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Sulphur: Its role in Agriculture and Horticultural crops

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1. Introduction

Sulphur is vital for enhancing crop productivity, quality, and nutrient efficiency in Indian agriculture, especially for oilseeds, pulses, and legumes. Sulphur plays a critical role in protein synthesis, enzyme activation, and chlorophyll formation, making it essential for plant growth and development. In India, sulphur deficiency is increasingly observed due to intensive cropping, reduced use of sulphur-containing fertilizers, and imbalanced nutrient management. Crops like groundnut, mustard, soybean, and pulses show significant yield and quality improvements with adequate sulphur nutrition, particularly in sulphur-deficient soils common across the Indo-Gangetic plains and parts of southern India. Sulphur also enhances nitrogen use efficiency and supports nodule formation in legumes, contributing to sustainable soil fertility and reduced fertilizer dependency. The inclusion of sulphur fertilizers such as gypsum, single superphosphate, and sulphur-bentonite in the Fertilizer Control Order (FCO) reflects its recognized importance in national nutrient policy (Anki Mibang et al., 2023).

2. Structure of Sulphur

Sulphur (S), atomic number 16, has a complex structure characterized by multiple allotropes, with the most stable form being cyclic octatomic molecules (S_8). In its elemental state, sulphur commonly exists as bright yellow crystals composed of puckered rings of eight sulphur atoms (S_8), forming a crown-like structure. Each sulphur atom in the ring is covalently bonded to two neighboring

atoms, creating a stable configuration. The electron configuration of sulphur is $1s^2$ $2s^2$ $2p^6$ $3s^2$ $3p^4$, indicating six valence electrons that facilitate its bonding versatility. Sulphur also exhibits several allotropes, including rhombic and monoclinic forms, which differ in crystal structure and stability depending on temperature and pressure conditions. These structural variations influence sulphur's reactivity and applications in agriculture, industry, and environmental systems.

3. Physiology of Sulphur nutrition

Sulphur nutrition plays a pivotal role in crop physiology by influencing protein synthesis, enzyme activity, stress tolerance, and overall metabolic function. Sulphur is a key component of essential amino acids like cysteine and methionine, which are foundational to protein formation and plant growth. It contributes to the synthesis of coenzymes and vitamins, supports chlorophyll production, and regulates redox reactions critical for photosynthesis and respiration. Sulphur also enhances nitrogen use efficiency and is vital for nodule development in legumes, thereby improving biological nitrogen fixation. Deficiency impairs these physiological processes, leading to reduced growth, chlorosis, and poor yield quality. Moreover, sulphur is involved in the biosynthesis of secondary metabolites such as glucosinolates, which aid in plant defense and stress resilience (**Zenda et al., 2021**).

4. Symptoms of Sulphur deficiency in crops

Sulphur deficiency in crops typically presents as uniform yellowing (chlorosis) of younger leaves, stunted growth, and delayed maturity, often resembling nitrogen deficiency but affecting the upper foliage first. This occurs because sulphur is immobile in plants, so new growth suffers first when supply is limited. Affected plants may also exhibit thin stems, reduced branching, and poor seed or fruit development. In oilseed crops like mustard and groundnut, deficiency leads to lower oil content, while in legumes, it hampers nodule formation and nitrogen fixation. Cereal crops such as wheat and maize show pale green to yellow upper leaves and reduced tillering. The symptoms are more pronounced in sandy, low organic matter soils or under high rainfall conditions that leach sulphate ions. Regular soil testing and balanced fertilization with sulphur-containing inputs like gypsum or elemental sulphur can help correct and prevent these issues.

5. Symptoms of Sulphur toxicity in crops

Sulphur toxicity in crops is rare but can occur due to excessive application of sulphur fertilizers or industrial contamination, leading to stunted growth, leaf tip burn, and nutrient imbalances. When sulphur levels exceed optimal thresholds, plants may exhibit chlorosis, necrotic leaf margins, and reduced root development, particularly in sensitive crops like beans and lettuce. High sulphur concentrations can interfere with the uptake of essential nutrients such as nitrogen, phosphorus, and

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molybdenum, resulting in poor plant vigor and diminished yield quality. In hydroponic systems or poorly drained soils, sulphur toxicity may also manifest as acidic root zones, further impairing nutrient absorption and microbial activity. Monitoring soil sulphate levels and balancing sulphur inputs with crop demand are essential to avoid these adverse effects.

6. Sources of Sulphur fertilization

Sulphur fertilization in crops is achieved through a variety of sources, broadly categorized into sulphate-containing fertilizers, elemental sulphur products, and sulphur-enriched compounds. Common sulphate-based fertilizers include ammonium sulphate, single superphosphate (SSP), potassium sulphate, magnesium sulphate, and gypsum, which provide readily available sulphate ions for plant uptake. Elemental sulphur, though slower to act, is used for long-term soil amendment and is often applied in the form of sulphur bentonite or coated fertilizers. Additionally, ammonium phosphate sulphate and thiosulphate-based liquid fertilizers like ammonium thiosulphate and potassium thiosulphate are used in precision farming and fertigation systems. These sources (table 1) are included in India's Fertilizer Control Order (FCO), ensuring regulated use and quality standards for sulphur nutrition across diverse cropping systems (Anki Mibang et al., 2023).

Table 1: Major sources of Sulphur-containing fertilizers used in agriculture and horticulture

Fertilizer Type	Product Name	Sulphur Form	Additional Nutrients	Remarks
Sulphate-based	Ammonium Sulphate	Sulphate (SO_4^{2-})	Nitrogen (21%)	Quick-release; widely used in cereals
	Single Superphosphate (SSP)	Sulphate	Phosphorus (16%)	Dual nutrient; improves root growth
	Potassium Sulphate	Sulphate	Potassium (50%)	Ideal for chloride-sensitive crops
	Magnesium Sulphate	Sulphate	Magnesium (10%)	Corrects Mg and S deficiencies
	Gypsum ($CaSO_4 \cdot 2H_2O$)	Sulphate	Calcium	Soil conditioner; improves structure
Elemental Sulphur	Elemental Sulphur (90–99%)	Elemental	None	Slow-release; microbial oxidation required
	Sulphur Bentonite	Elemental + Binder	None	Granular; better handling and dispersion
Liquid Sulphur Fertilizers	Ammonium Thiosulphate (ATS)	Thiosulphate	Nitrogen	Used in fertigation and precision farming
	Potassium Thiosulphate (KTS)	Thiosulphate	Potassium	Suitable for high-value horticultural crops
Compound Fertilizers	Sulphur-enriched NPK blends	Mixed forms	NPK + S	Customized for crop-specific needs

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7. Commercial application of Sulphur in Agriculture and Horticulture

Sulphur plays a multifaceted role in commercial agriculture and horticulture, serving as both a vital nutrient and a protective agent. It is an essential macronutrient required for the synthesis of amino acids like cysteine and methionine, which are critical for protein formation and enzymatic functions in plants. In India, sulphur deficiency is widespread due to intensive cropping and the reduced use of sulphur-containing fertilizers, especially in sulphur-deficient soils of the Indo-Gangetic plains and southern regions. To address this, sulphur is commercially applied through fertilizers such as single superphosphate (SSP), ammonium sulphate, gypsum, elemental sulphur, and sulphur-bentonite, which improve crop yield, oil content, and nitrogen use efficiency (table 2).

Table 2: Crop-wise commercial application of Sulphur in agriculture and horticulture

Crop Category	Example Crops	Sulphur Role	Recommended Sources	Key Benefits
Oilseeds	Mustard, Groundnut, Soybean	Enhances oil synthesis and seed quality	Ammonium sulphate, Gypsum, Sulphur bentonite	Higher oil content, improved yield
Pulses	Chickpea, Pigeonpea, Greengram	Supports protein synthesis and nodulation	SSP, Elemental sulphur, Ammonium sulphate	Better nitrogen fixation, improved grain quality
Cereals	Wheat, Maize, Rice	Boosts chlorophyll and enzyme activity	SSP, Gypsum, Ammonium sulphate	Enhanced tillering, grain filling, and nitrogen use efficiency
Vegetables	Onion, Garlic, Cabbage, Tomato	Improves flavor, aroma, and disease resistance	Sulphur bentonite, ATS, SSP	Stronger taste, better shelf life, reduced pest incidence
Fruits	Grapes, Citrus, Banana	Enhances sugar accumulation and disease control	Wettable sulphur, KTS, Gypsum	Improved fruit quality, mildew control
Spices & Medicinals	Turmeric, Coriander, Fenugreek	Boosts essential oil and secondary metabolite synthesis	Elemental sulphur, SSP, Sulphur-coated urea	Higher curcumin/oil content, better aroma
Floriculture	Rose, Chrysanthemum, Marigold	Enhances color, fragrance, and disease resistance	Sulphur bentonite, ATS, Wettable sulphur	Brighter blooms, longer vase life
Plantation Crops	Tea, Coffee	Improves leaf quality and pest resistance	Ammonium sulphate, Elemental sulphur	Better leaf color, reduced mite infestation

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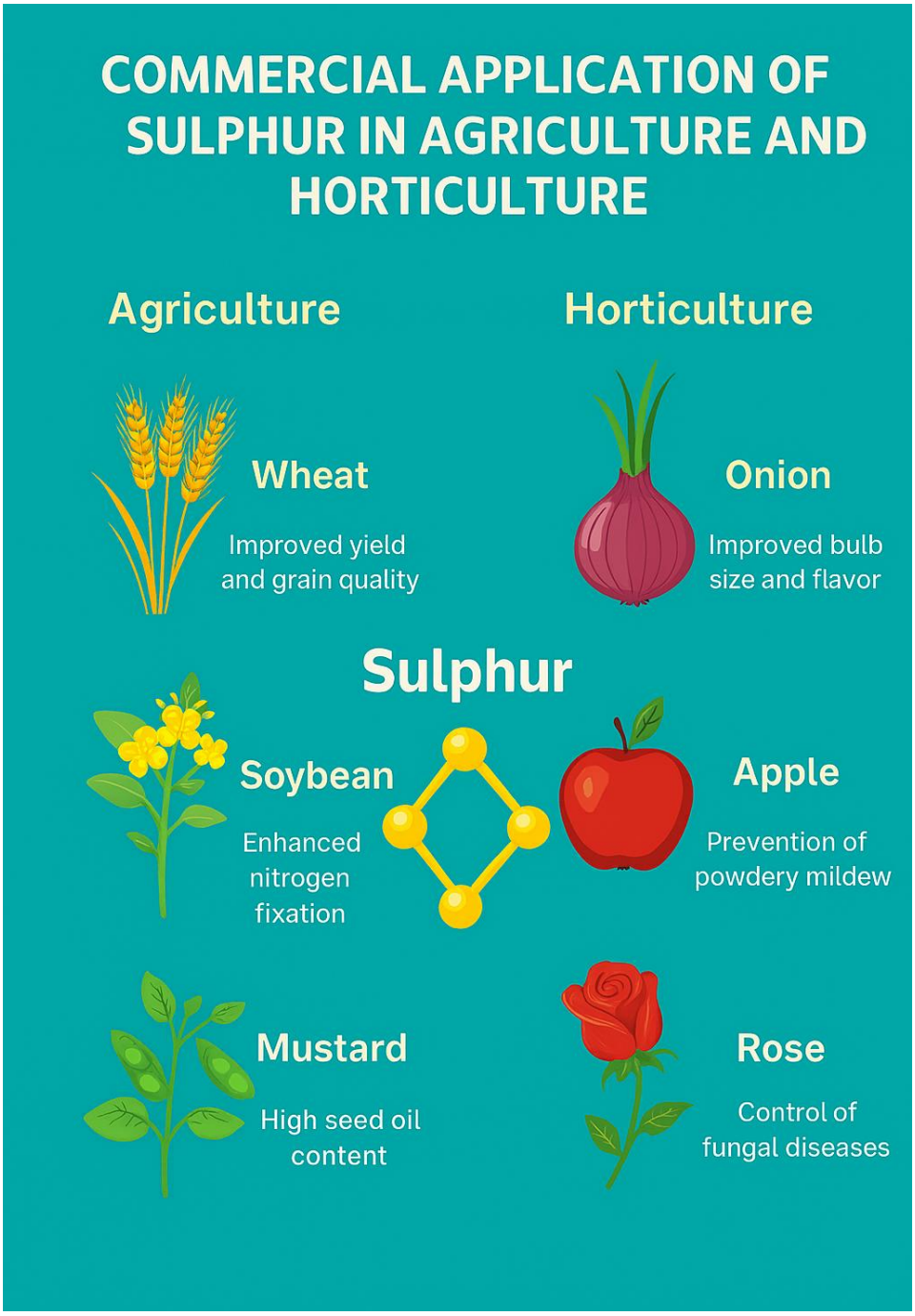

In horticulture, sulphur enhances the quality, flavor, and shelf life of fruits and vegetables. It is particularly beneficial in crops like onion, garlic, crucifers (e.g., cabbage, cauliflower), and grapes, where sulphur influences the synthesis of secondary metabolites such as glucosinolates and thiols that contribute to aroma and pest resistance. Sulphur also supports chlorophyll formation and photosynthetic efficiency, leading to better biomass accumulation and fruit development. Commercially, sulphur is used in fertigation systems and foliar sprays to correct deficiencies and boost crop performance under high-value cultivation practices like protected farming and organic horticulture.

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Beyond nutrition, sulphur has a significant role in plant protection. It is widely used as a fungicide and miticide in the form of wettable sulphur or dusting powders to control powdery mildew, rusts, and mites in crops such as grapes, apples, citrus, and roses. Its low toxicity to beneficial insects and compatibility with integrated pest management (IPM) systems make it a preferred choice in sustainable horticulture. The Fertilizer Control Order (FCO) in India includes sulphur specifications for various fertilizers, reflecting its strategic importance in nutrient management and crop protection. As demand for quality produce and sustainable inputs grows, sulphur's commercial relevance continues to expand across conventional and precision farming systems.

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