

A Monthly e Magazine

ISSN:2583-2212

May, 2026 Vol.6(5), 1411-1416

Popular Article

## Copper Nutrition in Sunflower, Beetroot, Tomato, Carrot, Onion, and Spinach: Physiological and Molecular Perspectives

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[doi.org/10.5281/ScienceWorld.20439304](https://doi.org/10.5281/ScienceWorld.20439304)

### *Abstract*

Copper (Cu) is an essential micronutrient required in trace amounts for plant growth and productivity. It functions as a catalytic cofactor in redox reactions, photosynthetic electron transport, lignin biosynthesis, and defense mechanisms. This review highlights the physiological and molecular roles of copper in sunflower, beetroot, tomato, carrot, onion, and spinach, emphasizing its importance in yield, quality, and stress tolerance. Strategies for copper fertilization, deficiency management, and future perspectives in precision nutrient management are discussed.

### **Introduction**

Copper is indispensable for plant metabolism despite being required in minute quantities. It plays a central role in photosynthesis, respiration, and antioxidant defense, making it vital for crops with high metabolic activity such as sunflower, beetroot, tomato, carrot, onion, and spinach. Deficiency or excess of copper can severely affect crop productivity, highlighting the need for balanced nutrition management (Marschner, 2012).

### **Physiological Role of Copper**

Copper is a structural and functional component of several key enzymes. Plastocyanin, a copper protein, mediates electron transfer in photosystem I, thereby sustaining photosynthetic efficiency (Yruela, 2005). Cytochrome oxidase, another copper-dependent enzyme, regulates mitochondrial respiration and energy production. Copper also contributes



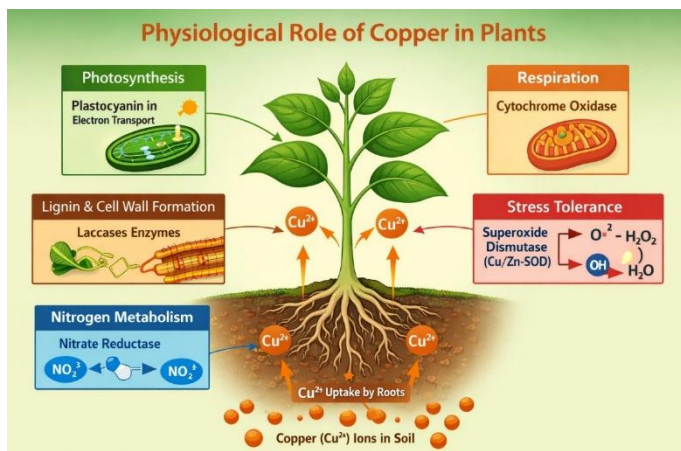
to lignin biosynthesis through laccases, strengthening vascular tissues and improving structural integrity (Broadley et al., 2012). Additionally, copper-containing superoxide dismutase (Cu/Zn-SOD) mitigates oxidative stress, enhancing tolerance to biotic and abiotic stresses (Figure 1)

### Copper Uptake and Assimilation

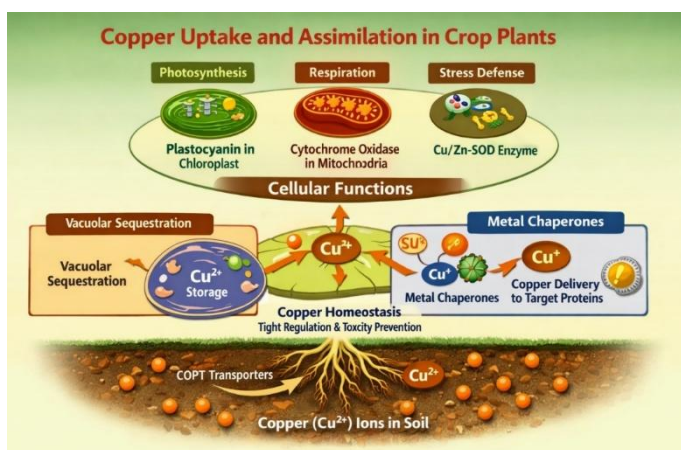
Plants absorb copper mainly in the form of  $Cu^{2+}$  ions through root transporters belonging to the *copt* family. Once inside, copper is delivered to target proteins by metallochaperones, ensuring safe intracellular transport and preventing toxicity (Burkhead et al., 2009). Vacuolar sequestration acts as a buffer, maintaining copper homeostasis. This tight regulation ensures that copper is available for essential metabolic functions while avoiding oxidative damage (Figure 2).

### Crop-Specific Roles

In sunflower, copper enhances seed oil quality and photosynthetic efficiency, while deficiency leads to chlorosis and poor seed set (Malhi et al., 2007). In beetroot, copper supports betalain pigment synthesis and sugar metabolism, with deficiency reducing root size and pigment intensity (Kumar et al., 2019). In tomato, copper is crucial for fruit set, lycopene biosynthesis, and disease resistance; deficiency manifests as leaf curling, chlorosis, and poor fruit quality (Sharma & Sharma, 2014). In carrot, copper is essential for root elongation and lignification, with deficiency causing weak roots and reduced carotenoid accumulation (Singh et al., 2016). In onion, copper improves bulb formation, enzyme activity, and flavor compounds, while deficiency results in reduced bulb size and poor storage quality (Tandon, 2013). In spinach, copper enhances



**Figure 1: Physiological Role of Copper in Crop Plants**



**Figure 2: Copper Uptake and Assimilation in crop plants**



chlorophyll stability and antioxidant activity, with deficiency leading to pale leaves and reduced nutritional value (Gupta & Jain, 2010).

### **Copper Deficiency Symptoms**

Copper deficiency is characterized by chlorosis of young leaves due to its immobility within the plant system. Other symptoms include leaf curling, necrotic spots, poor reproductive growth, and reduced lignification, which leads to lodging in sunflower and weak roots in carrot (Table 1) (Singh & Singh, 2015). These symptoms directly compromise yield and quality, making copper supplementation essential.

**Table 1: Copper Deficiency Symptoms in certain crops**

Crop	Key Symptoms
Sunflower	Pale young leaves, chlorosis at tips/margins, curling, necrosis, wilting of new shoots, poor seed set, dieback of shoot tips.
Beetroot	Symptoms appear on youngest leaves due to immobility of copper; reduced sugar yield, pale chlorotic foliage, stunted growth, poor root expansion.
Tomato	Reduced growth, upward/inward leaf curling, scorching, bronzing of chlorotic leaves, necrosis at margins, blackened veins, stiff rolling of older leaves, poor fruit set.
Carrot	Young leaves uniformly chlorotic, shoots withered, leaves turn blue-green before yellowing and curling; symptomless yield losses common on sandy/high pH soils.
Onion	Leaf tips turn white, twist corkscrew-like or bend at right angles, chlorosis, dieback; poor bulb skin finish and scale development.
Spinach	General plant symptoms: yellowing of young leaves, stunted growth, wilting, necrotic spots, curled leaves, poor seed set; copper deficiency often first visible in new growth.

### **Copper Requirement and Fertilization**

The recommended copper dose ranges between 2–6 kg Cu ha<sup>-1</sup>, depending on soil type and crop species (Tripathi & Sharma, 2017). Copper sulphate (CuSO<sub>4</sub>·5H<sub>2</sub>O), chelated copper (EDTA-Cu), and copper oxychloride are common sources (Table 2). Soil application ensures sustained availability, while foliar sprays provide rapid correction of deficiencies. Seed treatment with copper formulations has also been shown to improve early vigor and disease resistance (Singh et al., 2020).



**Table 2: Copper Requirement, Fertilizer Sources and Dosages in certain crops**

Fertilizer Source	Chemical Composition / Form	Recommended Dosage (kg Cu ha <sup>-1</sup> )	Application Method	Remarks
Copper Sulphate (CuSO <sub>4</sub> ·5H <sub>2</sub> O)	25% Cu	2–6	Basal soil application or foliar spray	Common and effective source; rapid correction of deficiency; suitable for most soils.
Chelated Copper (EDTA–Cu)	12–15% Cu	1–3	Foliar spray or fertigation	High efficiency and low phytotoxicity; ideal for precision nutrient management.
Copper Oxychloride (3Cu (OH) <sub>2</sub> ·CuCl <sub>2</sub> )	58% Cu	2–4	Foliar spray	Dual role as micronutrient and fungicide; improves disease resistance.
Copper Hydroxide (Cu (OH) <sub>2</sub> )	50–55% Cu	2–4	Foliar spray	Used for both nutrient supply and disease control; avoid overuse to prevent toxicity.
Copper Nitrate [Cu (NO <sub>3</sub> ) <sub>2</sub> ]	20–25% Cu	1–2	Foliar spray	Provides both Cu and N; suitable for quick correction during vegetative growth.
Copper Oxide (CuO)	75% Cu	1–2	Soil incorporation	Slow-release form; effective for long-term copper supply in deficient soils.
Nano-Copper Formulations	Variable (nano-scale Cu)	0.5–1	Foliar spray	Emerging technology; enhances uptake efficiency and reduces environmental load.

### Economic Importance

Copper fertilization enhances yield, quality, and market value by improving pigment synthesis in beetroot and spinach, oil content in sunflower, and flavor compounds in onion and tomato. Balanced copper nutrition reduces disease incidence, thereby lowering pesticide costs and improving profitability (Malhi et al., 2007).

### Future Perspectives



Emerging technologies such as nano-copper formulations promise precision delivery and higher nutrient use efficiency. Molecular breeding for copper-efficient genotypes and integrated nutrient management strategies combining organic amendments with micronutrient fertilizers are future directions. Soil testing and precision agriculture will be critical to avoid toxicity while ensuring sufficiency (Singh & Singh, 2020).

### **Conclusion**

Copper is indispensable for the physiological and molecular functioning of sunflower, beetroot, tomato, carrot, onion, and spinach. Its role in photosynthesis, respiration, lignification, pigment synthesis, and stress tolerance underscores the need for balanced copper nutrition. Sustainable management strategies, including nano-fertilizers and precision agriculture, will ensure productivity, quality, and profitability in these crops.

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