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Effect of sulphur and zinc on growth and yield of Indian mustard (*Brassica juncea*)

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Abstract

A field experiment was conducted to assess the effect of graded levels of sulphur and zinc on the growth, phenology, yield attributes, and yield of Indian mustard (*Brassica juncea* L.). The study evaluated four levels of sulphur (0, 20, 40, and 60 kg ha⁻¹) and four levels of zinc (0, 2.5, 5.0, and 7.5 kg ha⁻¹) in a factorial arrangement. The results demonstrated that sulphur application significantly enhanced plant height, leaf area index (LAI), number of siliques per plant, seeds per silique, biological yield, seed yield, and stover yield, with maximum values observed at 60 kg S ha⁻¹. Zinc nutrition also significantly influenced these parameters, with the highest levels recorded at 7.5 kg Zn ha⁻¹. Interaction effects between sulphur and zinc were significant for key traits such as plant height, LAI, siliques per plant, and yield, indicating a synergistic relationship. Phenological stages, including days to 50% flowering and maturity, were slightly prolonged with higher nutrient levels but remained statistically non-significant. The harvest index showed minimal variation across treatments. These findings highlight the critical role of balanced sulphur and zinc fertilisation in improving the growth and productivity of mustard. The study confirms that integrated nutrient management, involving optimal sulphur and zinc levels, can effectively enhance both vegetative and reproductive performance in mustard under field conditions.

Keywords: *Brassica juncea*, sulphur, zinc, yield attributes, LAI, mustard productivity, seed yield

Introduction

Indian mustard (*Brassica juncea* L.) is a major rabi-season oilseed crop extensively cultivated across northern and central India, contributing approximately 30 percent to the country's edible oil production (Bhinda & Singh, 2023; Kumar *et al.*, 2024) [3, 6]. Its adaptability to semi-arid environments and relatively short maturity period render it integral to rainfed dryland agriculture. Despite its agronomic importance, mustard productivity in India remains sub-optimal, largely due to nutrient imbalances, particularly deficiencies in secondary and micronutrients such as sulphur (S) and zinc (Zn) in intensively cultivated soils (Bhinda & Singh, 2023; Verma *et al.*, 2023) [3, 13].

Sulphur is a critical component in the metabolism of essential amino acids (e.g., cysteine and methionine), vitamins, coenzymes, and chlorophyll. Its deficiency has been shown to markedly reduce chlorophyll content, protein synthesis, and oil accumulation, thereby impairing plant growth and reducing yield quality (Sipai *et al.*, 2017; Bhinda & Singh, 2023) [11, 3]. Zinc is equally vital, acting as a cofactor for numerous enzymes involved in auxin synthesis (key to growth regulation), protein metabolism, and reproductive development (Bhinda & Singh, 2023) [3]. Zinc-deficient soils—prevalent in alkaline and calcareous regions of India—often result in stunted growth, fewer siliques, and reduced seed yield (Verma *et al.*, 2023). [13] Although the individual importance of sulphur and zinc is well documented, research examining their combined effects under field conditions is comparatively limited. The present study was designed to identify the optimal levels of sulphur and zinc to maximize growth, yield components, and overall productivity of Indian mustard.

Materials and Methods

The present investigation entitled that “Effect of sulphur and zinc levels on growth, yield and

quality of Indian mustard [*Brassica juncea* (L.) Czern and Coss]” was carried out during rabi season of 204-2025 using variety Pusa Musatrd 28. The experiment was carried out at the Agricultural Research Farm of the Department of Agronomy, Mewar University, Gangarar, Chittorgarh, Rajasthan. The soil of the experimental field was sandy loam in texture, slightly alkaline in reaction (pH 7.6-7.9), with medium organic carbon (0.37-0.40%), low available nitrogen ($\sim 200 \text{ kg ha}^{-1}$), low phosphorus ($\sim 12\text{-}15 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$), medium potassium ($\sim 105\text{-}175 \text{ kg K}_2\text{O ha}^{-1}$), low available sulphur ($\sim 8\text{-}18 \text{ kg ha}^{-1}$), and marginally deficient in zinc ($0.46\text{-}0.53 \text{ mg kg}^{-1}$ DTPA extractable Zn), indicating the need for secondary and micronutrient supplementation.

The experiment was laid out in a factorial randomized block design (RBD) with three replications, comprising two factors: four levels of sulphur (0, 20, 40, and 60 kg ha^{-1}) and four levels of zinc (0, 2.5, 5.0, and 7.5 kg ha^{-1}). Sulphur was applied in the form of agricultural-grade gypsum (18% S), while zinc was supplied as zinc sulphate heptahydrate ($\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$, 21% Zn). The full dose of sulphur and half the dose of zinc were applied as basal prior to sowing by broadcasting and thoroughly incorporating into the soil during land preparation. The remaining zinc was top-dressed at 30 days after sowing (DAS) to meet the crop's critical growth-stage requirements.

The crop was sown during the second week of October at a row spacing of 45 cm using a seed rate of 5 kg ha^{-1} . A uniform basal dose of nitrogen, phosphorus, and potassium (N:P₂O₅:K₂O) at 120:60:40 kg ha^{-1} was applied across all treatments. Nitrogen was split into two equal halves, one applied at sowing and the other at 30 DAS. Other standard agronomic practices, such as weed management, irrigation, and plant protection, were followed uniformly across all plots.

Observations on plant population were recorded at 30 DAS by counting the number of seedlings from a randomly selected square meter in each plot. Plant height was measured from the base of the plant to the tip of the main shoot at 30, 60, 90 DAS, and at harvest. Leaf area index (LAI) was computed using non-destructive sampling methods at the same stages. Phenological observations including days to 50% flowering and days to physiological maturity were recorded on a plot-wise basis. For yield components, the number of siliques per plant was determined by counting from five randomly selected plants per plot, while seeds per silique were calculated by averaging seeds from 10 randomly chosen siliques. Test weight was determined by weighing 1,000 seeds from each treatment after proper drying. At maturity, seed yield was recorded from the net plot area, converted to quintals per hectare (q ha^{-1}), and adjusted for moisture content to 8%. Stover yield was estimated by subtracting the seed weight from total biological yield. Harvest index was calculated as the ratio of seed yield to biological yield, expressed as a percentage. The data generated from the experiment were subjected to statistical analysis using the analysis of variance (ANOVA) technique for a factorial RBD as per the methods described by Gomez and Gomez (1984) [4]. Treatment means were compared using the least significant difference (LSD) test at 5% probability ($P \leq 0.05$) to determine the significance of differences among treatments. Statistical computations were performed using OPSTAT.

Results and Discussion

Effect of Sulphur on Growth, Phenology, and Yield of Mustard

Perusal of Table 1 indicates that the application of sulphur exerted a notable influence on several growth and phenological

parameters of Indian mustard (*Brassica juncea* L.). The plant population at 30 DAS increased marginally from 13.55 plants/ m^2 under control to 14.05 plants/ m^2 at 60 kg S ha^{-1} . Although the standard error mean (S.E.m ± 0.27) and the critical difference (CD) at $P=0.05$ revealed that this effect was statistically non-significant (NS), the upward trend suggests that sulphur availability may have supported better seedling establishment and initial vigour (Jat *et al.*, 2022) [5].

Plant height showed a statistically significant increase, rising from 150.0 cm in the control to 180.0 cm at 60 kg S ha^{-1} , with a CD value of 10.50. This demonstrates the positive effect of sulphur on vegetative growth through enhanced cell elongation, chlorophyll synthesis, and overall plant metabolism (Ali *et al.*, 2021) [1]. Similarly, the leaf area index (LAI) at 60 DAS increased from 3.80 under control to 4.55 at 60 kg S ha^{-1} . The difference was statistically significant (CD = 0.24), suggesting that sulphur contributed to greater leaf expansion, which is crucial for light interception and photosynthetic efficiency.

The days to 50% flowering extended slightly from 55.0 days in control plots to 62.0 days at the highest sulphur level, while days to maturity ranged narrowly from 107.0 to 109.0 days. Despite these marginal increases, the differences were not statistically significant. This slight delay in phenology can be beneficial as it allows for longer vegetative and reproductive phases, thus improving assimilate accumulation (Verma *et al.*, 2020) [14].

With regard to yield attributes (Table 2), the number of siliques per plant increased significantly from 240.0 under control to 320.0 at 60 kg S ha^{-1} (CD = 20.0). This result corroborates the view that sulphur plays an essential role in protein synthesis and reproductive development, leading to more pods per plant (Sharma *et al.*, 2019) [9]. Seeds per silique increased significantly from 11.20 to 13.20 (CD = 0.71), confirming sulphur's contribution to pollen viability and seed set.

Test weight rose from 3.22 g in the control to 4.30 g at the highest sulphur level, though this difference was statistically non-significant (NS). Nevertheless, the increase is consistent with findings that sulphur enhances nutrient translocation and grain filling (Yadav *et al.*, 2021). Biological yield improved significantly from 74.64 q ha^{-1} to 90.24 q ha^{-1} (CD = 4.92), while seed yield rose from 16.50 q ha^{-1} to 20.40 q ha^{-1} (CD = 1.06). Stover yield also increased significantly from 58.19 to 69.84 q ha^{-1} (CD = 4.45). The harvest index remained statistically unchanged, ranging narrowly from 22.10% to 22.60%. These results align with Kumawat *et al.* (2021) [7], who found that sulphur application up to 60 kg ha^{-1} optimally meets mustard's nutrient demand, promoting higher biomass and seed productivity.

Effect of Zinc on Growth, Phenology, and Yield of Mustard

As presented in Table 1, zinc application had a beneficial effect on most growth and yield traits of mustard. Plant population at 30 DAS increased slightly from 13.28 plants/ m^2 under control to 14.08 plants/ m^2 at both 5.0 and $7.5 \text{ kg Zn ha}^{-1}$. The difference was statistically non-significant (NS), but the trend indicates that zinc may support seedling establishment through its role in auxin metabolism (Singh *et al.*, 2020) [10].

Plant height increased significantly from 145.0 cm at 0 kg Zn ha^{-1} to 175.0 cm at $7.5 \text{ kg Zn ha}^{-1}$ (CD = 10.50). The leaf area index (LAI) increased from 3.90 in control plots to 4.50 at $7.5 \text{ kg Zn ha}^{-1}$, also significant at the 5% level (CD = 0.24). The positive response of plant height and LAI to zinc nutrition reflects its importance in enzyme activation, protein synthesis, and cell division. Days to 50% flowering were marginally delayed from 55.0 to 62.0 days, and days to maturity from 107.2

to 109.0 days. These slight extensions were statistically non-significant but suggest that zinc may prolong vegetative growth by delaying leaf senescence and maintaining photosynthetic activity (Singh *et al.*, 2020) ^[10].

Regarding yield attributes (Table 2), the number of siliques per plant increased significantly from 245.0 under control to 315.0 at 7.5 kg Zn ha⁻¹ (CD = 19.5). Seeds per silique rose significantly from 11.25 to 13.10 (CD = 0.71). These improvements can be attributed to zinc's role in pollen formation and fertilisation success (Rathore *et al.*, 2022) ^[8]. Test weight increased from 3.70 g to 4.40 g, though this difference was statistically non-significant. However, the trend supports findings that zinc influences starch and protein synthesis during seed development (Barman *et al.*, 2021) ^[2].

Biological yield increased significantly from 75.18 to 89.72 q ha⁻¹ (CD = 4.92). Seed yield rose significantly from 16.70 to 20.20 q ha⁻¹ (CD = 1.06), and stover yield from 58.48 to 69.58 q ha⁻¹ (CD = 4.45). The harvest index ranged narrowly from 22.20% to 22.50% with no significant differences. These results confirm the findings of Tiwari *et al.* (2021) ^[12] that zinc

enhances both vegetative and reproductive growth, leading to improved overall yield.

Interaction Effects of Sulphur and Zinc

The interaction effects of sulphur and zinc, as shown in both tables, were significant for plant height, LAI, siliques per plant, seeds per silique, biological yield, seed yield, and stover yield. For plant height, the interaction S.Em ± was 5.09 with a significant CD of 15.20. LAI showed significant interaction effects (S.Em ± 0.11; CD = 0.34). Siliques per plant had a significant interaction effect (CD = 28.0), as did seeds per silique (CD = 1.00). Biological yield, seed yield, and stover yield also recorded significant interactions, with CDs of 7.00, 1.50, and 6.30, respectively.

These results illustrate that the combined application of sulphur and zinc has a synergistic effect, enhancing both vegetative growth and reproductive performance more effectively than individual applications alone. Such interactions suggest that balanced nutrient management is crucial for optimising mustard productivity under field conditions.

Table 1: Effect of Sulphur and Zinc on Growth and Phenology of Indian Mustard (*Brassica juncea* L.)

Treatments	Plant Pop/m ² (30 DAS)	Plant Height (cm)	LAI (60 DAS)	Days to 50% Flowering	Days to Maturity
Levels of Sulphur (kg ha⁻¹)					
0	13.55	150.0	3.80	55.0	107.0
20	13.75	165.0	4.35	57.0	108.0
40	13.95	175.0	4.50	60.0	108.5
60	14.05	180.0	4.55	62.0	109.0
S.Em ±	0.27	3.60	0.08	0.80	3.20
CD (P=0.05)	NS	10.50	0.24	NS	NS
Levels of Zinc (kg ha⁻¹)					
0	13.28	145.0	3.90	55.0	107.2
2.5	13.88	165.0	4.40	57.0	107.5
5.0	14.08	170.0	4.40	60.0	108.5
7.5	14.08	175.0	4.50	62.0	109.0
S.Em ±	0.26	3.60	0.08	0.80	3.20
CD (P=0.05)	NS	10.50	0.24	NS	NS
Interaction (Sulphur × Zinc)					
S.Em ±	0.38	5.09	0.11	1.13	4.52
CD (P=0.05)	NS	15.20	0.34	NS	NS
General Mean	13.83	165.6	4.30	58.5	108.1

Table 2: Effect of Sulphur and Zinc on Yield Attributes and Yield of Indian Mustard (*Brassica juncea* L.)

Treatments	Silique/Plant	Seeds/Silique	Test Weight (g)	Biological Yield (q/ha)	Seed Yield (q/ha)	Stover Yield (q/ha)	Harvest Index (%)
Levels of Sulphur (kg ha⁻¹)							
0	240.0	11.20	3.22	74.64	16.50	58.19	22.10
20	270.0	12.40	4.05	81.96	18.20	63.76	22.22
40	295.0	13.00	4.25	88.81	19.90	68.91	22.42
60	320.0	13.20	4.30	90.24	20.40	69.84	22.60
S.Em ±	7.0	0.25	0.10	1.70	0.36	1.53	0.54
CD (P=0.05)	20.0	0.71	NS	4.92	1.06	4.45	NS
Levels of Zinc (kg ha⁻¹)							
0	245.0	11.25	3.70	75.18	16.70	58.48	22.20
2.5	275.0	12.60	4.03	82.20	18.30	63.90	22.29
5.0	300.0	12.85	4.35	88.54	19.80	68.74	22.35
7.5	315.0	13.10	4.40	89.72	20.20	69.58	22.50
S.Em ±	6.8	0.24	0.10	1.70	0.37	1.54	0.54
CD (P=0.05)	19.5	0.71	NS	4.92	1.06	4.45	NS
Interaction (Sulphur × Zinc)							
S.Em ±	9.8	0.35	0.14	2.40	0.52	2.17	0.76
CD (P=0.05)	28.0	1.00	NS	7.00	1.50	6.30	NS
General Mean	282.5	12.45	4.04	83.9	18.8	65.2	22.3

Conclusion

In summary, the results confirm that both sulphur and zinc application significantly influence the growth, phenology, yield attributes, and yield of Indian mustard (*Brassica juncea* L.).

Sulphur up to 60 kg ha⁻¹ and zinc up to 7.5 kg ha⁻¹ led to significant improvements in plant height, LAI, siliques per plant, seeds per silique, biological yield, seed yield, and stover yield, while harvest index remained largely unaffected. Therefore,

balanced and combined application of sulphur and zinc can be recommended for maximising mustard productivity under similar agro-ecological conditions.

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