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# Exploring the influence of sulfur on the growth and yield of mustard (*Brassica juncea*) in the Thal region

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**Abstract**

To evaluate the impact of different sulfur application levels on the growth and yield of mustard (*Brassica juncea*) crop, a field experiment using a randomized full block design was conducted at the Adaptive Research Farm in Karor, Pakistan during the winter seasons of 2019 and 2020. In the experiment, a control group (T1) was not subjected to any sulfur application, while four other treatments (T2 to T5) were administered with increasing quantities of sulfur (4, 6, 8, and 10 kg/ha, respectively). The treatments were administered in two halves: one during the sowing phase using granular sulfur, and another during the flowering stage through foliar application. The study criteria included plant population, plant height, the number of flowering branches per plant, the number of pods per plant, and yield. The results demonstrated that sulfur had a beneficial impact on all of the examined characteristics. In the 2020 season, the application of 8 Kg/ha of sulfur (T4) led to the most advantageous results in terms of plant height (83 cm), number of flowering branches per plant (37 branches/plant), number of pods per plant (19.14 pods/plant), and seed yield (1442.43 Kg/ha). Additional comprehensive research is required to examine the pathways via which sulfur can impact seed germination, plant growth, and productivity in mustard.

## 1. Introduction

Mustard (*Brassica juncea* L.) is a major oilseed crop cultivated primarily during the winter season in Pakistan and India. It is also known as Rai, Raya, or Laha in different regions [1]. This versatile plant is highly prized for its economic and nutritional benefits and is cultivated either as a sole crop or as an intercrop. Seeds are rich in essential components such as ascorbic acid, antioxidants, dietary fiber, vitamins, minerals, lipids, proteins, and carbohydrates [2]. *Brassica juncea*, apart from being renowned as an oilseed crop, fulfills diverse roles in various countries. While primarily cultivated as a condiment in Canada, this crop holds significant importance as an oilseed in India, China, and Pakistan. Due to its elevated oil content and abundance of unsaturated fatty acids, particularly the erucic fatty acid comprising approximately 40% of its composition, it is considered a highly favorable candidate for biodiesel production [3-5].

It is widely acknowledged that various nutrients have significant impacts on the growth and yield of oil crops. Sulfur, despite being frequently overlooked in plant nutrition, plays a crucial role in the growth and development of plants [6]. It is a vital nutrient that contributes to various cellular processes, such as the production of amino acids, proteins, and vitamins. Sulfur plays a crucial role in the synthesis of chlorophyll, a key component for photosynthesis. Additionally, it contributes to the production of enzymes and coenzymes that support a variety of biochemical reactions [7]. In addition, sulfur enhances a plant's ability to withstand abiotic and biotic stressors such as drought





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and diseases [8]. The presence of this substance is essential for achieving high crop yields and maintaining plant health.

The growth, development, and production of brassicas, such as mustard crops, have been hindered in recent decades due to various problems, including inconsistent and inadequate nutrient levels in the soil [9]. Global agricultural soils are experiencing a deficiency of essential mineral nutrients due to limited land availability and increasing demand for high-yield crop varieties. There is a significant scarcity of sulfur in agricultural soils, specifically in mustard crops, as indicated by multiple reports [10]. The issue of sulfur deficiency in soils has been significantly exacerbated, particularly in the northern and northwestern regions of Gujarat [11]. The deficiency of sulfur in Indian soil has reached a concerning range of 34-54% [12]. It is evident that micronutrients, such as sulfur, are indispensable for the growth and development of crops [13]. Therefore, in order to promote sustainable agriculture, it is essential to ensure the efficient utilization of soil resources, particularly in regions where there is a notable issue of soil micronutrient depletion.

Applying granular sulfur during sowing is vital for Brassica crops such as mustard due to their significant requirement for sulfur. Sulfur is administered in the form of sulfate fertilizers to guarantee sufficient availability during the critical initial growth phases [14]. Sulfur is additionally applied as a foliar spray during the flowering stage which is an important stage for plants to absorb nutrients and undergo reproductive development. During the flowering stage, the plant experiences heightened metabolic activity and therefore necessitates supplementary nutrients to achieve optimal growth and fruit yield [15][16]. The main objective of the current research is to evaluate the impact of varying levels of sulfur application on important indicators of mustard crop growth and yield in the Thal region.

## 2. Materials and Method

### 2.1. Study location

The study was carried out at the Karor Adaptive Research Farm, Pakistan. The farm is situated at an elevation of approximately 237 meters above sea level. The site was chosen based on its climatic conditions, which accurately represent the characteristics of the region, including the average temperature and rainfall patterns.

### 2.3. Land preparation and experimental design

This experiment utilized a randomized complete block design. There were five different treatment groups, with the first group (T1) acting as the control and not receiving any sulfur application. The remaining four groups (T2 to T5) received incremental doses of sulfur (4, 6, 8, and 10 Kg/ha, respectively), with half applied during sowing and the other half during flowering.

An experimental plot measuring one hectare was designated for the research. The region was divided into 15 plots, with each plot encompassing an area of 657 $m^2$. The division was established by categorizing the experiment into 5 distinct treatments, each of which was duplicated 3 times. The layout of the plots also considered the incorporation of suitable buffer zones between them. Two plowing operations were conducted to prepare the land for cultivation prior to sowing. The mustard cultivar RBJ-14017A was utilized in the present study with a seed rate of 11 kg/ha.

The initial dose (50%) of sulfur was administered in granular form (sulfur 90% WDG) at the time of sowing using the broadcast method. The latter portion involved the meticulous blending of the sulfur fertilizer with water, followed by the application of the resulting mixture via a foliar spray during the flowering stage. The application of NPK fertilizer at a rate of 80 kg/ha was done concurrently with the application of sulfur in all treatments (including the control). The fertilizer was split into two equal parts, with half applied during sowing and the other half during flowering. Weeding was performed manually as needed, and no additional chemical measures were taken to control pests and diseases.

## 2.3. Data collection

### 2.3.1. Plant population

The plots were inspected 14 days after sowing. The number of germinated seeds per square meter was recorded, and the average plant population was subsequently determined.

### 2.3.2. Plant height

The heights of 30 randomly selected plants at flowering (from the bottom of the stem to the top of the tallest leaf) from each plot were measured using a measuring tape, and an average was calculated for each plot.

### 2.3.3. Number of flowering branches

The number of flowering branches in 30 randomly selected plants from each plot was counted at the flowering stage, and an average was calculated for each plot and expressed in branches per plant.

### 2.3.4. Number of pods per plant

The number of pods was counted on 50 randomly selected plants from each plot at harvest time, and the average was calculated and expressed in pods per plant.

### 2.3.5. Seed yield

The entire crop was harvested, and the yield was weighed using a calibrated electronic scale. The yield per hectare was then calculated.

## 2.4. Statistical analysis

The data was analyzed using one-way ANOVA and the means were compared using Fisher's least significant difference (LSD) test at a significance level of 0.05.

# 3. Results

## 3.1. Plant population

The application of sulfur seems to increase the plant density per square meter. The plant population per square meter showed a significant increase in all sulfur application treatments, except for T2 (4 kg/ha sulfur), compared to the control. The T5 treatment (10 kg/ha sulfur) had the highest populations, with 139 and 149 plants/m2 recorded in 2019 and 2020, respectively. In contrast, the control group (T1) exhibited the lowest plant population values, measuring 80.8 and 89.2 plants/m2 in 2019 and 2020, respectively. An appreciable augmentation was observed in all treatments (T1-T5) when comparing the 2020 season with the 2019 season (Fig. 1 A).

## 3.2. Plant height

The results showed that T3, T4, and T5 plants exhibited a substantial elevation in height compared to the control (T1). The maximum values for this characteristic were documented in T4 (83 cm) and T5 (80 cm) during the 2020 season, whereas the minimum measurements were observed in the control group with 62 cm in 2019 and 67 cm in 2020. Plant height measurements of mustard plants in 2020 were higher than those in 2019 (Fig. 1 B).

## 3.3. Number of flowering branches

The application of sulfur resulted in a significant increase in the overall number of flowering branches in mustard. This increase was directly proportional to the amount of sulfur applied. The most prominent augmentation in this characteristic was noted in T4 and T5, with no significant disparities between the two treatments in both the 2019 and 2020 seasons. In 2020, the greatest number of flowering branches was observed in T4 and T5, with 37 branches/plant. Conversely, the control group (T1) had the lowest number of branches, with 15 branches/ plant in 2019 (Fig. 1 C).

### 3.4. Number of pods per plant

While the addition of sulfur greatly increased the number of pods per plant in all treatments compared to the control (except for T1 in 2019), the highest recorded value for this characteristic was observed in T4 (8 kg/ha sulfur) with 19.14 and 16.93 pods/plant in 2020 and 2019, respectively. On the other hand, there were some similarities between T3 and T5 plants in regard to the pod count per plant. In 2019, the control group had the lowest number of pods per plant, with a recorded average of 9.13 pods/plant (Fig. 1 D).

### 3.5. Seed yield

In 2020, there was a significant rise in seed yield compared to 2019, regardless of the treatment used. Both treatment levels T4 and T5 exhibited the highest mustard seed yield in both seasons, with T4 achieving a yield of 1442.43 in the 2020 season. However, there was no significant difference in yield between the two treatments (T4 and T5). In contrast, the control group (T1) had the lowest yield of only 1020.11 kg/ha in the 2019 season (Fig. 1 E).

## 4. Discussion

The distinct variations in plant population response to different levels of sulfur application throughout the two-year study period provide compelling evidence of the substantial influence of sulfur on mustard seed germination and seedling establishment, as previously observed in canola [17] and wheat [18]. An extensive examination of the specific mechanisms through which sulfur impacts the process of germination and growth has the potential to provide valuable insights into the management of mustard crops.

The present results unequivocally demonstrate that the application of sulfur to *Brassica juncea* plants has a beneficial effect on both plant height and the abundance of flowering branches. Prior studies have documented similar results, demonstrating that sulfur promotes the growth of mustard plants in terms of both height [20][21] and the number of flowering branches per plant [22]. The key role of sulfur in promoting cell extension and division [20] supports the elongation of plant stems and the development of secondary branches.

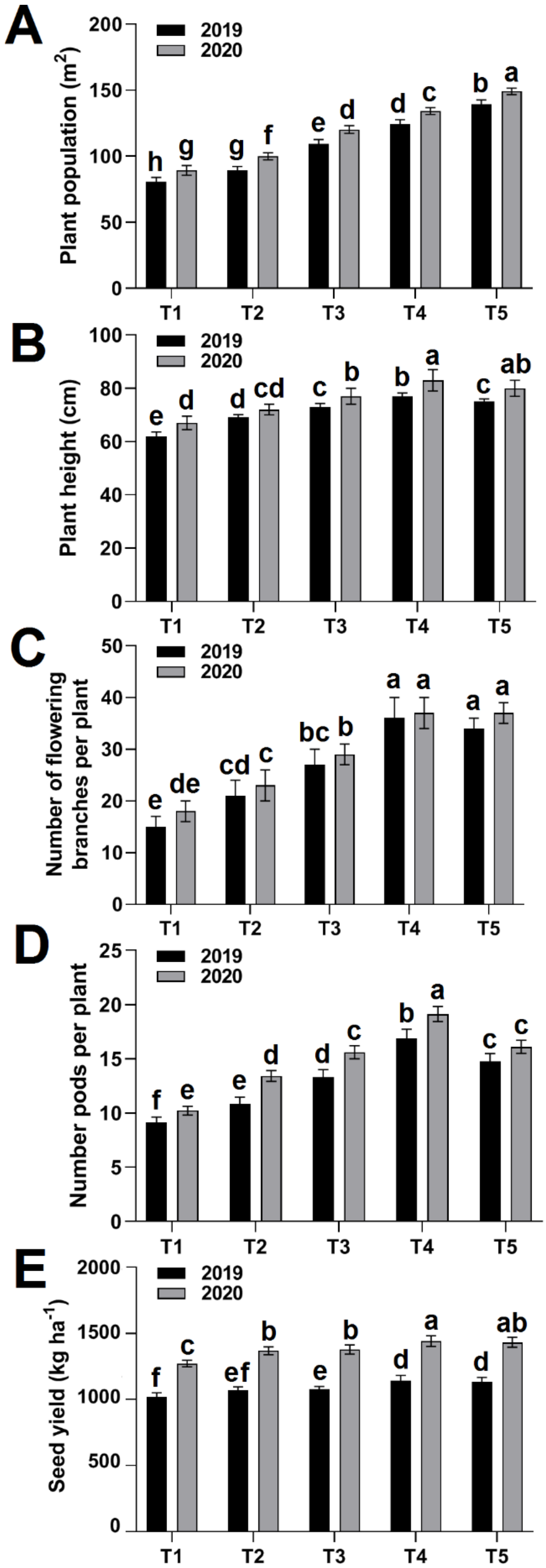


**Figure 1. The impact of sulfur application on plant population (A), plant height (B), number of flowering branches per plant (C), number of pods per plant, and seed yield of *Brassica juncea* grown in the Agricultural Research Farm of Karor, Pakistan during 2019 and 2020 seasons.** T1, T2, T3, T4, and T5 represent sulfur application levels (0, 4, 6, 8, and 10 kg/ha, respectively) delivered in two halves during the sowing (granular sulfur application) and flowering stage (foliar application). The results are represented as means and the error bars represent the standard deviation (SD). Different letters in separate columns indicate a statistically significant difference between the means of each trait as determined by Fisher's least significant difference (LSD) test at *p<0.05*.

The higher pod count per plant observed in the sulfur-treated group highlights the significance of this element in promoting flower and fruit formation in mustard plants. Indeed, the application of sulfur later in the flowering stage may have facilitated the fertilization of flowers and the development of fruit. This is supported by a similar finding in canola, where an increase in fertile pods was observed when sulfur was applied as a foliar fertilizer [24].

The observed augmentation in seed yield resulting from the application of sulfur is consistent with previous findings [1] that demonstrate the beneficial impact of sulfur on the growth and yield of *Brassica juncea*. Although T4 and T5 differed significantly in the number of pods per plant, with T4 having a higher number of pods per plant (Fig. 1 D), there were no significant differences in yield between these two treatments (Fig. 1 E). The comparable yield outputs observed may be attributed to the greater plant density in T5 as compared to T4 (Fig. 1 A).

Overall, the examined characteristics exhibited significant improvement in 2020 compared to 2019, resulting in a higher yield in 2020 irrespective of the treatment (Fig. 1). The disparities between the two seasons can be ascribed to the advantageous climatic conditions in the second season, in contrast to the first. These conditions led to enhanced seed germination and facilitated the growth of plants during their different phenological stages. The increase in 2020 may have been influenced by the implementation of effective agricultural practices, such as improved land preparation and fertilization, which have enhanced soil structure and fertility.

## 4. Conclusion

The findings of this study indicate that applying 8 Kg/ha of sulfur (T4) in two separate doses during sowing (granular sulfur) and during the flowering stage (foliar application) consistently resulted in the most favorable outcomes for plant height, number of flowering branches per plant, number of pods per plant, and ultimately seed yield. It is crucial to acknowledge that environmental factors may have had a role in these findings, specifically in the second season. However, additional detailed study is necessary to acquire a more profound comprehension of the fundamental mechanisms involved.

### Conflict of interest statement

The authors declared no conflict of interest.

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### Data availability statement

The authors declared that all related data are included in the article.

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