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## Zinc: The vital micronutrient for agricultural and horticultural crops and its commercial application

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### 1. Introduction

Zinc is a critical micronutrient in Indian agriculture, essential for crop productivity, soil health, and national nutritional security. In India, *over 50% of agricultural soils are zinc-deficient*, with some states reporting levels exceeding 80% due to intensive cultivation, imbalanced fertilizer use, and soil degradation. Zinc plays a vital role in enzyme activation, protein synthesis, auxin metabolism, and membrane integrity, directly influencing seedling vigor, photosynthesis, and reproductive development. Its deficiency leads to stunted growth, chlorosis, and poor yield, especially in cereals, pulses, and horticultural crops. Addressing zinc deficiency is not only crucial for crop health but also for human nutrition, as zinc-deficient soils produce zinc-poor food, contributing to widespread micronutrient malnutrition. Integrated nutrient management strategies including zinc-enriched fertilizers, foliar sprays, and biofortification are increasingly adopted to restore soil fertility and enhance crop resilience across diverse agro-climatic zones.

### 2. Structure

Zinc (Zn), with atomic number 30, is a transition metal that adopts a simple hexagonal crystal structure at room temperature, specifically the hexagonal close-packed (hcp) arrangement. This structure is characterized by atoms tightly packed in a repeating ABAB pattern, contributing to zinc's moderate density and relatively low melting point of 419.5 °C. The hcp lattice imparts anisotropic mechanical properties, meaning zinc exhibits different strengths and ductility depending on the

direction of applied force. This anisotropy is crucial in processes like rolling and extrusion, where zinc's formability is exploited. Zinc's metallic bonding and crystalline arrangement also affect its electrical conductivity and corrosion resistance, making it valuable for galvanization and alloying. The element belongs to Group 12 of the periodic table and has a standard atomic weight of approximately 65.38.

### 3. Role of Zinc in plants

Zinc is an essential micronutrient in plants, playing a pivotal role in enzyme activation, protein synthesis, and growth regulation. Zinc (Zn) is crucial for numerous physiological and biochemical processes in plants, despite being required in minute quantities. It functions as a cofactor for over 300 enzymes, facilitating key activities such as protein synthesis, auxin metabolism, and membrane integrity. Zinc is vital for the formation of ribosomes and the regulation of RNA transcription, directly influencing cell division and elongation. Deficiency symptoms include stunted growth, chlorosis, and malformed leaves, particularly in cereals and legumes. Zinc also enhances resistance to environmental stress and supports reproductive development, making it indispensable for crop productivity and quality. Sustainable agriculture practices increasingly emphasize zinc bioavailability through soil amendments and microbial mobilization strategies (Hamzah Saleem et al., 2022).

### 4. Zinc Deficiency symptoms

Zinc deficiency in plants manifests through distinct morphological and physiological symptoms, primarily affecting young tissues and overall growth. Typical symptoms include interveinal chlorosis yellowing between leaf veins especially in young leaves, along with stunted growth, reduced internode elongation, and leaf malformation. In dicotyledonous crops, this often results in rosetting, where leaves cluster due to shortened internodes. Other signs include necrotic spots, bronzing of leaves, and poor root development. These symptoms stem from zinc's role in auxin synthesis, enzyme activation, and protein metabolism, which are critical for cell division and elongation. Crops like maize, rice, citrus, and legumes are particularly sensitive, and deficiency is exacerbated in high pH soils or those with excessive phosphorus.

### 5. Zinc Toxicity symptoms

Zinc toxicity in plants leads to stunted growth, chlorosis, and nutrient imbalances, particularly affecting iron and phosphorus uptake. While zinc is an essential micronutrient, excessive concentrations often due to industrial contamination, over-application of zinc fertilizers, or acidic soils can disrupt plant metabolism. Common symptoms include reduced root and shoot growth, leaf chlorosis (especially interveinal), and in severe cases, necrotic spots on older leaves. High zinc levels interfere with the uptake of other essential nutrients like iron (Fe), manganese (Mn), and phosphorus



(P), leading to secondary deficiencies. Plants may also exhibit leaf curling, bronzing, and poor seed development. At the cellular level, excess zinc induces oxidative stress by generating reactive oxygen species (ROS), impairing photosynthesis and respiration (Kaur and Garg, 2021).

## 6. Fertilizer sources of Zinc

Zinc fertilizers are available in various forms, with zinc sulfate being the most widely used and effective source for correcting deficiencies in crops. The primary inorganic sources include zinc sulfate ( $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ ), which is commonly applied to soil or used in foliar sprays due to its high solubility and affordability. Other inorganic options are zinc oxide (ZnO) and chelated zinc compounds like Zn-EDTA, which are especially beneficial in calcareous or high pH soils where zinc availability is limited. Organic sources include zinc-enriched composts, farmyard manure, and microbial biofertilizers that mobilize native zinc through biological activity. The choice of source depends on soil type, crop sensitivity, and application method—whether basal, foliar, or seed treatment. Sustainable practices increasingly favor integrated approaches combining chemical and biological sources to enhance zinc uptake and long-term soil health (table 1).

**Table 1: Zinc containing compounds**

Compound	Formula	Zinc Content (%)
<i>Inorganic Compounds</i>		
Zinc sulphate monohydrate	$\text{ZnSO}_4 \cdot \text{H}_2\text{O}$	36
Zinc sulphate heptahydrate	$\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$	22
Zinc oxysulphate	$\text{ZnO} \cdot \text{ZnSO}_4$	20-50
Basic zinc sulphate	$\text{ZnSO}_4 \cdot 4\text{Zn}(\text{OH})_2$	55
Zinc oxide	ZnO	50-80
Zinc carbonate	$\text{ZnCO}_3$	50-56
Zinc chloride	$\text{ZnCl}_2$	50
Zinc nitrate	$\text{Zn}(\text{NO}_3)_2 \cdot 3\text{H}_2\text{O}$	23
Zinc phosphate	$\text{Zn}_3(\text{PO}_4)_2$	50
Zinc frits	Fritted glass	10-30
Ammoniated zinc	$\text{Zn}(\text{NH}_3)_4\text{SO}_4$	10
<i>Organic Compounds</i>		
Disodium zinc EDTA	$\text{Na}_2\text{ZnEDTA}$	8-14
Sodium zinc HEDTA	$\text{NaZnHEDTA}$	6-10
Sodium zinc EDTA	$\text{NaZnEDTA}$	9-13
Zinc polyflavonoid	--	5-10
Zinc lignosulphonate	--	5-8



## 7. Commercial application of Zinc in agriculture and horticulture crops

Zinc is commercially applied in agriculture and horticulture to enhance crop productivity, correct micronutrient deficiencies, and improve stress tolerance, especially in zinc-deficient soils prevalent across India (table 2 and Fig 1).

Commercial Application of Zinc in Agriculture and Horticulture Crops			
Crop	Zinc Dosage	Source	Stage of Application
Wheat	25 kg Zn/ha	Zinc Sulfate (ZnSO <sub>4</sub> +N	Basal
Rice	0.5% Zn Solution	Zinc Sulfate (ZnSO <sub>4</sub>	Foliar Spray
Maize	1% Zn Solution	Zinc Sulfate (ZnSO <sub>4</sub>	Knee-High
Pulses	25 kg Zn/ha	Zinc Sulfate (ZnSO <sub>4</sub>	Basal
Citrus	0.5% Zn Solution	Zinc Chelate like Zn-EDTA	Foliar Spray
Banana	2 g Zn/plant	Zinc Chelate like Zn-EDTA	Early Growth
Mango	0.3% Zn Solution	Zinc Chelate like Zn-EDTA	Vegetative Growth
Vegetable Crops	0.5% Zn Solution	Zinc Sulfate	Flowering
Flowers	25 kg Zn/ha	Zinc Sulfate (ZnSO <sub>4</sub>	Planting

**Fig 1: Commercial application of Zinc in Agriculture and Horticulture crops**

Zinc plays a vital role in plant metabolism, influencing enzyme activity, protein synthesis, and hormone regulation. Its commercial application is particularly significant in regions with widespread zinc-deficient soils such as India, where over 50% of agricultural soils lack adequate zinc, with some states reporting deficiencies exceeding 80%. In field crops like rice, wheat, maize, and pulses, zinc fertilizers such as zinc sulfate (ZnSO<sub>4</sub>·7H<sub>2</sub>O) are routinely applied through soil incorporation, seed



treatment, or foliar sprays to improve seedling vigor, chlorophyll formation, and grain quality (Laxman Navi et al., 2024). In horticultural crops especially citrus, mango, banana, and vegetables zinc enhances fruit set, leaf development, and resistance to abiotic stress. Foliar sprays of zinc chelates (e.g., Zn-EDTA) are commonly used in high-value crops to ensure rapid uptake and visible correction of deficiency symptoms. Further, Foliar sprays are typically prepared as 0.5% ZnSO<sub>4</sub> solution (i.e., 5 g per liter of water). Chelated zinc (Zn-EDTA) is preferred in high pH or calcareous soils due to better availability. Lime is added to foliar sprays to prevent leaf scorching.

**Table 2: Zinc application recommendations for key crops, including dosage, source, and stage of application.**

Crop	Zinc Dosage	Source	Stage of Application
Rice	25 kg/ha ZnSO <sub>4</sub> ·7H <sub>2</sub> O (soil)	Zinc sulfate heptahydrate	Basal (before transplanting or sowing)
Wheat	25 kg/ha ZnSO <sub>4</sub> ·7H <sub>2</sub> O (soil)	Zinc sulfate heptahydrate	Basal + foliar spray at tillering
Maize	5 kg/ha Zn (soil) + 0.5% foliar spray	ZnSO <sub>4</sub> or Zn-EDTA	Basal + foliar at 30–35 DAS
Groundnut	10 kg/ha ZnSO <sub>4</sub> ·7H <sub>2</sub> O	Zinc sulfate heptahydrate	Basal + foliar at flowering
Cotton	25 kg/ha ZnSO <sub>4</sub> ·7H <sub>2</sub> O	Zinc sulfate heptahydrate	Basal + foliar at square and boll formation
Chickpea	5 kg/ha Zn (soil)	ZnSO <sub>4</sub> or Zn-EDTA	Basal
Mango	0.5% ZnSO <sub>4</sub> foliar spray	Zinc sulfate	Pre-flowering and post-harvest
Citrus	0.5% ZnSO <sub>4</sub> + 0.25% lime (foliar)	Zinc sulfate + lime	Twice a year: spring and monsoon flush
Tomato	5–10 kg/ha ZnSO <sub>4</sub> (soil) + 0.5% foliar	Zinc sulfate or Zn-EDTA	Basal + foliar at flowering and fruit set
Onion	10 kg/ha ZnSO <sub>4</sub> (soil)	Zinc sulfate	Basal

Zinc also contributes to sustainable agriculture by improving nutrient use efficiency and resilience against drought and disease. Its role in *phytohormone synthesis* (e.g., *auxin*) and *membrane stability* supports better root development and water uptake, which is critical under climate stress conditions. Commercial formulations include granular zinc fertilizers, liquid foliar sprays, and zinc-enriched composts, tailored for different soil types and cropping systems. Precision agriculture increasingly integrates zinc application based on soil testing and crop-specific nutrient demand, optimizing input use and yield outcomes. Moreover, zinc mobilizing biofertilizers and microbial consortia are gaining traction as eco-friendly alternatives to synthetic inputs, especially in organic and climate-smart farming systems.



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