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Effect of sulphur on growth yield and quality attribution of Indian mustard

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Abstract
Indian Mustard (*Brassica juncea*), a plant that depends on the nutrient sulphur for development, is highly productive and has high quality. This study examines the many effects of sulphur on Indian Mustard, including how it affects growth, yield, and general quality characteristics. Increased biomass buildup from sulphur supplementation results in higher crop yields. Additionally, sulphur helps increase stress tolerance, allowing Indian Mustard to flourish in challenging circumstances. Enhancing nutrition intake and utilisation is made possible by optimising the efficiency of nutrient use. The quality of Indian Mustard output is also impacted by sulphur, with variables including oil content, nutritional composition, and insect resistance being impacted. For crop production to be efficient and of good quality, Sulphur's significance in Indian Mustard farming must be fully understood.

Keywords: Sulphur, Indian mustard, growth, yield, quality, nutrient uptake

Introduction
Indian Mustard (*Brassica juncea*) holds a significant position in global agriculture due to its adaptability as an oilseed crop and its high nutritional value. Understanding the variables that influence its growth, yield, and quality is essential for unlocking its full potential. Sulphur (S), an essential nutrient crucial for plant growth, plays a pivotal role in this regard. Sulphur has various effects on Indian Mustard, including promoting growth, increasing yields, and enhancing quality. This introduction provides a general overview of research into the 'Effect of Sulphur on Growth, Yield, and Quality Attributes of Indian Mustard,' shedding light on how the addition of sulphur to the diet can potentially have a significant positive impact on this important crop.

The purpose of this study is to explore the specific effects of sulphur supplementation on various aspects of Indian mustard cultivation, including its growth parameters, yield quantity, and quality attributes such as nutritional content and oil composition. Sulphur is known to play a crucial role in plant metabolism, particularly in the synthesis of essential compounds such as amino acids, proteins, and vitamins. However, its influence on Indian mustard, a significant oilseed crop with nutritional and economic importance, requires further investigation. By systematically analyzing the responses of Indian mustard to different sulphur levels, this study aims to provide insights into the optimal sulphur application rates for maximizing crop growth, improving yield quantity, and enhancing the nutritional quality of Indian mustard produce. The findings from this research could have practical implications for agronomic practices, helping farmers to adopt more effective fertilization strategies and ultimately contribute to sustainable agriculture and food security.

Indian Mustard: An Agricultural Staple
Brown mustard, also known as Indian Mustard (*Brassica juncea*), or "rai" in Hindi, is a commercially significant oilseed crop that is widely grown around the world, including India. This adaptable plant is a member of the Brassicaceae family, which also includes crucial crops like canola, cabbage, and broccoli.

Both the green leafy crops and the oil-rich seeds of Indian Mustard are prized. Indian Mustard is a rich source of edible oil due to its high oil content, making it a staple crop for many Indian farmers. In areas where edible oil is a dietary staple, it is very important. [9]. Indian Mustard is grown across the country, although the main producing states are the northern states of Rajasthan, Uttar Pradesh, and Madhya Pradesh. It is also grown in other nations, including as China and Canada [10]. Indian mustard comes in a variety of forms, such as those developed for oil production and those planted for their edible leaves, sometimes referred to as mustard greens. Varuna, Rohini, and Girnar are popular oilseed varieties, while Pusa Bold and Pusa Basanti are green types. [11].

Role of Sulphur in Indian Mustard

Sulphur is essential for the activation of numerous enzymes involved in plant metabolic pathways, including photosynthesis and respiration, as it is a constituent of several coenzymes. [2]. Cysteine and methionine, which are essential amino acids forming the fundamental components of plant proteins, rely on sulphur for their proper function. These proteins are integral to numerous cellular processes, including enzyme activity, structural support, and defense mechanisms [1]. Sulphur is necessary for the synthesis of chlorophyll, the green pigment crucial for photosynthesis. Adequate sulphur levels promote photosynthetic efficiency and overall plant growth [3]. Sulphur-containing compounds like glucosinolates aid plants in defending themselves against herbivores and diseases, acting as deterrents or toxic substances. [4]. Sulphur influences the uptake and transportation of essential nutrients such as nitrogen and phosphorus within plants, facilitating their overall nutrient absorption [5]. Sulphur enhances a plant's resilience to environmental stresses like dehydration and heavy metal toxicity, contributing to its overall stress tolerance [6]. Sulphur plays a role in the production of secondary metabolites, including sulfur-containing compounds like glucosinolates and alliin, which contribute to the flavor and fragrance of plants. [7]. Sulphur is involved in plant-microbe interactions, particularly in symbiotic associations with mycorrhizal fungi, which aid in nutrient absorption by plants. [8]. Indian and international growers of Indian mustard (*Brassica juncea)* depend heavily on sulphur. Sulphur is essential to the development, productivity, and oil quality of Indian mustard, a key oilseed crop. Cysteine and methionine, two amino acids that are required for the production of proteins in plants, include sulphur as a component. A sulphur deficit can result in stunted development and decreased crop output since proteins are the building blocks of plant tissues and enzymes [1]. Indian mustard is influenced by sulphur in ways other than protein production. It is essential for the production of glucosinolates, which are sulfur-containing substances that protect plants from diseases and herbivorous predators. These substances also help give Indian mustard seeds their distinctive flavour and pungency. The capacity of the plant to manufacture these substances is improved by adequate sulphur levels in the soil, which increases the crop's market value and insect resistance [4].

In the growth of Indian mustard, sulphur also aids in nutrient control. It affects how other crucial nutrients, including nitrogen and phosphorus, are absorbed and used. Therefore, a lack of sulphur can negatively affect a plant's capacity to grow in a variety of soil conditions and its overall nutritional status [5]. Furthermore, sulphur helps Indian mustard withstand environmental stresses including drought and heavy metal toxicity. A sufficient sulphur supply can increase the crop's adaptation and resilience in areas with a variety of environmental problems, thereby protecting farmers' livelihoods [6].

Nutritional Value

Indian mustard seeds are a great source of protein and oil (around 30-35%). Additionally nutritious, mustard greens are useful for their high levels of vitamins, minerals, and antioxidants [12].

Oil Extraction

Indian Mustard seed oil is obtained by pressing or solvent extraction techniques. Known for its unique flavour, mustard oil is utilised in a variety of culinary practises, particularly in Indian and South Asian cuisines [13].

Traditional and Medicinal Uses

Ayurveda and traditional Chinese medicine have historically used Indian Mustard as a traditional medicine in addition to its culinary purposes. It is said to provide a number of health advantages [14].

Challenges and Research

Growing Indian Mustard is difficult because of pests, illnesses, and shifting weather patterns. Ongoing research is being done to create high-yielding, hardy cultivars [15].

In India and other countries, Indian Mustard, or *Brassica juncea*, has a considerable agricultural and cultural significance. It contributes to food security and livelihoods by acting as a crucial source of nourishing greens and edible oil. Its distinct flavour and possible health advantages have also made it a versatile crop with a variety of uses.

Importance of Indian Mustard in Agriculture

For a number of reasons, Indian Mustard (*Brassica juncea*) is crucial to agriculture. It supports sustainable agricultural methods, oil production, and food security. We go through the main points of Indian Mustard's value to agriculture here:

Edible Oil Production

A significant oilseed crop and important source of edible oil is Indian Mustard. India and other nations use a lot of mustard oil during cooking. It is a popular option for many customers due to its unique flavour and health advantages [16].

Nutrient-Rich Oilcake

The leftover oilcake, a byproduct of processing Indian Mustard, is rich in minerals and protein after the oil has been extracted. It contributes to the production and nutrition of animals by serving as a useful source of feed [17].

Crop Rotation and Disease Suppression

Indian Mustard is frequently employed in crop rotation systems because of its ability to control pests and illnesses that are soil-borne. This procedure promotes soil health and lessens the requirement for chemical pesticides [18].

Green Manure and Soil Improvement

Indian Mustard is a good candidate for green manuring due to its quick growth and extensive root system. By incorporating it into the soil, it enriches it with minerals and organic matter, enhancing the soil's fertility and structure [19].

Adaptability to Diverse Climates
The capacity of Indian Mustard to adapt to varied agro-climatic situations is well documented. It is an adaptable crop for farmers in many regions since it can be cultivated in both rainfed and irrigated locations. [20].

Biodiesel Production
Indian Mustard seeds may be used to extract oil that can be used to make biodiesel, reducing dependency on fossil fuels and advancing the field of renewable energy [21].

Sustainable Agriculture Practices
Indian Mustard fits well into sustainable farming practices due to its ability to enhance soil health, reduce chemical inputs, and improve crop yields in subsequent rotations [22].

Table 1: Indian mustard in agriculture along with their effects

Property	Description	Effect
Oil Production	Indian mustard is cultivated primarily for its oil-rich seeds, which are used for cooking and as condiments.	Provides a valuable source of edible oil for culinary purposes.
High Yield Potential	Indian mustard exhibits relatively high yield potential compared to other oilseed crops, ensuring economic viability.	Increases agricultural productivity and income for farmers.
Adaptability	Indian mustard is adaptable to diverse agro-climatic conditions and various soil types, including semi-arid regions.	Enables cultivation in a wide range of environments, enhancing resilience to climate variability.
Fast Growth	Indian mustard has a fast growth rate, enabling quick crop establishment and shorter growing seasons.	Facilitates efficient land use and allows for multiple cropping cycles.
Nutritional Value	Indian mustard seeds are rich in essential fatty acids, proteins, vitamins (such as vitamin E), and minerals (such as calcium and iron).	Enhances human and animal nutrition, contributing to overall health and well-being.
Dual-purpose Crop	Indian mustard serves as both an oilseed crop and as a source of nutritious fodder for livestock.	Provides versatility in agricultural systems, offering additional income streams and livestock feed options.

Sulphur's Impact on Crop Yield and Quality
Sulphur (S) is an essential nutrient for crop growth, and its availability can significantly impact crop yield:

Protein Synthesis
Sulphur is an important part of amino acids, especially cysteine and methionine, which are necessary for the production of proteins in plants. Proteins have a role in a number of physiological activities, including as photosynthesis, food intake, and enzyme activity. Strong protein synthesis is encouraged by adequate sulphate availability, which supports overall plant growth and development [23].

Chlorophyll Formation
The creation of chlorophyll, the green pigment essential for photosynthesis, requires sulphur. In order for agricultural plants to create energy and carbohydrates, photosynthesis must be effective. Sulphur levels that are adequate boost chlorophyll synthesis, increasing photosynthetic activity and raising crop yields [24].

Nutrient Uptake and Utilization
Sulphur interacts with other crucial nutrients including phosphorus (P) and nitrogen (N). It affects how these nutrients are absorbed and used, which affects how readily available they are to plants. Sulphur levels that are balanced increase the effectiveness of using N and P, resulting in greater nutrient absorption and crop output [25].

Stress Tolerance
Sulphur helps increase a crop's resistance to numerous stresses, such as salt, drought, and heavy metal toxicity. Antioxidants like glutathione, which contain sulphur, shield plant cells from oxidative damage brought on by stressors. This tolerance to stress supports stable agricultural yields [26].

Nutrient Quality
Sulphur also affects how well crops are grown. It helps in the formation of secondary metabolites such phytochemicals that contain sulphur. These substances can improve the nutritional content, flavour, and scent of crops, making them more enticing to consumers [27].

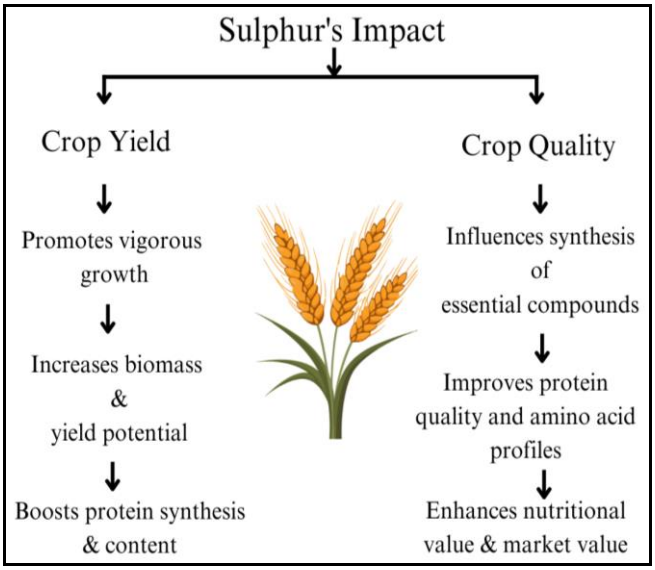

Fig 1: Sulphur's Impact on Crop Yield and Quality

Methods for Sulphur Application
Soil Application: Indian mustard plants are frequently given sulphur by soil spraying. The most common sulphur sources used in soil applications are elemental sulphur, gypsum (calcium sulphate), and ammonium sulphate. Elemental sulphur is a slow-release source because it needs to be converted to sulphate form by microbes before plants can absorb it [28]. In contrast, gypsum offers instant sulphate availability and can help enhance soil structure [29]. The crop's need for sulphur and the state of the soil influence the choice of sulphur source.

Foliar Application: Spraying a sulphur-containing solution directly onto Indian Mustard leaves is known as foliar application of sulphur. When sulphur supplementation is urgently needed during the growth season, this approach is helpful. Sulfur-containing substances, such as magnesium sulphate (Epsom salt), are frequently used topically [30]. Foliar

spraying promotes rapid sulphur deficiency eradication and enables effective nutrient uptake via the leaves.

Fertigation: A precise application technique called fertilisation combines irrigation and fertilisation. You can inject soluble sulphur fertilisers like ammonium sulphate into the irrigation system. This strategy guarantees precise fertiliser supply to the root zone and maximises the absorption of sulphur by Indian Mustard plants. In areas with managed irrigation systems, fertilisation can be very advantageous [31].

Best Practices for Sulphur Application in Indian Mustard

- **Soil Testing:** It is crucial to do soil testing to ascertain the pH and current sulphur levels before adding sulphur. Using this information, the proper sulphur source and application rate may be chosen [32].
- **Timing:** On the basis of the crop's development stage and sulphur need, sulphur applications should be timed. Split applications—applying sulphur both at planting and during the vegetative development stages—can be advantageous [33].
- **Sulphur Source Selection:** Select a sulphur source based on the demands of the crop and the soil. Alkaline soils may remedy sulphur deficiency using gypsum, whereas acidic soils can do so with ammonium sulphate [34].
- **Application Rate:** Determine the correct sulphur treatment rate based on the crop's needs, taking into account variables like yield targets and soil test findings [35].
- **Incorporation:** When employing elemental sulphur, make sure the soil is properly incorporated since microbial activity is necessary for the conversion of the element to its sulphate form. This can entail incorporating machinery or plough [36].
- **Monitoring:** Keep a close eye on crop development and sulphur levels and change spraying procedures as necessary. The yellowing of foliage, one of the visual signs of sulphur insufficiency, should be treated right once. [37].

Results from Sulphur-Enhanced Growth

Indian Mustard (*Brassica juncea*) growth and production have consistently benefited from sulphur (S), according to research studies and field observations. Indian Mustard requires sulphur as a nutrient, and studies have shown that applying it can improve a number of elements of plant growth [38]. Here are some important findings on the development of Indian Mustard with sulphur supplementation:

Increased Biomass and Yield: In Indian Mustard, sulphur treatment has been linked to greater crop yields and increased biomass output. The adequate protein synthesis necessary for plant growth and reproduction is ensured by sufficient sulphate availability. Indian Mustard plants grow larger and more productively as a consequence, increasing production [39].

Enhanced Photosynthesis: The production of chlorophyll, the pigment responsible for photosynthesis, depends heavily on sulphur. According to studies, adding sulphur to food increases the amount of chlorophyll and the effectiveness of the plant's photosynthetic process. This results in improved carbon absorption, which eventually helps to increase agricultural yields [40].

Resistance to Stressors: Supplemental sulphur has been found to improve Indian Mustard's resistance to environmental stresses. Glutathione is an example of a sulfur-containing molecule that functions as an antioxidant to shield plant cells from oxidative damage brought on by environmental stresses such salt, dehydration, and heavy metal toxicity. This ability to withstand stress promotes greater plant health and development [41].

Improved Nutrient Uptake: Sulphur influences the absorption and utilisation of other crucial nutrients by Indian Mustard plants, including nitrogen (N) and phosphorus (P). Sulphur guarantees effective nutrition absorption and utilisation, improving nutrient status and promoting general development [42].

Quality Enhancement: Application of sulphur can also improve the yield and quality of Indian Mustard crops. It encourages the production of sulfate-containing secondary metabolites, which influence the flavour and scent of the seeds as well as the plant's defence systems. This may result in mustard seeds of higher grade [43].

Enhancing Crop Yield with Sulphur

It is commonly known that sulphur (S), an important ingredient for crop development, increases crop output. Here, we examine the understandings and mechanisms underlying the elevated agricultural production attributable to sulphur supplementation.:

Protein Synthesis and Nutrient Uptake

Sulphur is an important part of amino acids, especially cysteine and methionine, which are necessary for the production of proteins in plants. Crops with more protein have greater protein contents, which are directly related to improved growth and production [43].

Chlorophyll Formation and Photosynthesis:

Chlorophyll, the pigment responsible for photosynthesis, needs sulphur to be formed. Sulphur levels that are enough promote better chlorophyll synthesis, which increases photosynthetic activity. Because of the enhanced photosynthesis, more carbohydrates are produced, which raises crop yields [44].

Nutrient Interaction and Uptake:

Sulphur interacts with other crucial nutrients including phosphorus (P) and nitrogen (N). It affects how well plants absorb and use these nutrients. By increasing the effectiveness of N and P absorption, sulphur supplementation can maximise the availability of nutrients for crop growth and development [45].

Secondary Metabolite Production:

Supplemental sulphur encourages the production of secondary metabolites in plants, such as phytochemicals that contain sulphur. These substances may act as defences against pathogens and pests, preserving crop output [46].

Table 2: Factors Influencing Yield Improvement

Factors Influencing Yield Improvement	Description
Genetic Factors	Choice of high-yielding crop varieties and improved genetics. [47]
Soil Fertility	Adequate levels of essential nutrients and soil pH balance. [48]
Nutrient Management	Proper application of fertilizers and micronutrients. [49]
Pest and Disease Control	Effective pest and disease management practices. [50]
Water Management	Efficient irrigation and water conservation techniques. [51]
Climate and Weather Conditions	Favorable weather patterns and climate conditions. [51]
Crop Rotation	Diversifying crops to break pest and disease cycles. [50]
Weed Management	Effective weed control strategies.
Technology and Innovation	Adoption of modern farming techniques and technology. [51]

Future Prospects in Sulphur-Aided Agriculture

As farmers and academics increasingly acknowledge sulphur's critical contribution to boosting crop output, the future of sulphur-aided agriculture offers bright potential. Sulfur's importance is anticipated to increase with rising worldwide needs for food security and environmentally friendly farming techniques. Sulphur supports contemporary agriculture's objectives by helping to improve crop quality, increase stress tolerance, and optimise nutrient uptake. Sulfur's function in enhancing stress resistance is crucial as climate change continues to affect agricultural harvests. Furthermore, growing knowledge of how sulphate affects nutritional content and biofortification of crops might enhance human nutrition, contributing to the larger effort to combat hunger and dietary inadequacies.

The Potential for Wider Adoption

The potential for sulphur-aided agriculture to be more widely used is significant. Farmers are likely to use sulphur in their nutrient management methods as more research demonstrates the advantages of sulphur supplementation. The focused use of sulphur can be facilitated further by precision agricultural techniques, which enable customised nutrient treatments. Government programmes and agricultural extension services may also be quite effective in encouraging farmers to use sulphur by teaching them about its benefits and giving them access to sulphur-containing fertilisers and technology.

Research and Development for Enhanced Results

Maximising the advantages of sulphur in agriculture requires ongoing research and development activities. Studies on sulphur application rates, timing, and strategies adapted to particular crops and agroecological circumstances are included in this. Slow-release fertilisers are one example of an innovation in sulfate-containing fertilisers that can increase nutrient availability while reducing negative environmental effects. Higher yields can also result from genetic research that creates crop types with improved sulphur usage efficiency. To improve sulphur-aided agricultural practises and achieve sustainable, high-yield crop production, agricultural researchers, agronomists, and farmers must work together.

Conclusion and Key Takeaways

The use of sulphur in agriculture has many advantages. By enhancing nutrient absorption and utilisation, it boosts crop yields and raises agricultural productivity. In order to maintain steady harvests, sulphur also helps crops tolerate environmental stresses like salt and drought. It also raises the standard of agricultural products, enhancing their appeal to customers. Malnutrition may be addressed by sulphur's effect on nutritional content in crops, and prudent sulphur management encourages environmentally friendly and sustainable farming methods. Sulfur's potential in contemporary agriculture is still being unlocked by study and innovation, leading to improvements in fertilisers, genetics, and agricultural methods. A crucial component in increasing crop output, quality, and sustainability in agriculture is the use of sulphur.

In conclusion, Numerous advantages of using sulphur in agriculture include increased productivity and sustainability of agricultural production. As a crucial nutrient, sulphur is essential for improving plant development, stress resistance, and nutrient uptake.

Overall, sulphur is a key component of contemporary farming methods, promoting food security, higher crop quality, and ecologically friendly farming. In order to reap the maximum benefits of sulphur for agriculture and society at large, it is important to promote the use of sustainable sulphur application techniques and to support research initiatives. A route to a more prosperous and resilient agricultural future is sulphur-aided agriculture.

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Conflict of Interest

No authors declared Conflict of Interest.

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