



## Importance and Role of Micronutrients in Vegetable Cultivation

Santosh Kumari, \*Ankita and Anjali Kumari

Dept. of Vegetable Science, College of Horticulture and Forestry, Neri, Hamirpur, Dr  
YS Parmar University of Horticulture and Forestry, Nauni, Solan, HP, India

\*Corresponding Author's email: [ankita1511999@gmail.com](mailto:ankita1511999@gmail.com)

Vegetables are rich sources of vitamins, minerals and dietary fibre. Adequate plant nutrition plays a key role in the successful cultivation of vegetable crops. The balanced and integrated application of micronutrients along with macronutrients is essential for increasing crop productivity and preserving the nutritional quality of vegetables. Although required in smaller amounts, micronutrients are equally important as macronutrients in promoting optimal plant growth, yield and quality. Micronutrients are vital elements needed by plants in very small quantities for proper growth, development and reproduction (Behera et al., 2025). Despite their minimal requirement, they play crucial roles in numerous metabolic and physiological functions. These essential elements include iron (Fe), copper (Cu), zinc (Zn), manganese (Mn), boron (B), molybdenum (Mo), nickel (Ni) and chlorine (Cl). They are necessary for maintaining overall plant health, as each involved in specific biochemical and physiological processes that contribute to growth and productivity. Any imbalance or deficiency of these micronutrients can lead to physiological disorders, restricted growth, reduced yield and inferior quality produce.

Micronutrients also significantly influence the quality, vigour and nutritional value of vegetable crops. As trace elements essential for plant development, their proper application and balanced management not only enhance growth and yield but also improve the appearance and sensory attributes of the produce. This includes better size, color and flavor which collectively contribute to higher productivity and resilience. Additionally, micronutrients help maintain important quality traits such as firmness, uniform coloration and antioxidant properties thereby improving the overall market and nutritional value of vegetables.

### Role of Micronutrients in Vegetable Crops

Micronutrients play a crucial role in regulating enzymatic activity and photosynthesis in vegetable crops. Elements such as zinc (Zn), iron (Fe) and manganese (Mn) act as cofactors for several enzymes involved in metabolic processes, including chlorophyll synthesis and electron transport. This enhances photosynthetic efficiency, leading to better vegetative growth and biomass production in vegetables like spinach, cabbage and tomato. They significantly influence reproductive growth in vegetables. Adequate supply of micronutrients, particularly boron (B) and zinc (Zn), improves flowering, pollen viability, fruit setting and seed development. In crops such as tomato, brinjal and chilli, boron plays an essential role in pollen germination and pollen tube growth resulting in better fruit set and reduced flower drop (Malek & Rahim, 2011).

Micronutrients further enhance the quality attributes of vegetable produce. They contribute to the synthesis of vitamins, sugars and pigments, thereby improving nutritional value, color, taste and shelf life such as iron (Fe) improves chlorophyll content in leafy vegetables, while zinc (Zn) enhances carbohydrate metabolism leading to better taste and

quality in crops like tomato and capsicum. Balanced micronutrient nutrition also helps maintain firmness and prolong post-harvest shelf life of vegetables.

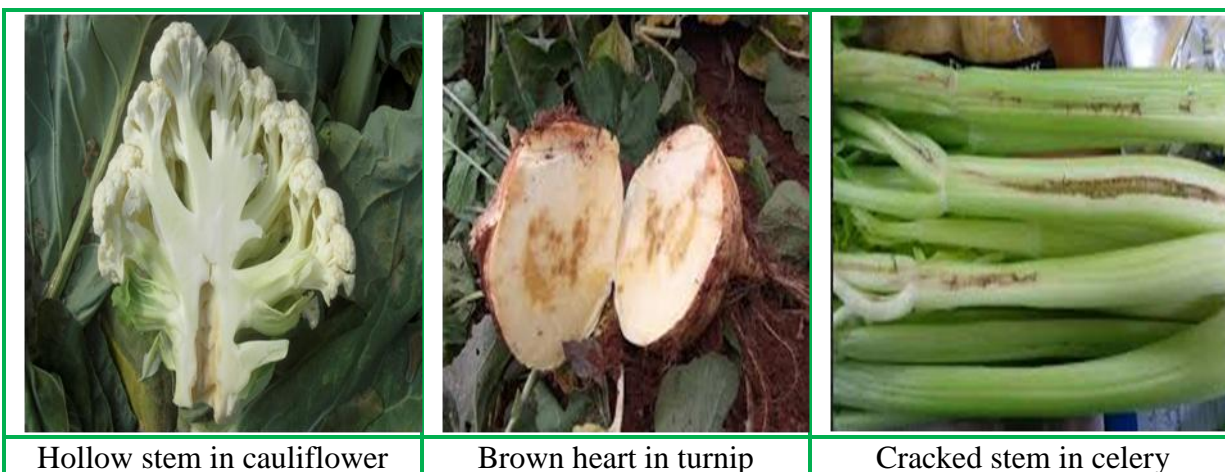
In addition, micronutrients increase the resistance of vegetable crops to biotic and abiotic stresses. Zinc (Zn), manganese (Mn) and copper (Cu) are involved in activating antioxidant enzymes that protect plants from oxidative damage caused by drought, salinity and temperature stress. They also enhance resistance against diseases by strengthening plant defense systems, which is particularly important in vegetable crops that are highly sensitive to environmental fluctuations. Zinc (Zn) application improves plant growth, yield and fruit quality in vegetables such as tomato and chilli by promoting auxin synthesis and enzyme activity while, boron (B) enhances fruit development, reduces physiological disorders and improves quality traits like size, shape and uniformity in crops such as cauliflower, cabbage and tomato.

### Micronutrient Deficiencies in Vegetable Crops

Micronutrients play a vital role in the metabolic processes of plants. In vegetable cultivation, productivity is often limited by micronutrient-related issues, including both deficiencies and toxicities. Even a slight imbalance from the optimum level can lead to significant reductions in yield. The appearance of deficiency symptoms depends on the mobility of micronutrients within the plant. Mobile nutrients tend to move toward actively growing regions during deficiency, causing symptoms to appear first on older or lower leaves whereas, immobile nutrients cannot be translocated to growing points, so their deficiency symptoms are observed in younger plant parts. For achieving high yield and superior quality, it is important to detect micronutrient deficiencies at an early stage, even before visible symptoms appear, commonly referred to as “hidden hunger.” Hence, precise and balanced application of micronutrients is essential for ensuring optimum productivity and quality in vegetable crops.

**Zinc (Zn) deficiency:** In vegetable crops, zinc deficiency is indicated by interveinal chlorosis on older leaves, which may gradually turn greyish-white, dry out and shed early. Typical symptoms also include smaller leaves and shortened internodes. This deficiency is more common under cold and wet conditions due to limited root growth and activity and it is further intensified by excessive phosphorus levels that hinder zinc uptake. Crops such as tomato, potato, beans and onion are highly susceptible. Common disorders include mottling, rosetting and fern leaf symptoms in potato.

**Boron (B) deficiency:** Boron deficiency frequently occurs in light-textured, dry soils where root activity is restricted. Its deficiency symptoms first appear in the growing points and younger tissues. It leads to reproductive issues such as sterility, poor fruit set, reduced fruit size, and deformation, ultimately lowering yield. Crops like cabbage, cauliflower, potato and beetroot are particularly sensitive. Typical symptoms include hollow stem in cauliflower, brown heart in turnip and beetroot, knob splitting in knol-khol, akashin in radish, cracked stem in celery and fruit cracking in tomato.



**Iron (Fe) deficiency:** Iron deficiency is commonly manifested as interveinal chlorosis in young leaves, where the veins remain green while the surrounding tissue turns yellow due to decreased chlorophyll synthesis (Patel et al., 2022).

**Copper (Cu) deficiency:** Copper deficiency leads to reduced plant growth, deformation of young leaves, necrosis of the apical meristem, curling of leaf tips, dieback of shoots and irregular leaf margins. It is often observed in sandy, calcareous and soils rich in organic matter.

**Manganese (Mn) deficiency:** Manganese deficiency results in interveinal chlorosis accompanied by pale green or yellow mottling between veins. Common symptoms include marsh spot in pea, yellow striping in onion, leaf chlorosis and necrosis in beans and speckled yellowing in beetroot. This deficiency is prevalent in alkaline, calcareous and sandy soils, and is further aggravated by high soil pH and excess iron, which interfere with manganese uptake.



Chlorosis in beans



Whiptail in cauliflower

**Molybdenum (Mo) deficiency:** Molybdenum deficiency is typically found in acidic soils (pH below 5.2) and heavily leached sandy soils, especially affecting leguminous crops that rely on nitrogen fixation. It leads to reduced nitrogen fixation and poor plant growth. Vegetables such as cauliflower, broccoli, spinach, lettuce, radish and beans are highly sensitive. A prominent symptom includes whiptail in cauliflower.

**Chlorine (Cl) deficiency:** Chlorine deficiency is relatively rare but may cause chlorosis in young leaves along with general wilting of the plant. Crops like potato and beans are more prone to this deficiency.

**Nickel (Ni) deficiency:** Nickel deficiency mainly affects leguminous vegetable crops, where it delays the formation of root nodules and reduces the efficiency of nitrogen fixation. It is especially important during the reproductive stage in crops such as cowpea.

### Causes of Micronutrient Deficiency

- **Soil Related Factors:** Micronutrient deficiency in vegetable crops is largely influenced by inherent soil characteristics that affect nutrient availability. Soil pH is one of the most critical factors. Highly alkaline soils reduce the solubility of micronutrients such as zinc, iron and manganese, while very acidic soils may lead to toxicity or imbalance. In addition to this, sandy soils with low organic matter have poor nutrient-holding capacity resulting in leaching losses of micronutrients. Low cation exchange capacity and calcareous conditions further restrict the availability of essential micronutrients making soil properties a primary cause of deficiencies in vegetable production.
- **Imbalanced Fertilization Practices:** Improper and excessive use of fertilizers, especially macronutrients is another major cause of micronutrient deficiencies. High application of phosphorus fertilizers can inhibit the uptake of zinc and iron leading to induced deficiencies. Continuous use of NPK fertilizers without supplementing micronutrients depletes soil reserves over time. This imbalance disrupts nutrient interactions and reduces the efficiency of nutrient uptake by plants ultimately affecting growth, yield and quality of vegetable crops.

- **Environmental and Climatic Conditions:** Environmental factors significantly influence the availability and uptake of micronutrients. Factors such as excessive rainfall can lead to leaching of nutrients particularly in light-textured soils, while drought reduces nutrient mobility and root activity. Low temperatures and waterlogged conditions also impair root growth and microbial activity limiting nutrient absorption. These stress conditions often increases the micronutrient deficiencies resulting in poor plant vigour and reduced productivity.
- **Biological and Management Constraints:** Biological factors such as low soil microbial activity and inadequate organic matter recycling also contribute to micronutrient deficiencies. Soil microorganisms play a key role in nutrient mineralization and chelation enhancing micronutrient availability to plants. Intensive cultivation practices that reduce organic matter content weaken these biological processes.

### Methods of Micronutrient Application

- **Soil application:** Soil application is the most common method of supplying micronutrients such as zinc (Zn), iron (Fe), boron (B), copper (Cu) and manganese (Mn). These nutrients are applied directly to the soil either before sowing or during land preparation. They are usually mixed with fertilizers or organic manures to ensure uniform distribution. For example, zinc sulphate and borax are commonly used sources. This method provides a long-term supply of nutrients but may be less efficient in soils with high pH, calcareous nature or poor nutrient availability.
- **Foliar application:** Foliar spray involves applying micronutrients directly to plant leaves in the form of aqueous solutions. It is one of the most effective and rapid methods to correct micronutrient deficiencies, especially during critical growth stages. Nutrients like iron, zinc, manganese and boron are commonly sprayed. This method ensures quick absorption and is particularly useful when soil conditions limit nutrient availability.
- **Seed treatment:** In this method, seeds are treated with micronutrients before sowing. Seeds may be soaked in micronutrient solutions or coated with nutrient formulations. This ensures better germination, early seedling vigor and improved nutrient uptake during initial growth stages. Zinc and molybdenum are commonly used in seed treatment. It is a cost-effective method but provides nutrients only during early plant growth.
- **Fertigation:** Fertigation is the application of micronutrients through irrigation systems, especially drip irrigation. Water-soluble micronutrient fertilizers are dissolved and delivered directly to the root zone. This method ensures efficient nutrient use, uniform distribution and reduced losses. It is widely used in protected cultivation and high-value vegetable crops. Fertigation allows precise control over nutrient supply but requires proper infrastructure and management.
- **Soil drenching:** Soil drenching involves applying micronutrient solutions directly around the root zone of plants. This method is useful for correcting deficiencies of nutrients like iron and boron. It ensures better availability of nutrients in the root zone compared to dry soil application. However, it may be labor-intensive and less practical for large-scale cultivation.
- **Use of chelated micronutrients:** Chelated forms of micronutrients (such as EDTA-chelated zinc or iron) are applied either through soil or foliar spray. These forms are more stable and available to plants especially in alkaline soils where nutrient fixation is high. Chelated micronutrients improve nutrient efficiency but are relatively more expensive than inorganic salts.

### References

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