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Influence of zinc and sulphur on growth and yield attributes of Indian mustard (*Brassica juncea* L.) under Doon valley conditions

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Abstract
In India, mustard (*Brassica juncea* L.) is a vital rabi oilseed crop, especially in mid-altitude areas like the Doon Valley. The average productivity in Uttarakhand (858 kg ha^{-1}) and India (1499 kg ha^{-1}) is low despite its potential because of mineral deficiencies, particularly in zinc (Zn) and sulfur (S). Zinc is essential for photosynthesis, nitrogen metabolism, and enzyme activation, whereas sulfur aids in protein synthesis, enzymatic processes, and oil content. In order to assess the impact of S and Zn on the growth and yield characteristics of mustard (variety HY-805), a field study was carried out during the 2023-24 rabi season at the Agronomy Research Farm, Jigyasa University, Dehradun. Eight treatments were set up in a factorial Randomized Block Design with three replications, comprising the recommended amount of fertilizer (RDF: 60 kg N, 40 kg P, 40 kg K ha^{-1}) either by itself or in combination with Zn (10-12 kg ha^{-1}) and S (25-75 kg ha^{-1}). Test weight, number of siliquae per plant, number of seeds per siliqua, dry matter accumulation, plant population, and plant height were all noted. With the highest plant population (193.67 plants/plot), plant height (148.54 cm), dry matter accumulation (43.65 g/plant), number of siliquae (37.57/plant), seeds per siliqua (16.38), and test weight (3.60 g) recorded in RDF + Zn 12 kg/ha + S 75 kg/ha, the results demonstrated that the combined application of Zn and S significantly enhanced growth and yield attributes. Additionally, intermediate treatments outperformed control and RDF alone. According to the study, assimilate partitioning, vegetative growth, and reproductive development are all enhanced by balanced Zn and S supplementation, which paves the way for increased mustard output in the Doon Valley.

Keywords: Indian mustard, *Brassica juncea*, zinc, sulphur, growth attributes

Introduction
The main rabi oilseed crop in India is mustard (*Brassica juncea* L.), which is a member of the Brassicaceae family. It is grown extensively throughout tropical and subtropical areas and is quite important in northern India. Mustard and rapeseed are two of the most important rabi oilseeds for increasing oilseed output, especially in mid-altitude areas (less than 1300 m), where enhanced production technologies can yield 8-12 q ha^{-1}. The average productivity in Uttarakhand (858 kg ha^{-1}) and India (1499 kg ha^{-1}) is still below the global average, notwithstanding its potential (Directorate of Economics & Statistics, 2020-21; Directorate of Agriculture, Uttarakhand, 2021-22).

A primary cause of low productivity is the insufficient availability of vital nutrients, especially zinc (Zn) and sulfur (S). Through its involvement in protein synthesis, enzymatic processes, and the creation of amino acids (cysteine and methionine), sulfur is known to enhance crop development. Additionally, it affects oil content, chlorophyll generation, and overall crop vigor (Shukla *et al*., 2018) [12]. Likewise, zinc plays a key part in photosynthesis, nitrogen metabolism, enzyme activation, and cell division. By 2050, zinc deficiency is expected to rise to 63%, making it a major yield-limiting factor in Indian soils (Bhatt *et al*., 2020) [1].

Therefore, both zinc and sulfur are essential for attaining the best crop growth and production characteristics. Productivity is directly influenced by growth parameters like plant height, branch count, and leaf area as well as yield characteristics like the number of siliquae per plant, seeds per siliqua, and 1000-seed weight. However, little is known about how zinc and sulfur work

together to affect mustard's growth and yield characteristics in the Doon Valley.

Hence, the present study entitled "Influence of Zinc and Sulphur on Growth Performance and Productivity of Indian Mustard (*Brassica juncea* L.) under Doon Valley Conditions" was undertaken with the following objectives:

- To evaluate the influence of sulphur application on growth performance of mustard.
- To study the effect of sulphur and zinc on yield-contributing characters of mustard.

Zinc and sulfur have been shown in numerous studies to have beneficial impacts on Indian mustard (*Brassica juncea* L.) growth. According to Bhinda *et al*. (2023) [2], applying 40 kg of sulfur and 5 kg of zinc per hectare greatly boosted plant height and dry matter accumulation at 30, 60, 90, and harvest. In a two-year field study, Verma *et al*. (2023) [19] discovered that sulfur at 900 ppm increased plant height and primary and secondary branches. According to Raj *et al*. (2022) [11], zinc at 15 kg ha^{-1} produced the tallest plants (126.50 cm). Zinc application boosted vegetative development metrics, such as plant height, leaf number, and branching, according to Shahria *et al*. (2020) [17] and Vineet *et al*. (2016) [20]. According to Mishra *et al*. (2023) [7], at 90 DAS, S @ 40 kg ha^{-1} markedly increased plant height, leaf count, and branch count. In rainfed conditions, Rahangdale *et al*. (2022) [10] found that S treatment up to 35 kg ha^{-1} increased plant height, leaf number, and branches per plant. Maximum plant height, primary, and secondary branches were reported by Singh *et al*. (2023) using S @ 60 kg ha^{-1}. Both Mani *et al*. (2021) [5] and Saini *et al*. (2020) [16] attested to the positive impacts of sulfur on mustard growth characteristics.

All things considered, these studies consistently show that applying zinc and sulfur enhances branching, biomass accumulation, and vegetative growth—all of which are critical factors that determine prospective yield.

Zinc and sulfur application had a good impact on mustard yield components as well. According to Raj *et al*. (2022) [11], Zn @ 15 kg ha^{-1} produced the most branches per plant, siliquae per plant, and seeds per siliqua. Singh *et al*. (2017) [14] and Rimi demonstrated that zinc supplementation increased the number of siliquae per plant and seeds per siliqua, while S application significantly improved seed weight. Verma *et al*. (2023) [19] and Verma *et al*. (2018) [18] found increased numbers of siliquae per plant, seeds per siliqua, and 1000-seed weight with combined application of Zn and S. Kumar *et al*. (2022) [3], Nandan *et al*. (2022) [8], and Rahangdale *et al*. (2022) [10] also reported enhanced yield attributes such as number of siliquae, seeds per siliqua, and test weight with S fertilization.

Mani *et al*. (2021) [5], Meena *et al*. (2018) [6], and Singh *et al*. (2022) [15] confirmed that combined applications of N, S, and Zn significantly increased key yield attributes, indicating a strong synergistic effect of these nutrients on mustard productivity.

Materials and Methods

During the rabi season of 2023-2024, the current study, "Influence of Zinc and Sulphur on Growth Performance of Indian Mustard (*Brassica juncea* L.) under Doon Valley Conditions," was conducted at the Agronomy Research Farm, Department of Agriculture, Jigyasa University, Selaqui, Dehradun, Uttarakhand. The farm is located at an elevation of 650 meters above mean sea level and is located at 31°21'50" N latitude and 78°18'27" E longitude. A sub-tropical environment with hot summers (40-44 °C), chilly winters (<1 °C), and an annual rainfall of about 2073 mm—mostly during the monsoon months of June to September, with sporadic winter rains in December and January—defines the experimental location. Mustard (*Brassica juncea* L., variety HY-805) was sown on 2nd November 2023 and harvested on 15th March 2024, with a crop duration of 135 days.

Eight treatments and three replications were used in the factorial Randomized Block Design (RBD) experiment. The recommended fertilizer dosage (RDF: 60 kg N, 40 kg P, and 40 kg K ha^{-1}) was applied either alone or in conjunction with zinc (10-12 kg ha^{-1}) and sulfur (25-75 kg ha^{-1}) as part of the treatments. Plots were 2 x 3 m in size, with 50 cm between rows, and irrigation channels were kept 1 m apart. To guarantee adequate soil moisture, the land was completely plowed, harrowed, leveled, and irrigated one week prior to planting. Seeds were manually sowed, and fertilizers were applied in accordance with the treatment schedule. Thinning was performed at 20-25 DAS to maintain optimum plant density, while manual weeding and irrigation were carried out at 30 DAS and during the pod-filling stage.

Five randomly tagged plants in each plot were used to record growth parameter observations. Dry matter accumulation was assessed at harvest, plant height was measured at 30, 60, and 90 DAS from the root-shoot junction to the main raceme's apex, and the number of plants was tallied following thinning. From tagged plants, yield-attributing characteristics such test weight, quantity of siliqua per plant, and seeds per siliqua were also noted. All growth and yield attribute data were analyzed statistically using OPSTAT software at a 5% level of significance.

Results and Discussion

The present study was conducted to evaluate the influence of zinc and sulphur on the growth and productivity of Indian mustard (*Brassica juncea* L.) under Doon Valley conditions. Data recorded on different growth parameters and yield attributes were statistically analyzed and are presented below.

Growth Parameters

Significant differences were seen in the plant population among the various treatments (Table 1). T_8 (RDF + Zn 12 kg/ha + S 75 kg/ha) had the largest population of plants per plot (193.67), followed by T_7 (RDF + Zn 12 kg/ha + S 50 kg/ha) with 188.69 and T_6 (RDF + Zn 12 kg/ha + S 25 kg/ha) with 178.43. The control (T_1) group had the lowest plant population, measuring 113.22. According to these results, applying zinc and sulfur together, especially at larger quantities, improved plant establishment and survival. This is consistent with the findings of Kumar *et al*. (2016) [4], who found that applying sulfur enhanced plant population and other growth metrics.

In all treatments, plant height steadily rose as crop size increased (Table 1). T_8 reached the highest height of 40.42 cm at 30 DAS, followed by T_7 at 38.65 cm, while the control (T_1) reached the lowest height of 13.74 cm. There was a noticeable trend of height gain with greater Zn and S dosages, even if differences were not statistically significant at this point.

There were notable variations at 60 DAS, with T_8 reaching a height of 69.50 cm as opposed to 32.09 cm for T_1. At 90 DAS and harvest, similar patterns persisted, with T_8 having the tallest plants (148.54 cm) and the control having the shortest (97.22 cm). The enhanced height can be attributed to the role of sulphur in protein synthesis and vegetative growth, as well as zinc's involvement in auxin production, which stimulates cell elongation. These results corroborate the findings of Pandey *et al*. (2017) [9] and Verma *et al*. (2023) [19], who observed

significant increases in mustard plant height with Zn and S supplementation.

Plant height and dry matter accumulation per plant at harvest showed a similar pattern (Table 1). The control yielded the lowest dry weight of 14.84 g/plant, while T_8 generated the highest dry weight of 43.65 g/plant, followed by 41.74 g in T_7 and 37.24 g in T_6. Enhanced photosynthetic efficiency, nitrogen absorption, and general plant vigor are indicated by the rise in biomass following zinc and sulfur administration. Similar findings were reported by Bhinda *et al*. (2023) [2], who highlighted the synergistic effect of increased Zn and S doses on mustard development by showing that the highest dry matter accumulation was observed under these levels.

Overall, the findings unequivocally show that the administration of zinc and sulfur together, especially at the highest concentrations (T_8), greatly improved growth metrics such as plant population, height, and accumulation of dry matter. Zinc's function as a cofactor in enzymes and auxin synthesis, as well as sulfur's role in the manufacture of amino acids and proteins, are responsible for these benefits, which together promote plant vigor and vegetative development. Significant improvement over the RDF alone and control was also seen by treatments with intermediate amounts of Zn and S (T_6 and T_7), suggesting a dose-dependent response.

The present findings suggest that strategic supplementation of zinc and sulphur along with the recommended dose of fertilizers can optimize mustard growth and establish a foundation for improved yield and productivity under the climatic conditions of the Doon Valley.

Yield Attributes

There were substantial differences in the number of siliqua per plant between the treatments (Table 2). T_8 (RDF + Zn 12 kg/ha + S 75 kg/ha) had the most siliqua per plant (37.57), followed by T_7 (RDF + Zn 12 kg/ha + S 50 kg/ha) with 35.97 and T_6 (RDF + Zn 12 kg/ha + S 25 kg/ha) with 32.03. At 12.77, the control (T_1) had the fewest siliqua per plant. Improved vegetative growth and nutrient availability, which favorably affect flowering and pod development, are responsible for the greater siliqua production under higher Zn and S levels. These findings are consistent with Nandan *et al*. (2022) [8] and Verma *et al*. (2018, 2023) [18, 19], who reported increased siliqua number with combined application of zinc and sulphur in mustard.

The quantity of seeds per siliqua varied significantly between treatments as well (Table 2). T_8 had the most seeds per siliqua (16.38), followed by T_7 (15.72) and T_6 (13.45), whereas the control group had the fewest seeds per siliqua (8.76). A greater number of seeds per pod was probably produced by the treatment of zinc and sulfur, which improved the physiological processes related to flowering and fertilization. These results are in agreement with Verma *et al*. (2018, 2023) [18, 19], who observed similar improvements in seed set per siliqua with micronutrient application.

There were notable variations in the test weight of mustard seeds between treatments (Table 2). The control (T_1) had the lowest test weight of 3.01 g, while T_8 had the highest weight of 3.60 g, followed by T_7 with 3.52 g and T_6 with 3.43 g. better seed filling and quality are indicated by the rise in test weight, which could be the result of better nutrient intake and effective assimilate translocation to developing seeds. Similar observations were reported by Singh *et al*. (2015) [13] and Verma *et al*. (2018) [18], highlighting the beneficial effects of zinc and sulphur on seed quality parameters.

Overall, yield attributing characters including siliqua per plant, seeds per siliqua, and test weight were significantly influenced by the application of zinc and sulphur, with the highest levels (T_8) producing the best results. The improvements can be attributed to the synergistic effect of zinc and sulphur in promoting vegetative growth, reproductive development, and assimilate partitioning. These enhanced yield components ultimately contribute to higher grain yield and better crop performance under Doon Valley conditions.

Summary

The study showed that zinc and sulfur had a major impact on Indian mustard's growth and yield characteristics. Plant establishment, height, dry matter accumulation, and branching were all enhanced by higher Zn and S dosages. Under combined nutrient administration, yield-contributing parameters such as the number of siliquae per plant, seeds per siliqua, and 1000-seed weight were improved. The results consistently showed that the most efficient way to promote growth and yield was to combine RDF with Zn 12 kg/ha and S 50-75 kg/ha. The synergistic impact of zinc and sulphur on photosynthesis, enzyme activity, protein synthesis, and reproductive development is responsible for these enhancements. For Doon Valley to maximize mustard yield, micronutrient control in addition to suggested fertilizers is essential.

Table 1: Effect of Treatments on Plant Population, Plant Height, and Dry Weight

Treatment	Plant population	Plant Height (cm)				Dry weight (g/plant)
		30 DAS	60 DAS	90 DAS	Harvest	
T_1 = Control	113.22	13.74	32.09	65.24	97.22	14.84
T_2 = RDF	155.40	24.33	54.42	87.37	129.66	26.27
T_3 = RDF + Zn @ 10kg/ha + S @ 25kg/ha	161.21	27.90	56.61	90.77	134.33	30.13
T_4 = RDF + Zn @ 10kg/ha + S @ 50kg/ha	174.64	31.76	58.11	93.07	138.98	34.30
T_5 = RDF + Zn @ 10kg/ha + S @ 75kg/ha	175.23	33.44	61.71	97.88	140.29	36.11
T_6 = RDF + Zn @ 12kg/ha + S @ 25kg/ha	178.43	34.48	64.33	101.74	143.98	37.24
T_7 = RDF + Zn @ 12kg/ha + S @ 50kg/ha	188.69	38.65	67.29	104.58	147.26	41.74
T_8 = RDF + Zn @ 12kg/ha + S @ 75kg/ha	193.67	40.42	69.50	107.28	148.54	43.65
C.D. at 5%	6.52	1.23	1.69	3.29	5.85	1.33
S.Em (±)	2.13	0.40	0.55	1.08	1.91	0.46

Table 2: Effect of Treatments on Yield Attributes

Treatment	Siliqua per plant	Seeds per siliqua	Test weight (g)
T_1 = Control	12.77	8.76	3.01
T_2 = RDF	22.63	10.81	3.18
T_3 = RDF + Zn @ 10kg/ha + S @ 25kg/ha	25.97	11.25	3.24
T_4 = RDF + Zn @ 10kg/ha + S @ 50kg/ha	29.53	11.95	3.29
T_5 = RDF + Zn @ 10kg/ha + S @ 75kg/ha	31.10	12.88	3.36
T_6 = RDF + Zn @ 12kg/ha + S @ 25kg/ha	32.03	13.45	3.43
T_7 = RDF + Zn @ 12kg/ha + S @ 50kg/ha	35.97	15.72	3.52
T_8 = RDF + Zn @ 12kg/ha + S @ 75kg/ha	37.57	16.38	3.60
C.D. at 5%	0.42	0.57	0.17
S.Em (±)	0.60	0.19	0.06

Conclusion

Under Doon Valley circumstances, balanced zinc and sulfur application along with suggested fertilizers greatly improves Indian mustard growth parameters and production qualities. It was discovered that the most efficient combination of RDF + Zn 12 kg/ha + S 50-75 kg/ha improved test weight, plant population, plant height, dry matter accumulation, number of siliquae per plant, and seeds per siliqua. These results emphasize how crucial micronutrient supplementation is to producing sustainable production, increased yield potential, and higher-quality seeds in mustard farming.

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