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An Overview on Role of Micronutrients in Vegetable Production

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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

The nutrients which are required in small quantities are called as micronutrients. Micronutrients are equally important as macronutrients for enhancing growth, yield and quality of plants. Micronutrients perform various functions, such as plant metabolism, nutrient regulation, chlorophyll synthesis, reproductive growth, flower retention, fruit and seed development. Micronutrients, which are essential for all higher plants, are iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), molybdenum (Mo), nickel (Ni) and chlorine (Cl). Micronutrients like Cl, Cu, Fe and Mn are involved in various photosynthetic processes and Zn, Cu, Fe and Mn are associated with various enzymatic activities, Mo is specific for nitrate reductase only. This study investigated the characteristics of micronutrients, their roles in the growth and development of plants and crops as well as the prevalent micronutrient deficiencies found in vegetable crops. Additionally, the study emphasizes the impact of micronutrients on vegetable quality which includes improved nutritional value and bioactive compounds. Concerns regarding the sustainable and

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effective use of micronutrients, along with future research goals are analyzed, including practical implications and recommendations for micronutrient management systems. Taking this into consideration, the current review focuses on the role of micronutrients in improving the quality of vegetables, as well as the possible impact of further research on this topic.

Keywords: Micronutrients; vegetable crops; deficiency; functions.

1. INTRODUCTION

"Micronutrients are essential elements that are required by plants in small amounts to promote optimal growth, development, and reproduction. Micronutrients are required in small quantities as compared to macro nutrients but play+ an important role in several metabolic and physiological processes" (Bahera et al*.,* 2025). "It includes iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), molybdenum (Mo), nickel (Ni) and chlorine (Cl). Of the eight micronutriets, Fe, Mn, Zn, Cu and Ni behave like cations while B, Mo and Cl behave like anions in soil" (Deb et al*.,*2012). "Micronutrients plays a vital role in the growth, development and metabolic activities of plants, which include cell wall development, respiration, photosynthesis, chlorophyll formation, nitrogen fixation and various other metabolic processes. However, their deficiencies may result in various physiological disorders in plants, which may consequently reduce the quality of crops" (Khatun et al*.,* 2024). "Micronutrients also help to enhance the effectiveness of macronutrient utilization. The presence of micronutrients at higher concentrations can lead to toxic effects, endangering the growth of plants. It is crucial for growers to follow the recommended guidelines for micronutrients closely to avoid unnecessary expenses and to prevent any toxic effects or detrimental interactions with other nutrients" (Maurya et al*.,* 2018).

"Soil serves as the foundation of agriculture and introduces various factors. Soil pH is a crucial element influencing the availability of micronutrients. In acidic soils, elements such as iron, manganese, zinc and copper are more accessible. Conversely, alkaline soils generally exhibit a greater availability of calcium, magnesium and molybdenum, although phosphorus may become less accessible due to its interactions with calcium. Soils with near-neutral pH typically provide ideal conditions for the availability of phosphorus, potassium, various forms of nitrogen, sulfur, and copper. Nonetheless, it is essential to recognize that other soil characteristics also contribute to the determination of nutrient accessibility. The mobility of micronutrients also differs, elements like Mo and B are able to move freely and are readily absorbed while others such as Fe and Zn exhibit a restricted range requiring closeness to root structures for effective absorption" (Ahmed et al*.,* 2024).

"Micronutrients must be absorbed by plants from the soil or provided through foliar application, which enhances vegetative growth and increases crop yield. The application of micronutrients through foliar methods is more effective than through soil application, since the uptake and assimilation of micronutrients through the latter method requires more time" (Sidhu et al*.,* 2019).

Presently, micronutrients are increasingly gaining importance in vegetable crops due to their beneficial nutritional support, which also leads to improved yields and returns. A comprehensive understanding of the micronutrients present in vegetable crops is essential to satisfy the increasing demand for vegetable production. However, there is limited information available regarding the effects of foliar micronutrient nutrition on vegetable crops. The main objective of this study is to draw attention to the vital role of micronutrients in vegetable production by employing suitable application techniques to overcome the challenges of micronutrient deficiencies and developing suitable management strategies for sustainable olericulture.

2. ROLE OF MICRONUTRIENTS

"Iron plays an important role in different biological processes such as photosynthesis, chlorophyll synthesis, respiration, nitrogen fixation, uptake mechanisms and DNA synthesis" (Rout and Sahoo, 2015).

"Manganese plays a vital role in the oxidation and reduction processes in plants, such as facilitating electron transport during photosynthesis. Manganese is essential for the activation of several enzymes that participate in oxidation reactions, carboxylation, carbohydrate metabolism, phosphorus reactions and the citric acid cycle" (Sahu et al*.,* 2020). "Furthermore, it helps to enhance the antioxidant defences of plants in response to particular environmental stressors such as drought, salinity, and ozone damage, along with certain soil-borne diseases" (Alejandro et al*.,* 2020).

"Copper is an essential micronutrient for the normal growth and metabolism of plants. Copper is involved in the activation of various enzymes in plants, contributing to the process of chlorophyll synthesis. Copper is an essential component of plastocyanin and is vital for the function of key enzymes such as cytochrome oxidase, superoxide dismutase, ascorbate oxidase, and polyphenol oxidase. Furthermore, it plays a significant role in lignin synthesis, which contributes physical strength of shoots and stems" (Jayara et al*.,* 2023).

"Zinc is a vital micronutrient acting as a component and an activator for numerous plant enzymes. Zinc is essential for numerous physiological functions, ranging from glucose metabolism to the synthesis of RNA, DNA and proteins. It plays a significant role in the production of chlorophyll and auxin, the plant hormones that regulate stem elongation, root branching, and the timing of flower initiation" (Nandal and Solanki, 2021). "Zinc is necessary for the integrity of cellular membranes, which is important for maintaining the structural orientation of macromolecules and ion transport systems. Its interaction with phospholipids and the sulfhydryl groups found in membrane proteins is essential for the preservation of membranes" (Hafeez et al*.,* 2013).

"Boron plays an important role in various structural, physiological and biochemical functions of plants. Boron is necessary for cell wall formation, carbohydrate metabolism, nitrogen fixation and plant reproduction. It also plays an important role in the growth of pollen tubes+, pollen germination and seed development" (Arun Kumar et al., 2018). "The application of boron improves disease resistance in plants, including potato scab and damping -off fungi in tomato and cabbage" (Saleem et al*.,* 2011).

Table 1. Major micronutrient carriers

Micronutrient	Name of salt	Micronutrient content (%)
Iron	Ferrous sulphate	19
	Ferric sulphate	17
	Ferric chloride	5-18
	Chelated Fe	12
Manganese	Manganese sulphate monohydrate	30-32
	Manganese sulphate trihydrate	26-28
	Manganese oxysulphate	40-49
	Manganese dioxide	55-65
	Chelated Mn	5-12
Copper	Copper sulphate heptahydrate	24
	Copper sulphate monohydrate	35
	Copper oxysulphate	13-53
	Copper - EDTA	9-13
Zinc	Zinc sulphate heptahydrate	33
	Zinc sulphate monohydrate	21
	Zinc oxysulphate	55
	Zinc oxide	55-70
	Chelated Zn	12
Boron	Borax	10.5
	Solubor	20
	Boric acid	17.5
Molybdenum	Sodium molybdate	37-39
	Ammonium molybdate	54
Nickel	Nickle chloride	25
	Nickle nitrate	20
	Nickle oxide	79
Chlorine	Potassium chloride	48

"Molybdenum facilitates nitrogen fixation and also increases the uptake of phosphorus in plants. (Arabhanvi et al., 2015). It plays an important role in protein synthesis, sulphur metabolism and carotenoid formation. It also aids in the absorption and movement of iron within plants" (Sidhu et al., 2019).

"Nickel enhances the activity of the urease enzyme, which plays a crucial role in nitrogen metabolism and the regulation of senescence. Additionally, it can replace zinc and iron as a cofactor for various enzymes" (Patel et al., 2022).

"Chlorine is ubiquitous in nature. Chlorine is crucial for photosynthesis and contributes to osmo regulation (cell elongation and stomatal opening) and charge compensation which is necessary for the growth of shoot apices and roots. It also improves the quality of fruits, which includes factors such as appearance, soluble solids content, acidity, pH, texture, flavour and shelf life, as well as managing microbial growth '(Rattan and Goswami, 2012).

3. DEFICIENCY SYMPTOMS

"Iron is not translocated within the plant; deficiency symptoms are first observed on the new growth. Iron deficiency in individual plants is indicated by yellow leaves accompanied by dark green veins, a phenomenon referred to as interveinal chlorosis. In cases of severe deficiency, the entire plant may be affected, turning a very light yellow or even white" (Mohammad et al., 2014).

"In plants, a deficiency of manganese frequently manifests as a hidden disorder, without distinct visual symptoms. It leads to a decrease in chlorophyll content and higher susceptibility to pathogen infections. Its deficiency also increases the number of root hairs. If the deficiency intensifies root tips may suffer from severe necrosis." (Alejandro et al., 2020).

Table 2. Effect of micronutrients on vegetable crops

Crop	Micronutrient	Improved Characters	References
Cauliflower	Boron (1.50 %)	Plant height, Plant spread, weight of curd, diameter of curd and yield	Singh et al., 2011
Potato	2.5 kg Zinc ha^{-1} @ at the time of planting + Foliar Application of zinc sulphate @ 2 g L^{-1} (400 PPM Zn) at 25 and 50 days after planting.	TSS, Starch, Total sugar, Reducing sugar, dry matter of tuber and zinc content	Bhumarkar et al., 2025
Tomato	BA + $ZnSO_4$ + $CuSO_4$ @ 250 ppm each	Plant Height, Number of branches,Number of flowers, Fruit yield, TSS, Ascorbic acid	Barche et al., 2011
Broccoli	Molybdenum @ 0.05% at 30+45 DAT	Plant Height, Number of leaves, Leaf length, Head weight and Total yield per plant	Saha et al., 2010
Cucumber	Zinc 30 ppm + Boron 40 ppm	Number of fruits, Average fruit weight, Fruit diameter and Fruitgirth	Sidhu et al., 2020
Tomato	Fe @ 3.0 kg ha^{-1}	Plant height, Plant diameter, Fruit length, Fruit diameter, Fruit weight, TSS and Titratable acidity	Turhan and Ozmen, 2022
Okra	zinc sulphate 100 ppm + ammonium molybdate 50 ppm + copper sulphate 100 ppm + ferrous sulphate 100 ppm + manganese sulphate 100 ppm	Fruit length, Fruit diameter and fruit yield	Narayan et al., 2021
Okra	(Zn, B, Fe, Cu, Mo and Mn) @ 50 ppm	Plant Height, Number of leaves, Number of podes, Pod length and diameter and yield	Mehraj et al., 2015

"Deficiency symptoms of copper are characterised by restricted terminal growth, dieback of twigs, death of growing points and occasionally rosetting, along with the formation of multiple buds at the tips of twigs" (Sahu et al*.,* 2020).

"Zinc deficiency may result in multiple symptoms in plants. The symptoms of zinc deficiency first appear on young leaves of plants, because zinc cannot be transferred from older tissues to younger ones, due to its immobility. (Mohammad et al*.,* 2014). Stunted growth, along with shape distortion and clustering of leaves on short branches, referred to as rosette, are another deficiency symptoms of zinc" (Sahu et al*.,* 2020).

"Boron is not readily transported within the plant, so its deficiency first appears in young tissues, growing points, root tips and developing fruits. Its deficiency also affects the transport of sugars, starches, nitrogen, and phosphorus, in addition to the synthesis of amino acids and proteins. Leaves become wrinkled and curled with light green colour" (Baburai et al*.,* 2017). "Deficiency of boron also leads to cracking and distorted growth in fruits. In the absence of boron, pollen tubes may experience rupture due to the essential role of boron in structural integrity of cell wall in the pollen tube" (Jehangir et al*.,* 2017). Its deficiency is also responsible for creating male sterility and causes floral abnormalities (Saleem et al*.,* 2011).

"Symptoms of molybdenum deficiency often resemble those associated with nitrogen deficiency, with stunted growth and chlorosis. Further symptoms of molybdenum deficiency include pale leaves that may exhibit scorching, cupping, or rolling. Leaves may also look thick or brittle and will eventually wither, leaving solely the midrib" (Shrefu and Zewide, 2021).

"Nickel deficiency leads to reduction in the activity of urease enzymes along with other enzymes that play a role in nitrate reduction. An evident disruption in protein synthesis together with a significant reduction in total nitrogen levels has been observed in the context of nickel deficiency" (Gad et al*.,* 2007).

"Chlorine deficiency is rare, as chlorine is present in the atmosphere and in rainwater. Vegetable crops such as potatoes and beans exhibit a higher sensitivity to chlorine deficiency" (Sidhu et al*.,* 2019).

4. CONCLUSION

Micronutrients are essential for the metabolism and maintenance of tissue function and play a critical role in the growth and development of crops, especially vegetables. It is essential to acknowledge that the quality of crops can be adversely affected by both an excess and a deficiency of micronutrients in the growing environment. An excess of micronutrients, beyond the critical thresholds level required may lead to an array of physiological aberrations in crops including toxicity symptoms. On the other hand, a lack of vital micronutrients can also have similarly harmful consequences on crop quality. So, the judicious and balanced method of application of micronutrients is critical for optimal nutrient efficiency and sustainable crop production. Foliar nutrition is recognized as one of the most effective approaches to applying micronutrients, especially in comparison to soil application, as the latter involves a longer time for the absorption and assimilation of micronutrients. This approach is particularly important in the current context, where global food security relies not only on the quantity of food but also on the quality of food products, which is now acknowledged as a critical issue alongside conventional yield and growth factors. Effectively managing micronutrient elements is a crucial component of contemporary agriculture, playing a vital role in meeting the changing dietary requirements of the global population. This underscores the necessity for a comprehensive approach that includes both quantity and quality in vegetable production.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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