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The role of sulphur application on growth, yield and oil content of rapeseed-mustard

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Abstract

Rapeseed-mustard is an important oilseed crop in India because of its nutrient availability that has a considerable impact on its productivity. Sulphur (S) appears as a vital component for this crop's optimal growth, yield, and oil quality. Sulphur contains essential amino acid, protein, and enzyme that plays an important role in many physiological processes, including photosynthesis, protein synthesis, and oil accumulation. Shortage of sulphur can cause slower growth, lower chlorophyll content and seed yield. On another hand appropriate application of sulphur can significantly increase its growth, yield, oil content and its quality. In addition, sulphur interacts with other vital nutrients, altering their uptake and usage by the plant. Consequently improving sulphur application strategies taking into record soil sulphur levels and interactions with other nutrients, is vital for increasing rapeseed-mustard productivity and assuring India's oilseed output sustainability.

Keywords: Oil, productivity, rapeseed, sulphur, source

1. Introduction

India's agricultural sector has long been strongly reliant on oilseeds. Among the different oilseed crops cultivated in the nation, rapeseed-mustard occupies a substantial share of both total area and production. Rapeseed (*Brassica napus* L.) position second to sunflower as an important oilseed crop Sukirtee ^[1] because of its high oil content and prospective yield. It is primarily growing in the states of Rajasthan, Uttar Pradesh, Haryana, Madhya Pradesh, Gujarat, West Bengal, Assam, Bihar, and Punjab. The primary purpose of oilseed crops is to create edible oil. Mustard seeds have an oil content of 37–49% Bhowmik ^[2] with 27% oleic acid and 38–57% eruric acid Singh ^[3]. It is nutritionally rich because it contains seeds with 28-36% protein. Rapeseed crop is probably grown in the winter (Rabi) season, because it is more inclined to colder temperatures and adequate soil moisture levels during their growing season. It grows wells in well-drained sandy loam soil under rainfed (20.8%) and irrigated (79.2%) conditions. To increase and balance rapeseed-mustard productivity and production, it is crucial to productively manage natural resources, use integrated approaches to plant-water, nutrient, and pest management, and increase cultivation to new areas under different cropping systems. Sulphur, phosphorus, and nitrogen are vital nutrients for increasing productivity and quality of rapeseed.

Sulphur is increasingly recognize as the fourth major plant nutrient after nitrogen, phosphorus, and potassium Jamal ^[4] To achieve 90% of their potential output, rapeseed-mustard plants need a leaf sulphur content between 0.33% and 0.40%. Cheema and Arora ^[5]. Oilseed crops remove 10-25 kg of sulphur per hectare annually, while legumes remove 5-10 kg, depending on various factors Singh and Singh ^[6]. Sulphur deficiency is common found in Indian soils. In India, more than 41% of soils are sulphur deficient Singh ^[7]. Sulphur plays a critical role in oilseed development. Rapeseed has a higher sulphur demand than crops like cereals or legumes, making it more exposed to sulphur deficiency Zhao ^[8]. Sulphur deficiency is more common in sandy or light soils that have low organic matter. It is also more likely in areas with heavy rainfall, in crop

rotations that include pulses and oilseeds, where sulphur-free fertilizers are used, and in places far from industries that release sulphur gases into the air Prasad. Sulphur ^[9] deficiency significantly affects rapeseed growth and development. During the flowering stage, a lack of sulphur can alter petal colour and shape. It also disturbs amino acid balance, which negatively affects nitrogen uptake and assimilation. As a result, the plant's ability to produce protective compounds against environmental stress is reduced. Severe sulphur deficiency decreases photosynthetic activity Hawkesford and De Kok ^[10], leading to poor plant growth and yield losses of up to 40% in rapeseed and other oilseed crops. Soil sulphur levels below 10 ppm are generally considered deficient Venkatesh and Satyanarayana ^[11] Sulphur deficiency is commonly observed in coarse-textured soils with low organic matter content. Soil texture strongly influences sulphur availability by affecting water movement, nutrient retention, and microbial activity. Sandy and sandy loam soils have large pore spaces that promote sulfate (SO_4^{2-}) leaching with percolating water. These soils also possess low organic matter and low cation exchange capacity (CEC), reducing their ability to retain nutrients, including sulfate — the plant-available form of sulphur. Consequently, sandy soils are often sulphur-deficient unless supplemented with fertilizers or organic amendments.

Soil texture also influences biological processes related to sulphur transformation. Elemental sulphur (S^0) must be oxidized into sulfate before plants can absorb it. This oxidation process is carried out by sulphur-oxidizing microorganisms, whose activity depends on soil moisture, oxygen diffusion, and pore connectivity. In coarse soils, limited water films and isolated pore spaces can slow microbial oxidation of elemental sulphur, further reducing sulphur availability compared to finer-textured soils.

Organic matter serves as the primary reservoir of sulphur in soils, with 95–98% of total soil sulphur present in organic forms such as plant residues, microbial biomass, and humified compounds. However, this organic sulphur is not directly available to plants. It must be mineralized by soil microorganisms to release sulfate (SO_4^{2-}). Mineralization rates depend on soil organic matter content, microbial activity, moisture, temperature, and nutrient status. Higher organic matter levels enhance microbial biomass and enzymatic activity, increasing sulphur turnover. In contrast, soils low in organic matter often show limited sulphur mineralization, contributing to deficiency. Therefore, management practices such as residue retention, organic manure application, and reduced tillage can improve sulphur availability by enhancing soil organic matter and microbial activity.

Rainfall and irrigation also affect sulphur dynamics. Since sulfate is highly soluble, it moves with soil water and can be easily leached below the root zone when water movement exceeds plant uptake. In high rainfall or intensively irrigated regions, particularly in sandy soils, sulphur losses through leaching are more pronounced, reducing its availability to crops. Soil pH plays an important role in sulphur transformations. The oxidation of elemental sulphur into sulfate occurs most efficiently in neutral to slightly acidic soils (pH 6–7). Extremely acidic or alkaline conditions can suppress microbial activity and slow sulphur oxidation. Sulphur-oxidizing bacteria, such as *Thiobacillus* species, are more active under near-neutral pH conditions. In strongly acidic soils, slower oxidation rates can limit the conversion of elemental sulphur into plant-available sulfate.

At present, sulphur management in oilseed crops largely follows

generalized fertilizer recommendations rather than site-specific soil testing. Precision nutrient management systems mainly emphasize nitrogen (N), phosphorus (P), and potassium (K), while sulphur is often neglected. Field-based understanding of sulphur mineralization, elemental sulphur oxidation, and their interaction with soil properties and climate factors remains limited. Additionally, the impact of climate stress on sulphur availability, uptake, and oil quality in oilseed crops is not well quantified. Bridging this gap requires integrated, data-driven, and farmer-friendly management strategies to improve sulphur use efficiency and enhance resilience in oilseed production systems.

2. Importance of Sulphur in Rapeseed –Mustard

Adequate sulphur (S) is essential for oilseed crops to achieve their full growth and productivity potential Ryan ¹². After nitrogen, phosphorus, and potassium, sulphur is considered the fourth major nutrient required for plant growth. Among oilseed crops, rapeseed–mustard has particularly high sulphur requirements.

Sulphur plays a fundamental role in plant growth and development, contributing significantly to both yield and quality. It is involved in several important physiological processes, including the synthesis of sulphur-containing amino acids such as cysteine and methionine, chlorophyll formation, and oil production. By supporting chlorophyll synthesis, sulphur enhances vegetative growth and photosynthetic activity.

In oilseed crops, sulphur also participates in redox reactions during respiration and in the formation of glucosides and glucosinolates, which are responsible for the characteristic pungency of mustard oil. Research shows that sulphur fertilization can substantially increase mustard yields. Under rainfed conditions, yield improvements of 17% to 124% have been reported, while under irrigated conditions, increases of 12% to 48% have been observed Bhattacharje ^[13] Jat ^[14] also reported a positive relationship between sulphur application rates and straw yield in Indian mustard.

Optimal sulphur nutrition is critical for maximizing oil content and overall yield. It is essential for protein and amino acid synthesis, enzyme activation, oil formation, and the production of vitamin A components. Since sulphur is a structural component of several amino acids and proteins, protein metabolism is highly sensitive to sulphur deficiency.

The widespread occurrence of sulphur deficiency in agricultural soils is mainly due to the increased use of high-analysis sulphur-free fertilizers, intensive cropping systems that remove large amounts of sulphur from the soil, and inadequate replenishment through fertilization. Additionally, reduced atmospheric sulphur emissions over the past two decades have decreased natural sulphur deposition, further increasing the need for sulphur fertilization.

Sulphur deficiency symptoms typically appear as pale green to yellowing leaves, reduced stem growth, and smaller, narrower leaves, ultimately leading to lower productivity.

Smaller levels of sulphur introduced into soil from the air do not meet the nutritional needs of plants, especially those with high sulphur requirements, such as rapeseed. Mineral fertilizers must now be used to supplement soil sulphur deficiencies. Sulphur's most important functions in plants are due to its presence in protein amino acids (cystine, cysteine, and methionine), which play an important role in the formation of proteins as well as precursors of other important compounds such as glutathione, thiamine (vitamin B1), biotin (vitamin H), coenzyme A, lipoic acid, thioredoxin, and sulpholipids. They participate in redox

reactions within cells, catalyze various enzymatic processes, are responsible for glucose metabolism and photosynthesis, and are required for the synthesis of fatty acids, chlorophyll, and lignin. Amino acids account for 90% of total sulphur in plants. Sulphur's yield-forming effect in plants is mostly due to its participation in nitrogen metabolism, which is reflected not only in good effects on yield and seed quality, but also in lowering the risk of nitrate leaching. Sulphur is a crucial component of glucosinolates and the majority of proteins, as well as a contributor to fat production, therefore the quantity of sulphur available to plants has a considerable impact on the amount of these nutritionally important compounds. Several studies point to the interactive influence of sulphur and nitrogen in the creation of yield and content of protein, fat, and glucosinolates in the seed, as well as the profile of fatty acids in oil. Glucosinolates, like many other sulphur-containing organic molecules such as hydrogen sulphide, glutathione, sulfolipids, and phytoalexins, serve a vital function in plants, boosting their resistance to environmental stress and providing protection against pests and diseases. The purpose of this study was to highlight the role of sulphur in the development of seeds and oil from winter oilseed rape.

3. Effect of Sulphur on Crop Yield, Growth Quality and Economic Attributes

The economic worth of oilseeds is defined by their production and quality, which are influenced by the grower's capacity to exploit the plant's genetic makeup as well as less tractable aspects of the environment in which they grow. The oil with minimal erucic acid is nutritionally superior for human intake. Low-glucosinolate meals are appropriate as cattle feed. Sulphur is a component of oil compounds, and its application enhances oil content in most oilseeds crops. Sulphur fertilization increased oil content by an average of 5% Naiknaware ^[15]. The effect of sulphur administration on cell division, enlargement, and elongation results in an overall improvement in plant organs linked with faster and more uniform vegetative growth of the crop Noman ^[16]. Several studies have demonstrated the positive effects of sulphur application on mustard crop. Chhonkar and Shrotri ^[17] observed that increasing the levels of sulphur influences the growth of oilseed. In Phagwara, Punjab, Mathpal (2023) ^[18] reported significant improvements in growth, yield, and yield components with a sulphur application of 60 kg ha⁻¹, compared to lower rates (15 and 30 kg ha⁻¹) and control. Similarly, Dogra ^[19] found that applying up to 60 kg ha⁻¹ of sulphur in Rajasthan, significantly increased yield-related characteristics which ultimately increased its economics. In Bhagalpur, Bihar Kumar ^[20] Studied the impact of different sulphur application rates and sources on mustard yield. They determined that bentonite was the most effective sulphur source, with an optimal application rate of approximately 49.6 kg ha⁻¹. Iron pyrite (53.4 kg ha⁻¹) and gypsum (57.1 kg ha⁻¹) also proved beneficial, though slightly higher application rates were required.

The All India Coordinated Research Project on Rapeseed Mustard ^[21] AICRP-RM recommends applying 40 kg ha⁻¹ of sulphur to improve mustard seed yield and profitability in various cropping systems. For canola and similar crops, especially in sulphur-deficient soils, the recommended rate is 15-30 kg ha⁻¹ of sulphate-S. Studies by Piri and Sharma ^[22] showed that increasing sulphur application significantly boosts seed and straw yields, with the most significant impact observed at 45 kg S ha⁻¹.

Applying sulphate-S during sowing is generally more effective

than applying it during early flowering stages. While applications at early flowering can partially alleviate the negative effects of sulphur deficiency, applying it during the bolting stage can significantly improve seed production Malhi ^[23]. According to Nibedita ^[24] the foliar application of nitrosulf (33% sulphur liquid formulation) at concentrations of 0.15% and 0.2% significantly increased seed and oil yields in rapeseed.

4. Different Sources of Sulphur Used for Oilseed Crops

Sulphur is supplied to oilseed crops through various sources. The most regularly used sulphur-containing fertilizers in India are ammonium sulphate (24% S), single superphosphate (12% S), gypsum (13% S), pyrite (22-30% S), and elemental sulphur (85-100% S). Other less widely used sources of sulphur include phosphogypsum (16% S), magnesium sulphate (13% S), press mud (2-3% S), and sulphur sludge (10-16% S). Pyrites and elemental sulphur should be sprayed 20-25 days before planting because elemental sulphur requires oxidation, and pyrites are a slow-release fertilizer Tivari ^[25]. Gypsum and phosphogypsum are excellent for all types of soils and calcium-requiring crops, such as groundnut Rao ^[26]. Single superphosphate is the best source of fertilizer for oilseeds as it supplies both P and S. Ammonium sulphate is indicated for nitrogen and sulphur-deficient soils. Broadcast-incorporation of fertilizer in moist areas often results in similar seed yields to side-banding Malhi ^[27].

5. Impact of climate vulnerability on Mustard Crop

Climate stressors have a significant impact on mustard species like *Brassica juncea* and *Brassica napus*, especially during germination, seed development, and flowering. Thermal, hydric, and atmospheric stresses brought on by climate change have a significant impact on plant health, production, and oil quality. In *Brassica juncea*, high temperatures during blooming decrease pollen viability and fertilization rates, resulting in a 20% to 30% decrease in yield Meena ^[28]. Elevated temperatures can affect seed oil accumulation and enzymatic activity, generating oxidative stress and poor seed quality Sakpal ^[29]. Depending on timing and severity, yield losses from drought stress might range from 17% to 94% Srivastava ^[30]. Additionally, it reduces the oil's nutritional value by changing its fatty acid profile Hatzig ^[31]. Elevated ozone (eO₃) levels negatively affect photosynthesis in Indian mustard, resulting in a marked drop in stomatal conductance and chlorophyll levels, which ultimately lead to poorer yields. Key antioxidant enzymes like superoxide dismutase (SOD), catalase (CAT), peroxidase (POX), and ascorbate peroxidase (APX) are activated by plants in response to this oxidative stress in order to counteract its effects. Elevated carbon dioxide (eCO₂) directly stimulates vigorous plant development by promoting photosynthesis and boosting chlorophyll content, which enhances the leaf area index and improves water usage efficiency. Additionally, by encouraging stomatal closure, increased CO₂ levels successfully lower ozone absorption. There is certainly evidence that eCO₂ reduces some of the negative consequences of eO₃ Jawahar ^[32]. Additionally, exposure to ozone (O₃) can increase oxidative stress in plants, which may reduce their ability to defend themselves. This makes them more susceptible to diseases, such as wilt and leaf spots. Elevated CO₂ enhances the photosynthetic rate, resulting in increased biomass accumulation in mustard crops Sabagh ^[33].

The progression of powdery mildew in *Brassica juncea*, concluding that the ideal conditions for outbreaks occur at temperatures between 25 °C and 30 °C, with nighttime lows above 10 °C and relative humidity below 50%. For instance,

Alternaria blight alone can cause a yield loss of 10-80% under conducive climatic conditions Banerjee ^[34].

6. Conclusion

Sulphur is an important nutrient for rapeseed-mustard, influencing productivity, oil content, and quality. Sulphur is crucial for plant growth, especially for making proteins, chlorophyll (for photosynthesis), and oils. To get the best crop yields and high-quality oil, farmers need to test their soil and use the right amount of sulphur fertilizer. Furthermore, understanding how sulphur interacts with other nutrients is critical for developing sustainable and effective crop management strategies in rapeseed-mustard production systems.

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