through foliar methods boost cell division, elongation, enzyme functions, auxin production (zinc), chlorophyll synthesis (iron) and the development of cell walls (boron), all of which facilitate enhanced vegetative growth and stem elongation. Foliar spray allows quick absorption of nutrients, resulting in increased physiological activity and internodal length. Similar effect of micronutrients was obtained by (Hazra *et al*., 1987), Mehraj *et al*. (2015), Kumar *et al*. (2020) and Ayobi *et al*. (2022) [5, 12, 16, 19] in okra. Micronutrients support cell division in meristematic tissues, which are crucial for plant growth and additionally contribute to the synthesis and movement of vital biomolecules such as sugars, nitrogen and hormones, all of which leads to the thickening of stems. The outcomes were supported by research on okra conducted by Mehraj *et al*. (2015), Maliha *et al*. (2022), Ayobi *et al*. (2022) and Dixit *et al*. (2018) [5, 9, 17, 19] in tomato. The increase in ascorbic acid content due to the improved nutritional status of the plants, which enhances various physiological, biochemical processes, enzymatic activity, stress tolerance and antioxidant metabolism. These factors collectively stimulate the biosynthesis and accumulation of ascorbic acid in the pods, resulting in improved fruit quality and higher vitamin C content. This is in agreement with the findings of Dubalgunde *et al*. (2017), Deshmukh *et al*. (2023), Javeed *et al*. (2023) in okra, Swetha *et al*. (2018), Verma *et al*. (2018), Himanshu *et al.* (2022) [10, 13, 14, 26, 28, 29] in tomato, Bharati *et al*. (2018) [6] in bitter gourd, Moklikar *et al*. (2018) [6] in cauliflower, Angami *et al*. (2017) and Malik *et al.* (2020) [2, 24] in chilli. Chlorophyll content increase in okra pods because the combined micronutrients enhanced chlorophyll synthesis and stabilized chloroplast structure. The improved nutrient availability supported efficient photosynthetic activity and better plant vigour, leading to increased chlorophyll accumulation in the pods. Similar results were found by Alrawi and Aljumail (2018), Javeed *et al*. (2023) in okra, Mishra *et al.* (2012) [1, 20, 26] in tomato, Karthick *et al*. (2017) [15] in bitter gourd and Sai *et al*. (2023) [26] in cabbage.

Table 1: Effect of foliar application of micronutrients on growth and quality attributes of okra

Treatment	Plant Height (cm)		Internodal length (cm)	Stem girth (cm)	Ascorbic acid (mg/100g)	Chlorophyll content (mg/100g)
	60 DAS	Final Harvest				
T_1	57.51	74.77	4.48	4.62	13.38	1.51
T_2	55.92	73.89	4.44	4.46	13.15	1.73
T_3	62.24	82.65	5.41	5.80	15.25	2.73
T_4	58.31	76.89	4.53	4.48	14.34	1.72
T_5	52.14	76.81	4.61	4.59	15.67	1.44
T_6	58.64	75.58	4.92	4.57	13.24	1.64
T_7	65.94	87.75	5.44	5.83	14.05	2.81
T_8	66.41	90.29	5.50	5.97	16.14	2.84
T_9	51.97	65.80	4.12	3.86	11.82	1.73
SEm (±)	2.46	3.63	0.11	0.20	0.86	0.13
CD at 5 %	7.38	10.89	0.33	0.60	2.58	0.40
CV (%)	7.25	8.04	7.28	7.11	10.56	11.40

Conclusion

The results of the study revealed that all growth and quality parameters were strongly influenced by foliar spray of different micronutrients at 25 DAS and 40 DAS tested but among all the treatments, T_8 (General Grade- IV @ 1.5% + Zinc sulphate @ 0.5 %) was the most effective. This treatment significantly improved key growth and quality parameters such as plant height, internodal length, stem girth, ascorbic acid content and chlorophyll content.

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Ethical Issue

None

Disclosure statement

No conflict of interest found between authors

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