



International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
© Agronomy
NAAS Rating (2026): 5.20
www.agronomyjournals.com
2026; 9(5): 741-746
Received: 02-03-2026
Accepted: 09-04-2026

KM Sapana
School of Agriculture, Uttarakhand
University, Dehradun,
Uttarakhand, India

Diksha Nautiyal
School of Agriculture, Uttarakhand
University, Dehradun,
Uttarakhand, India

Sharad Pandey
School of Agriculture, Uttarakhand
University, Dehradun,
Uttarakhand, India

Corresponding Author:
KM Sapana
School of Agriculture, Uttarakhand
University, Dehradun,
Uttarakhand, India

Impact of different doses of sulphur on oil content, growth and yield of Sunflower (*Helianthus annuus* L.): A review

KM Sapana, Diksha Nautiyal and Sharad Pandey

DOI: <https://www.doi.org/10.33545/2618060X.2026.v9.i5j.5612>

Abstract

Sunflower (*Helianthus annuus* L.) is among the most significant oil seed crops worldwide, being of great economic value because of its edible oil that is rich in polyunsaturated fatty acids, vitamin E, and natural antioxidants. Sulphur has become the fourth major plant nutrient in addition to nitrogen, phosphorus and potassium as the nutrient is essential in improving crop productivity and quality of oil. The scientific literature reviewed and critically evaluated to determine the effect of different levels of sulphur on sunflower growth, yield and oil content was published between 2000 and 2025. In accordance with the principles of systematic reviews, which are in line with PRISMA guidelines, relevant studies were identified in reputed databases (Scopus, Web of Science, Google Scholar, ScienceDirect, and ICAR publications) and included in the systematic review. The results suggest that sulphur increases physiological and biochemical functions including chlorophyll formation, protein synthesis, enzyme activation and fatty acid metabolism, which increase plant growth, seed yield, and percentage of oil. The majority of researches indicate the best responses with a level of the application of sulphur between 20-40 kg ha⁻¹ basing on the fertility and agro-climatic conditions. The fertilizers containing Sulphur guarantee immediate availability of nutrients to the soil whereas the elemental Sulphur guarantees the long-term fertility of the soil as a result of gradual oxidation. Combined nutrient management which comprises the use of sulphur with macronutrients and micronutrients also improves the efficiency of nutrient utilization and crop performance. Although significant progress has been achieved, issues like the prevalence of sulphur deficiency, absence of region-specific recommendations, and scarcity of long-term researches still exist. Sustainable nutrient management has potential in emerging technologies such as nano-fertilizers, sulphur-oxidizing biofertilizers, precision agriculture, and artificial intelligence. This review offers holistic information to researchers, agronomists, policymakers and farmers to formulate effective approaches to managing sulphur that would enhance the productivity of sunflower, oil quality and environmental sustainability to promote food and nutritional security in the world.

Keywords: Oil content, growth and yield, sulphur accumulation, sunflower

1. Introduction

Sunflower (*Helianthus annuus* L.) is a leading oilseed crop in the globe, which has high-quality edible oil, abundant in polyunsaturated fatty acids, especially the linoleic acid, vitamin E and natural antioxidants. It is a member of the family Asteraceae and is commonly grown because of its flexibility to various agro-climatic conditions, brief period, and its ability to fit in a variety of cropping systems. Sunflower is a major producer of vegetable oil in the world as it is one of the top oil seed crops alongside soybean, rapeseed, and groundnut. In India, it is important because it helps fill the gap in the demand and supply of edible oils in the country, enhancing agricultural sustainability and economic growth. Proper nutrition of plants is needed to increase productivity and the quality of oil in sunflower. Sulphur has become the fourth major plant nutrient, after nitrogen, phosphorus and potassium. It is vital in physiological and biochemical activities like the development of chlorophyll, synthesis of proteins, activation of enzymes, and the production of oils. Sulphur is an essential element in sulphur-containing amino acids such as cysteine and methionine, which are crucial to plant growth and development. It is especially important in the case of the oil seed crops, where it increases the yield of the seed, the amount of oil content, and the general quality of the seed. Sulphur deficiency in agricultural soils has become a common

occurrence in the last few decades because of increased use of high analysis sulphur-free fertilizers, less use of organic manures, and decreased atmospheric deposits of sulphur. This has become one of the greatest drawbacks restricting the productivity and profitability of oilseeds crops such as sunflower. This has necessitated the need to optimise the use of sulphur as a fertilizer to enhance nutrient utilisation efficiency, crop performance and soil health. As many studies have shown, proper application of sulphur greatly improves plant growth, head diameter, seed yield and percentage of oil in sunflower but the reaction is different with different soils, climatic conditions and doses of sulphur.

This review will focus on synthesising and critically evaluating available scientific evidence on how various levels of sulphur affect the growth, yield and oil content of sunflower. It seeks to summarize the research results of both national and international journals to determine the best amount of sulphur and their physiological and agronomic effects. Moreover, the review discusses the role of sulphur in enhancing the uptake of nutrients, growth of oil biosynthesis, and sustainable production of crops in different agro-ecological systems.

The main aims of this review are

- To evaluate the influence of different doses of sulphur on growth parameters of sunflowers.
- To assess its impact on yield and yield attributes. To analyse the effect of the sulphur
- on oil content and quality.
- To identify the optimum amount of sulphur to be fed to maximize productivity.
- To determine research gaps and future of sustainable nutrient management.

The review is very pertinent to agronomists, soil scientists, researchers, policymakers and farmers since it offers detailed information on the importance of sulphur nutrition in the cultivation of sunflower. The results will be used in the design of effective nutrient management plans that will help to boost the production of oilseeds, maintain food security and enhance sustainable agricultural growth.

2. Background

Sulphur (S) is a vital secondary macronutrient that has a crucial role in the growth, development and productivity of the plants. Its significance has grown tremendously in the past few years because of pervasive shortages witnessed in agricultural soils. Sulphur is one of the structural elements of sulphur containing amino acids like cysteine and methionine, which play a vital role in protein synthesis, enzymes and metabolic regulation. It also participates in the synthesis of photosynthesis, chlorophyll and production of vitamins and coenzymes. Sulfur is also a significant factor in oilseed crops like sunflower (*Helianthus annuus* L.), because it directly affects the creation of fatty acids and oil accumulation, which then impacts both the yield and the quality of the oil (Khan *et al.*, 2022; Singh *et al.*, 2021) [14, 20]. Recent researches have indicated that sulphur positively affects the parameters of plant growth including height of the plant, leaf area and accumulation of the dry matter by increasing the efficiency of photosynthesis and the uptake of the nutrients. Sulphur is also essential in the nitrogen metabolism by ensuring that there is an optimal level of nitrogen to sulphur ratio, necessary in protein synthesis and biomass production. Sulphur deficiency causes the decrease in chlorophyll levels, retarded growth, maturity, low yield, and oil content in sunflower

(Hussain *et al.*, 2025; Ali *et al.*, 2020) [10, 2]. Sulphur is found in organic and inorganic forms as far as soil science is concerned. Organic sulphur makes up most (approximately 9095) of the total soil sulphur and is made available by microbial mineralization and inorganic sulphur comprises mainly sulphate (SO₄²⁻), the form absorbed by plants. Recent studies highlight the importance of soil microbes in controlling sulfur availability, especially when elemental sulfur is added to the soil and then oxidized before plants can use it (Choudhary *et al.*, 2023) [4]. The main sources of sulphur used as fertilizers can be broadly divided into sulphate-based fertilizers (e.g. gypsum and ammonium sulphate), elemental sulphur and sulphur containing compound fertilizers. The sulphate forms are instantaneous and the elemental sulphur is a slow-release source, which makes it perfect in managing the soil fertility in the long term. In the past, there was no serious concern with sulphur deficiency because there was adequate deposition of sulphur in the atmosphere and also the use of organic manure. Nevertheless, the current farming practices, which are typified by intensive farming systems, less use of organic fertilisers, and extensive use of sulphur-free fertilisers like urea, and diammonium phosphate have resulted in the rapid depletion of soils in sulphur. Also, the tougher environmental laws have minimized industrial sulphur emissions, which further curtails natural sulphur into agricultural soils. Consequently, sulphur, a vital nutrient, has become a major limiting factor in many areas, especially in South Asia (Singh *et al.*, 2021; Tiwari *et al.*, 2022) [20, 23]. Furthermore, recent agricultural research has highlighted the importance of sulphur in improving the quality of oil, particularly its fatty acid profile and antioxidant levels. Research shows that an adequate supply of sulphur can boost oil biosynthesis pathways, resulting in increased oil content, and better nutritional value of sunflower seeds (Khan *et al.*, 2022) [14]. Moreover, recent studies emphasize the potential of sulphur as an agent that improves tolerance to abiotic stressors like drought and nutrient deficiency in plants by promoting antioxidant activity and physiological stability (Hussain *et al.*, 2025) [10]. On the whole, the recent literature definitively proves that sulphur is an important nutrient to ensure the production of sunflower in a sustainable manner. It does not just play a mere role in ensuring the nutrition of plants but also enhances yield, the quality of oils, nutrient efficiency, and stress resilience.

3. Methodology

The systematic and comprehensive approach adopted in this review paper to analyse the effect of various doses of sulphur on the growth, yield, and oil content of sunflower (*Helianthus annuus* L.) was used to conduct the review paper. The research is founded on secondary data gathered through original and peer reviewed scientific literature in order to guarantee accuracy, credibility and relevance. Internationally recognized databases, such as Google Scholar, Scopus, Web of Science, ScienceDirect, SpringerLink, Wiley Online Library, Taylor and Francis Online, JSTOR, CAB Direct, AGRIS (FAO), ICAR e-Publications, and ResearchGate were searched to identify the necessary materials. The main keywords were: sulphur fertilization in sunflower, effect of sulphur on sunflower, sulphur nutrition in oilseed crops, sunflower growth and yield sulphur, sulphur and oil content in sunflower and sulphur response. Other combinations like sulphur levels AND sunflower, sulphur fertilization AND oilseed crops, sulphur deficiency in soils were used. The spelling sulphur/sulphur was used in both British and American forms to provide as many relevant pieces of literature to be retrieved as possible. The choice of the sources was based on the explicit

inclusion and exclusion criteria. The articles encompassed in this review were peer-reviewed journal articles, review papers, scholarly books, and institutional reports published between 2000 and 2025 and a few classical references that are necessary to understand the theoretical aspect. Only articles in English and pertaining to sulphur nutrition in oilseeds and sunflower crops were taken into account. The studies that were indexed in Scopus, Web of Science, and UGC-CARE-listed journals were given priority. On the other hand, non-peer-reviewed articles, duplicates, unpublished manuscripts, predatory journals, non-English articles and sources with low scientific rigor or methodology were rejected to uphold the quality and reliability of the review. Data pertaining to the topic were identified and systematically compiled in the chosen articles, such as the authorship, year of publication, geographical location, experimental design, sources of sulphur and rate of application and their impact on plant growth, yield characteristics, seed yield, and content of oils. The data obtained were critically analysed, compared and synthesized into thematic categories to give a coherent explanation of the role of sulphur in the production of sunflower. The focus was on the identification of the most effective doses of sulphur, evaluation of patterns in various agro-climatic areas, and gaps in research. The general choice of literature and synthesis were informed by the principles aligning with protocols of systematic reviews like PRISMA to achieve transparency and reproducibility (Page *et al.*, 2021) [17].

4. Thematic Review / Discussion

• The effect of Sulphur on Growth parameters of Sunflower (*Helianthus annuus* L.) was studied as follows

Sulphur is an important factor in the development of physiology of sunflower and its vegetation. Being a vital secondary macronutrient, it plays a significant role in the formation of chlorophyll, amino acid synthesis, and enzyme activation, which encourage a healthy growth of plants. Proper nutrition in terms of sulphur enhances plant height, leaf area index, stem girth, and dry matter accumulation leading to an increased crop productivity. Sunflower, a type of oil seed crop, has a comparatively high sulphur requirement because of its participation in the production of proteins and oil (Marschner, 2012; Scherer, 2001) [15, 19].

Several studies have shown that the application of sulphur has a beneficial effect on the growth of sunflower. According to Ahmad *et al.* (2011) [1], sulphur fertilization boosted plant height, leaf area, and biomass because there was increased utilization of nitrogen and metabolic activities. On the same note, Jat and Ahlawat (2006) [12] found that the use of sulphur stimulated vegetative growth and uptake of nutrients leading to better crop performance. This is improved by the fact that sulphur is involved in the production of required amino acids like cysteine and methionine that are basic in plant growth.

Some studies by Intodia and Tomar (1997) [11] indicated that the application of sulphur had a significant influence in promoting height of plants, dry matter and head diameter in sunflower. Similarly, Patil *et al.*, (2011) [18] indicated a positive growth parameter such as the leaf area and stem diameter with increase in sulphur levels. These results suggest that sulphur can boost photosynthetic performance and contribute to the increased assimilate translocation in the plant system. Subsequent researches affirm that the most effective doses of sulphur increase physiological performance and biomass. Gokhale *et al.*, (2004) [8] discovered that the use of sulphur enhanced growth characteristics and encouraged healthy plant growth.

Similar finding was made by Deolankar and Patel (1994) [5] who reported a great growth of plant height and mass accumulation with the use of the sulphur fertilizer. These enhancements are mainly related to a higher synthesis of chlorophyll and improved assimilation of nutrients. The

positive influences of sulphur go hand in hand with its synergistic relationship with nitrogen. Sulphur nutrition is balanced to guarantee effective metabolism of nitrogen, which results in a rise of protein synthesis and better growth of a vegetation (Fageria, 2009) [6]. Plants in soils with low levels of sulphur are characterized by chlorosis, retarded growth and poor leaf development which ultimately reduces productivity.

In general, the literature suggests that the application of sulphur has demonstrated a great improvement in the parameters of growth of sunflower, and the optimal responses were usually achieved at a range of 20-40 kg S ha⁻¹ in accordance with the soil fertility and agro-climatic conditions. A high or a low amount of sulphur, however, can cause a poor growth emphasizing the need to maintain nutrients in balance.

• Impact of Sulphur on Yield and Yield Attributes of Sunflower: Comparative Analysis of various Approaches

It is important to note that the fertilization of sunflower (*Helianthus annuus* L.) is a key aspect of the enhancement of yield and yield characteristics of the oilseed crop, which has a comparatively high requirement of sulphur. Several experiments have been conducted to assess the effects of different amounts of sulphur, sources and modes of application on sunflower productivity. These studies provide a consistent emphasis on sulphur as a determinant of seed yield, head diameter, number of seeds per capitulum, test weight and oil yield. To determine the best management practices, however, the differences in experimental methods, agro-climatic conditions and nutrient interactions require the comparative and critical analysis. Among the most widespread methods of research is the assessment of graded levels of sulphur in a field.

Research conducted by Jat and Ahlawat (2006) [12] proved that 40 kg S ha⁻¹ was an effective treatment to increase yield of seeds, head diameter and oil yield as compared to lower concentrations. Equally, Ahmad *et al.*, (2011) [1] found that the sulphur fertilization improved the yield properties by increasing the nutrient uptake and efficiency of metabolism. This research indicates that sulphur helps in effective absorption of nitrogen and facilitates better growth of the seed. Nonetheless, they are usually carried out on particular types of soils, which can restrict the external validity of the advice.

The other method focuses on the effects of various sulphur sources, including gypsum, elemental sulphur, ammonium sulphate, and single superphosphate. Fertilizers that contain sulphur such as gypsum and ammonium sulphate are ready sources of sulphur and therefore lead to immediate benefits in yield, but elemental sulphur is a slow-release source that has to be oxidized by microbes. Scherer (2001) [19] observed that the sulphate-based manure usually yields quicker responses, whereas elemental sulphur has long-term soil-fertilizing effects. Tandon (2011) [22] also highlighted that the efficacy of the sulphur sources is determined by the soil qualities, microbial activity and the environmental conditions. Other studies on integrated nutrient management (INM) have also shown the synergistic effects of sulphur in combination with other nutrients.

A study of Patil *et al.*, (2011) [18] showed that the combination of sulphur with the recommended amount of nitrogen and

phosphorus greatly promoted seed yield and yield components. On the same note, Fageria (2009) ^[6] also found that balanced fertilization enhances efficiency in the use of nutrients and crop production. The results of this study highlight the significance of sulphur in the enhancement of nutrient interactions, especially between it and nitrogen that is vital in protein synthesis and biomass production.

The interactive effects of sulphur with other micronutrients like boron and zinc have been studied in a number of studies. Tahir *et al.*, (2014) ^[21] noted that the use of the combination of sulphur and boron had a great effect of enhancing the seed yield and head diameter in sunflower. These synergies have a positive effect on reproductive development, pollen viability, and seed formation. Nevertheless, although integrated approaches are more productive, it also results in an increased input cost, and maximum efficiency is achieved only with site-specific recommendations. Comparison studies on dose-response studies of sulphur show that yield improvements tend to increase with increase in sulphur levels to an optimum limit after which the response levels off. Intodia and Tomar (1997) ^[11] have found substantial improvements in seed yield with the use of sulphur to 40 kg ha⁻¹.

In the same way, Gokhale *et al.*, (2004) ^[8] noticed improved yield characteristics between 20 and 40 kg S ha⁻¹. However, overuse of sulphur can cause nutrient imbalance and economic inefficiency, which means that it is necessary to determine the most appropriate levels of applying sulphur. Sulphur response is also affected by geographical variability. Experiments in sulphur-deficient soils of India have reported more yield responses than areas with sufficient soil sulphur. This emphasizes the need to test the soil and use nutrient management that is site-specific. Although there is consistent information about the positive impact of sulphur, problems exist in the generalization of recommendations based on the variability in experimental conditions, which include soil type, climate, cultivar and management practices. Importantly, the majority of research is based on short-term field experimentation, which might not be able to reflect long-term consequences of sulphur fertilization on soil health and sustainability. Secondly, there is little research on high-tech sulphur formulations like nano- sulphur and sulphur-oxidizing biofertilizers.

The next-generation studies ought to be on precision nutrient control, extended trials, and development of cost effective and environmentally sustainable methods of fertilization. Finally, comparative studies of different researches show that sulphur fertilization greatly increases the yield and its components of sunflower. Although traditional sulphate-based fertilizers are beneficial in the short-term, integrated nutrient management methods offer greater productivity and sustainability. Most of the literature suggests an optimum amount of sulphur to be 20-40 kg per ha depending on the soil fertility and the agro-climatic conditions. So, to achieve maximum productivity and economic returns of sunflower, site-specific sulphur management is necessary.

5. Problems and Research gaps

Although much has been researched on the impact that sulphur has on the growth, yield, and oil content of sunflower (*Helianthus annuus* L.), there are still a number of challenges and gaps in the research that do not allow developing specific and region-specific nutrient management techniques. These gaps should be addressed in order to increase the productivity of sunflower, improve the quality of their oil and make the

agricultural practices sustainable. The fact that most agricultural soils are deficient in sulphur is one of the main problems and this is especially common in developing nations like India. This shortcoming has occurred as a result of the heavy application of high-analysis sulphur-free manures, the decrease in the use of organic manure and the lesser deposition of sulphur to the atmosphere. This has contributed to unbalanced nutrition and low crop yields (Tandon, 2011; Scherer, 2001) ^[22, 19]. Sulphur fertilization has been successful but its use is still limited among the farmers because of poor awareness and absence of soil testing center.

The other significant limitation is that there are no region-specific guidelines on the use of sulphur in sunflower. The agro-climatic conditions under which most studies have been conducted are localized and hence it may be hard to generalize the findings in a wide range of soils and environments. Fluctuating soil characteristics, climate, irrigation techniques, and types of crops play an important role in determining the reaction of sunflower to sulphur fertilization (Fageria, 2009) ^[6]. As such, site-specific nutrient management strategies are required in order to maximise the use of sulphur.

There is also a gap in research due to limited long-term experimental data. A lot of research available is founded on short-term field experiments, which is not sufficient to determine the long-term residual effects of sulphur on the soil fertility, nutrient processes and crop yield. Continuous sulphur application needs long-term studies to assess the sustainability and environmental impacts of the practice (Marschner, 2012) ^[15]. Moreover, there are not enough comparative studies of various sources of sulphur, including gypsum, ammonium sulphate, elemental sulphur, pyrite, and phosphogypsum.

The effectiveness of these sources is affected by pH of soil, microbial activity and environment. Elemental sulphur, e.g. must be oxidized by microbes to be made accessible to plants and its efficacy in various soils needs to be explored further (Scherer, 2001) ^[19]. Hence, further studies are required to establish cost effective and efficient sulphur fertilizers to grow sunflower. The inter-relationship between sulphur and other nutrients especially nitrogen, phosphorus, boron and zinc has not been sufficiently studied in sunflower. The balanced management of nutrients is essential to achieve the maximum yield and quality of oil but extensive research on the synergistic and antagonistic effects of sulphur is still scarce. The approach of integrated nutrient management (INM) based on organic and inorganic source needs further development and testing against diverse agro-ecological backgrounds (Fageria, 2009) ^[6].

The other research gap is that not much has been researched on advanced technologies like nano-sulphur, sulphur-coated fertilizers and sulphur-oxidizing biofertilizers. These innovations have potential to enhance the efficiency of nutrient use and environmental sustainability, but they need to be widely tested on the fields and studied economically. On the same note, the use of precision agricultural applications, such as remote sensing, Geographic Information Systems (GIS), and decision-support systems, is not adequately used in sulphur management in sunflower. Moreover, limited studies on the effect of sulphur on oil quality parameters, including the fatty acid compositions, tocopherols and oxidative stability, are limited. The majority of research is directed at increasing the yield, instead of overall quality evaluation that plays a vital role in improving the nutritional and industrial qualities of sunflower oil. There is also a scarcity of economic analyses and research with farmers as the main focus. The cost-benefit ratio, profitability and the potential of adopting the sulphur fertilization in the sunflower-based

cropping systems lack adequate information. Knowledge of these socio-economic factors is vital to encouraging the use of sulphur by farmers and enhance edible oil production.

The other important issue is environmental concerns. Too much or unbalanced sulphur use can cause acidification of the soil and imbalanced nutrients (especially sensitive ecosystems). Thus, further studies are necessary to find sustainable practices in managing sulphur that can be productive and environmentally friendly. To conclude, despite the fact that a lot of progress has been achieved regarding the role of sulphur in the growth of sunflower, there are still a lot of gaps. Long-term and multi-location studies, creation of sulphur-efficient sunflower strains, testing of novel sulphur fertilisers, and adopting more precise methods of nutrient management should be the core of future studies. Overcoming these issues will help to achieve increased crop productivity, better quality of oil and sustainable development of agriculture.

6. Future Directions

The recent advances in the digital agriculture, agronomy and plant science have given new opportunities to improve the sulphur management in sunflower (*Helianthus annuus* L.). Recent literature stresses the necessity of the combination of the latest technologies, control over nutrients, and sustainability to improve productivity and the quality of the oil in the conditions of the evolving climate. Optimisation of the sulphur as well as other nutrients, most notably the micronutrients such as zinc is one of the most significant emerging directions. A recent study by Hussain *et al.* (2025) ^[10] revealed that sulphur (40 kg ha⁻¹) combined with zinc was highly beneficial on the growth, flowering, achene and oil production in sunflower hybrids. This implies that future research must be more vigilant to the interactions of multi-nutrients, as compared to the use of single sulphur application because synergies have the potential of boosting crop performance to a considerable degree. The other potential trend is the application of artificial intelligence (AI) and machine learning to crop prediction and management. Recent studies have demonstrated that deep learning models have the ability to reflect the true forecast of sunflower oil yield under different environmental conditions such as drought stress. They may be integrated with nutrient management systems to maximize the use of sulphur, with real time field data, which leads to precision agriculture and decision-making.

Recent reports indicate that sulphur has taken a role in stress tolerance due to its capacity to boost physiological metabolism as well as augmenting plant flexibility to adverse conditions such as drought and nutrient stress. Due to the changing climate in South Asia, future research should focus on the explanation of the role of sulphur nutrition in order to develop stress-tolerant sunflower production systems. Moreover, there is an increasing awareness in new fertilizer technologies, such as nano-sulphur, sulphur-coated fertilizers, and slow-release formulations. Such high inputs can become effective in improving the efficiency in the utilisation of nutrient and reducing losses and sustaining the supply of sulphur to plants. Despite their promise, these technologies need to be validated in field conditions to determine their agronomical effectiveness, economic viability as well as their environmental safety.

The other new field is the combination of biotechnological and genetic methods. The recent investigations of oil seeds crops have emphasized the importance of genetic enhancement to enhance the characteristics of oil yield and quality. Molecular biology and breeding technologies can be utilized to produce sulphur-efficient types of sunflowers that have a higher nutrient

use efficiency and composition of oils. Use of biofertilizers and sulphur oxidizing microorganisms are also attracting attention as possible alternative to chemical fertilizers that would be sustainable. These microbes increase the rate of transformation of the elemental sulphur to the plant forms making the soil healthier and less harmful to the environment. Unlike microbial consortia, further research work should be carried out on how they interact with sunflower in different soil conditions. In addition, recent studies indicate that parameter of oil quality also should be taken into consideration rather than yield.

Subsequent investigations should be on the effects of sulphur on the fatty acid composition, tocopherol level and the stability of the oxidation process that holds significance in nutrition and industry. This will assist in enhancing the quantity and quality of sunflower oil. Lastly, there is great need to conduct long and multi-location research to develop region specific sulphur recommendations. Some of the factors, which influence the sulphur response, include differences in soil type, climate and cropping systems. In this regard, a field research study along with a set of digital instruments (e.g., GIS and remote sensing) will help to develop adequate and place-based nutrient management strategies.

7. Conclusion

This review has provided a comprehensive overview of the impact of various doses of sulphur on growth, yield and oil content of sunflower (*Helianthus annuus* L.) underlining its indispensable role in improving crop productivity and quality of oils. Sulphur, the fourth essential nutrient in plants, after nitrogen, phosphorus, and potassium, is very important in essential physiological and biochemical functions, such as chlorophyll synthesis, amino acid synthesis, enzyme activation, and lipid metabolism.

The results of many experiments repeatedly prove that sulphur fertilization can significantly enhance the plant height, leaf area, head diameter, seed yield, and oil percentage in sunflower, which leads to increased economic returns and improved crop performance. The review also suggests that the use of sulphur improves the efficiency of nitrogen use and leads to balanced nutrient uptake, leading to a better accumulation of biomass and reproductive growth. Ideal sulphur levels are about 20-40 kg/ha at least depending on the nature of the soils, climate, and the management activities. Fertilizers like gypsum and ammonium sulphate, which are sulphate based, are able to provide instant nutrient supply, whereas elemental sulphur is able to provide long term nutrient supply through progressive oxidation.

Combined nutrient management practices with the use of sulphur alongside nitrogen, phosphorus and micronutrients have demonstrated better outputs in yield and quality of oil. Nevertheless, even with the significant advancements, there are still a number of challenges such as a general deficiency in sulphur in the soils, no region-specific guidelines, and absence of long-term research. The new research offers the significance of innovative technologies like nano-fertilizers, sulphur-oxidizing biofertilizers, and precision agriculture equipment, such as remote sensing, artificial intelligence, and geographic information system. These technologies have a colossal potential to improve the use of nutrients efficiently, make the environment sustainable, and promote climate-resilient agriculture.

This review is important as it summarizes the available scientific information and outlines gaps in the research and future opportunities. It is very beneficial to agronomists, soil scientists, researchers, policymakers and farmers since it has created

awareness on the need to balance the application of sulphur in the production of sunflowers. The results would help in the creation of effective nutrient management practices that could enhance the productivity of oil seeds, enhance food and nutritional security, and sustainable agricultural development. Conclusively, the growth, yield and oil quality of sunflower cannot be maximized without optimal nutrition of sulphur. The next studies need to be devoted to multi-location trials, micro-management of nutrients, new sources of sulphur, and the creation of sulphur-efficient cultivars. These practices will be critical towards closing the supply and demand disparity of edible oil as well as ensuring economic sustainability and environmental sustainability in the contemporary farming.

References

- Ahmad G, Jan A, Arif M, Jan MT, Khattak RA. Influence of nitrogen and sulphur fertilization on growth and yield of sunflower (*Helianthus annuus* L.). Sarhad Journal of Agriculture. 2011;27(4):531-536.
- Ali A, Ahmad A, Akhtar M. Influence of sulphur application on growth and yield of sunflower under different soil conditions. Journal of Plant Nutrition. 2020;43(12):1785-1795. doi:10.1080/01904167.2020.1724303.
- Aulakh MS. Crop responses to sulphur nutrition. Fertiliser News. 2003;48(5):15-28.
- Choudhary R, Yadav LR, Meena RS. Role of sulphur oxidizing microorganisms in improving sulphur availability in soils. Soil Biology and Biochemistry. 2023;176:108890. doi:10.1016/j.soilbio.2022.108890.
- Deolankar KP, Patel JC. Effect of sulphur and phosphorus on sunflower. Indian Journal of Agronomy. 1994;39(3):443-446.
- Fageria NK. The use of nutrients in crop plants. Boca Raton: CRC Press; 2009.
- Fink A. Conducting research literature reviews: from the internet to paper. 5th ed. Thousand Oaks: SAGE Publications; 2019.
- Gokhale DN, Bhoi PG, Polara KB. Effect of nitrogen, phosphorus, and sulphur on sunflower. Journal of Oilseeds Research. 2004;21(2):268-270.
- Havlin JL, Tisdale SL, Nelson WL, Beaton JD. Soil fertility and fertilizers: an introduction to nutrient management. 8th ed. Boston: Pearson Education; 2014.
- Hussain S, Khalili A, Qayyum A, Khan SU, Mehmood A, Ahmad G, et al. Optimizing sunflower (*Helianthus annuus* L.) hybrids growth, achene and oil yield through soil-applied sulphur and zinc. Scientific Reports. 2025;15:13829. doi:10.1038/s41598-025-96800-2.
- Intodia SK, Tomar OP. Effect of sulphur on growth and yield of sunflower. Indian Journal of Agricultural Sciences. 1997;67(1):46-48.
- Jat JR, Ahlawat IPS. Direct and residual effect of sulphur on growth, yield, and quality of sunflower (*Helianthus annuus* L.). Indian Journal of Agronomy. 2006;51(1):80-83.
- Khalifani S, Darvishzadeh R, Amjad SHM, Shayesteh MG, Akbari N, Arzhang S, et al. Prediction of oil yield in sunflower using deep learning regression algorithm under normal and drought stress conditions. BMC Plant Biology. 2026;26:365.
- Khan N, Bano A, Rahman MA. Sulphur nutrition improves oil content and fatty acid composition in oilseed crops. Industrial Crops and Products. 2022;178:114589. doi:10.1016/j.indcrop.2022.114589.
- Marschner P. Marschner's mineral nutrition of higher plants. 3rd ed. London: Academic Press; 2012.
- Oil Crop Science. The importance of sulphur in oilseed production: a South Asian context. Oil Crop Science. 2025;10(2):118-130.
- Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2021;372:n71. doi:10.1136/bmj.n71.
- Patil VC, Halikatti SI, Hiremath SM, Babalad HB, Sreenivasa MN. Effect of sulphur on growth and yield of sunflower. Karnataka Journal of Agricultural Sciences. 2011;24(3):382-385.
- Scherer HW. Sulphur in crop production. European Journal of Agronomy. 2001;14(2):81-111. doi:10.1016/S1161-0301(00)00082-4.
- Singh D, Kumar R, Yadav SS. Emerging role of sulphur in oilseed crop production: a review. Agricultural Reviews. 2021;42(2):123-130.
- Tahir M, Nadeem MA, Tanveer A, Rehman HU. Effect of sulphur and boron on growth and yield of sunflower. Pakistan Journal of Scientific and Industrial Research. 2014;57(3):137-142.
- Tandon HLS. Sulphur in soils, crops and fertilizers. New Delhi: Fertiliser Development and Consultation Organisation; 2011.
- Tiwari KN, Pathak AN, Singh A. Sulphur management in Indian agriculture: challenges and opportunities. Indian Journal of Fertilisers. 2022;18(3):220-230.
- Xiao Y, Watson M. Guidance on conducting a systematic literature review. Journal of Planning Education and Research. 2019;39(1):93-112. doi:10.1177/0739456X17723971.
- Zhang Y, et al. Enhancing oil content in oilseed crops: genetic insights and breeding approaches. Frontiers in Plant Science. 2025.