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Effect of different levels of sulphur and zinc on growth, yield and quality of Indian mustard (*Brassica juncea* L.)

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Abstract

The present investigation entitled “Effect of Different Levels of Sulphur and Zinc on Growth, Yield and Quality of Indian Mustard (*Brassica juncea* L.)” was carried out during the Rabi season of 2024-25 at the Research Farm, Department of Agronomy, Faculty of Agriculture and Allied Sciences, United University, Rawatpur, Jhalwa, Prayagraj (U.P.). The experiment was laid out in a Factorial Randomized Block Design (FRBD) with sixteen treatment combinations, comprising four levels of sulphur (0, 25, 35, and 55 kg/ha) and four levels of zinc (0, 5, 10, and 15 kg/ha), replicated thrice. The results revealed that combined application of sulphur and zinc significantly influenced the growth, yield, and quality parameters of mustard. Among the treatments, the combination of sulphur @ 55 kg/ha and zinc @ 15 kg/ha (S_5Z_3) recorded the maximum plant height, number of branches per plant, number of siliques per plant, seed yield, harvest index, and oil content. The improved growth attributes under this treatment translated into higher productivity and superior oil quality, indicating the synergistic effect of sulphur and zinc nutrition in enhancing mustard performance. The study concludes that the integrated application of sulphur and zinc at higher levels can be recommended for optimizing yield and quality of mustard under agro-climatic conditions of Prayagraj region.

Keywords: Sulphur, Zinc, Indian mustard, *Brassica juncea*, growth, yield

1. Introduction

Indian mustard (*Brassica juncea* L.) belongs to the family Brassicaceae and commonly called as Rai. It contains good amount of oil usually 30-38%. India is having 6.23 million ha area under rapeseed-mustard and 9.34 million tonnes production with average productivity of 1499 kg ha⁻¹, which is about three-fourth of the world's average productivity (1960 kg ha⁻¹) (DAC and FW, 2020) [3]. Rajasthan having first position in terms of area and production accounting for 2.37 m ha and 4.08 Mt followed by Uttar Pradesh with around 0.75 m ha and 1.12 Mt out of the total rapeseed mustard area and production respectively. In UP Mathura district has the highest area, production and productivity which is 0.053 Mha, 0.077 Mt and 1453 kg ha⁻¹ respectively” (Directorate of economics and statistics, 2020-21 [4] (DAC and FW). Indian mustard is a cool-season crop that grows in both tropical and temperate climates. It thrives in cooler temperatures and requires a dry period for harvesting. In India, it is primarily cultivated during the Rabi (winter) season, from September-October to February-March. Indian mustard can tolerate annual rainfall ranging from 50 to 420 cm, temperatures between 6 °C and 27 °C, and a pH range of 4.3 to 8.3. While it grows best in neutral pH soil (7), it can also adapt to alkaline and slightly saline soils, as well as temperatures between 15°C and 20 °C. With its efficient photosynthetic response through the C3 pathway, rapeseed-mustard thrives in well-drained, non-waterlogged soils. It can grow in various soil types, from sandy loam to clay loam, but performs best in light loam soils. Due to its relatively low water requirements (24-40 cm), it is well-suited for rainfed cropping systems. It requires temperature between 06° - 26° C. It is generally grown in rainfed condition. It requires well drained soil and is moderately tolerant to acidic soil. Water requirement of mustard is low (240-400 mm) which is sufficient for rainfed cropping system. Oil content in mustard varies from 37% to 49% with 14-15% carbohydrate, 25-30% protein, 10-12% fibre, 1 1.5% minerals and vitamins, 2-3% glucosinolate. Mustard oil contains about

40-60% of erucic acid, 4.5 to 13% linolenic acid and 25-30% of oleic acid. Linoleic acid has a higher nutritive value. In India, mustard is cultivated on large scale in Rajasthan, MP, Haryana, Panjab, Assam, Bihar, Gujarat, WB, etc. Rajasthan ranks first in both area (40.74%) and production (44.97%). (Chavan *et al.*, 2021) [2]. Oilseed crops are the second most important field crops after cereals in shaping agricultural economies. The self-sufficiency in oilseeds achieved during the "Yellow Revolution" in the early 1990s was short-lived. Currently, India is one of the largest importers of vegetable oils, despite being the fifth-largest producer of oilseeds globally. The use of vegetable oil has grown significantly in recent years, both for industrial and consumer purposes. The main sources of vegetable oils in India include nine oilseeds: Soybean, Rapeseed and Mustard, Groundnut, Sunflower, Sesame, Niger seed, Castor, Safflower, and Linseed, which are primarily grown under rain-fed conditions across an area of approximately 26 million hectares. Among these, soybean (34%), groundnut (27%), and rapeseed and mustard (27%) account for over 88% of total oilseed production and more than 80% of vegetable oil production, with mustard contributing the largest share (35%), followed by soybean (23%) and groundnut (25%). Oilseed production increased from 27.38 million tonnes in 2014-2015 to 40 million tonnes in 2022-2023. (Ministry of Agriculture and Farmer Welfare, 2023) [13]. Mustard has primary centre of its origin in central Asia with secondary centres in central and western China, eastern India, Burma and through Iran to Near East cultivated for centuries in many parts of Eurasia. However, the principal growing countries are Bangladesh, Central Africa, China, India, Japan, Nepal and Pakistan, as well as southern Russia in north of the Caspian Sea (Kumar *et al.*, 2016) [9]. Mustard seeds are excellent source of minerals such as magnesium, calcium, potassium and phosphorus. It is a great source of dietary folate and Vitamin A (Tripathi *et al.*, 2010) [20]. Mustard leaves or greens are a great source of essential minerals such as calcium, potassium and phosphorus. It is a great source of dietary fibre and magnesium (Pandey *et al.*, 2006) [14]. The oil content in mustard seeds varies from 37-49 percent (Bhowmik *et al.*, 2014) [1]. Effective nutrient management is essential for maximizing mustard yield. Mustard, like other oilseed crops, requires more sulfur than cereals, but this vital nutrient is frequently neglected, resulting in a common deficiency.

Sulphur (S) is a vital secondary macronutrient essential for plant growth, development, and metabolism, often referred to as the fourth major plant nutrient (Holmes, 1980) [6]. It is particularly crucial in oilseed crops like mustard, where it significantly contributes to the synthesis of amino acids, proteins, oils, vitamins (biotin and thiamine), chlorophyll, and glucosinolates (Saini *et al.*, 2024) [15]. Sulphur deficiency is widespread globally, including in India, and is especially prevalent in high-input agricultural regions (Marschner, 2012) [12]. Deficiency symptoms include stunted growth, yellowing of leaves, and poor seed development, ultimately reducing mustard yield and quality. Mustard, particularly Brassica species, has a high sulphur requirement due to its content of sulphur-rich glucosinolates (Karthikeyan and Shukla, 2008) [7]. Sulphur uptake is essential for synthesizing sulphur-containing amino acids—methionine (21% S), cysteine (26% S), and cystine (27% S)—which form the building blocks of proteins. Sulphur also enhances root growth, nutrient absorption, stress resistance, and oil content. Its application has been shown to increase mustard yields by 12-48% under irrigated and 17-124% under rainfed conditions, with an agronomic efficiency of 7.7 kg yield increase

per kg of sulphur applied (Katyal *et al.*, 1997) [8].

Zinc is a vital micronutrient essential for the growth, development, and metabolism of mustard crops, playing a key role in enzyme activation, hormone regulation, and several physiological processes (Sharma and Singh, 2015) [16]. It is crucial in photosynthesis, protein synthesis, seed formation, and early plant development, particularly by promoting root growth and seed germination, which directly influence plant establishment and productivity. Zinc deficiency in mustard leads to stunted growth, chlorosis (yellowing of leaves), poor flowering, and reduced seed yield, severely impacting both the quality and quantity of the harvest. Application of zinc fertilizers in Indian mustard has been shown to increase yield by 11 to 40% (Sinha *et al.*, 2000) [18]. Zinc is a component of many enzymes involved in various metabolic activities and regulates growth hormones such as Indole-3-acetic acid (IAA) and Auxin. It enhances pod setting, seed formation, and oil synthesis, thereby increasing both biological seed and stover yield. Zinc also stabilizes cytoplasmic ribosomes, supports cell division, activates enzymes like dehydrogenase and proteinases, and promotes starch formation, seed maturation, protein synthesis, and carotene production (Mandal *et al.*, 2002) [11]. Regions with alkaline or calcareous soils often experience low zinc availability, making mustard crops more vulnerable to deficiency symptoms like poor root development and low resistance to environmental stresses and pests (Singh *et al.*, 2019; Das *et al.*, 2020) [19, 5]. Recent studies emphasize the importance of zinc supplementation in improving mustard crop performance under varied soil conditions (Kumar *et al.*, 2017; Sharma *et al.*, 2020) [10, 17]. In Uttar Pradesh, widespread micronutrient deficiencies, aggravated by intensive cropping and high-yielding varieties, result in poor vegetative growth, flower and fruit drop, and low seed production. Among micronutrients, sulphur and zinc are most critical for oilseed crops' growth and development (Verma *et al.*, 2023) [21]. Thus, adequate zinc management is indispensable for enhancing mustard crop productivity and quality, especially in zinc-deficient soils.

2. Materials and Methods

The field experiment was carried out at the Crop Research Farm of United University, U.P India during rabi season of the year 2024- 2025 Prayagraj is located at 25.45°N and 81.84 °E in the southern part of Uttar Pradesh at an elevation of 98 meters (322 ft). The soil of the experimental field was silty loam in texture and slightly alkaline in reaction with P^H, 7.2, EC 0.20 dsm⁻¹ organic carbon 0.40% and available Nitrogen 196 kg ha⁻¹ Phosphorus 18.9 kg ha⁻¹ and potassium 260.50 kg ha⁻¹ at 0-15 cm soil depth. The experiment was laid out in factorial randomized block design with 16 treatment each replicated thrice. The study was carried of two factor viz. sulphur and zinc with four dose of sulphur and zinc viz. 0, 15, 35, 55 kg ha⁻¹ and 0, 5, 10, 15 kg ha⁻¹ respectively were applied basal dose. The sowing was done on the 23 October 2024. The crop was sown by using 3.5 to 5 kg ha⁻¹ and recommended fertilizer was applied 120kg N, 60kg P₂O₅ 40kg K₂O ha⁻¹ uniformly in all plots as a feeder dose and plant protection measure were spraying malathion 50EC @1 liter dissolved in 1000 liters of water ha⁻¹ for the control of hairy caterpillar. Spraying of Imidachloroprid 17.8 EC @ 375 ml in 1000 liters of water ha⁻¹ was applied as per requirement for the control of aphids. The crop was harvested manually at the maturity dated on 1 march 2024 and seed and stover were recorded.

3. Results and Discussion

3.1 Effect of sulphur and zinc on growth attribute of Indian mustard

3.1.1 Plant Population (plants/m²)

At both the initial and final stages of crop growth, sulphur and zinc application significantly influenced plant population. The highest plant population was consistently observed with 55 kg/ha sulphur (S3), recording 24.58 plants/m² initially and 28.42 plants/m² at the final stage. Zinc application at 15 kg/ha (Z3) also resulted in higher populations, with 21.08 plants/m² initially

and 25.42 plants/m² at the final stage. The lowest populations were seen in control treatments without sulphur (S0) and zinc (Z0). Notably, the interaction of 55 kg/ha sulphur and 15 kg/ha zinc (S3Z3) produced the highest overall plant population—28.33 plants/m² initially and 32.33 plants/m² at the final stage. In contrast, the S0Z0 treatment (no sulphur or zinc) had the lowest plant population at both stages, with 8.33 and 10.67 plants/m² respectively. These results highlight the positive effect of sulphur and zinc, individually and in combination, on crop stand establishment and growth.

Plant population at initial stage (plants/m ²)						Plant population at final stage (plants/m ²)				
Treatments	Z ₀ -(Zinc 0 kg/ha)	Z ₁ -(Zinc 5 kg/ha)	Z ₂ -(Zinc 10 kg/ha)	Z ₃ -(Zinc 15 kg/ha)	Mean S	Z ₀ -(Zinc 0 kg/ha)	Z ₁ -(Zinc 5 kg/ha)	Z ₂ -(Zinc 10 kg/ha)	Z ₃ -(Zinc 15 kg/ha)	Mean S
S ₀ - (Sulphur 0 kg/ha)	8.33	10.67	12.00	15.33	11.58	10.67	14.67	16.33	17.33	14.75
S ₁ - (Sulphur 15 kg/ha)	12.33	17.33	19.00	19.33	17.00	19.33	24.00	23.33	24.67	22.83
S ₂ - (Sulphur 35 kg/ha)	15.00	19.33	19.67	21.33	18.83	22.00	24.00	26.33	27.33	24.92
S ₃ - (Sulphur 55 kg/ha)	18.67	25.00	26.33	28.33	24.58	24.00	28.33	29.00	32.33	28.42
Mean Z	13.58	18.08	19.25	21.08		19.00	22.75	23.75	25.42	
Factors		Factor S	Factor Z	Factor (S x Z)			Factor S	Factor Z	Factor (S x Z)	
'F' Test		S	S	NS			S	S	NS	
SE. m (±)		0.38	0.38	0.77			0.30	0.30	0.60	
CD 0.05		1.11	1.11	-			0.87	0.87	-	

3.1.2 Plant height (cm)

Plant height measurements taken at 30, 60, and 90 days after sowing (DAS) showed significant variation depending on the levels of sulphur and zinc applied. At 30 DAS, the tallest plants were observed in the S3 treatment (55 kg/ha sulphur) with 19.84 cm, followed by S2 (35 kg/ha) at 19.64 cm, while the shortest plants were in S0 (0 kg/ha) with 14.30 cm. For zinc, Z3 (15 kg/ha) recorded the highest height at 19.85 cm, and Z0 the lowest at 14.30 cm. The S3Z3 combination yielded the maximum height (22.25 cm), while S0Z0 recorded the minimum

(14.30 cm). At 60 DAS, plant height peaked at 89.02 cm in S3 and 87.91 cm in Z3, with S0 and Z0 showing the lowest values at 77.68 cm and 75.99 cm, respectively. The interaction S3Z3 again produced the tallest plants at 94.82 cm, and S0Z0 the shortest at 76.57 cm. At 90 DAS, the tallest plants were seen in S3 (140.31 cm) and Z3 (134.71 cm), while S0 and Z0 showed the lowest growth at 112.57 cm and 118.16 cm, respectively. The maximum height of 150.82 cm was recorded in S3Z3, and the minimum (112.57 cm) in S0Z0. Overall, plant height increased with higher sulphur and zinc levels.

Plant height (cm) at 30 DAS						Plant height (cm) at 60 DAS				
Treatments	Z ₀ -(Zinc 0 kg/ha)	Z ₁ -(Zinc 5 kg/ha)	Z ₂ -(Zinc 10 kg/ha)	Z ₃ -(Zinc 15 kg/ha)	Mean S	Z ₀ -(Zinc 0 kg/ha)	Z ₁ -(Zinc 5 kg/ha)	Z ₂ -(Zinc 10 kg/ha)	Z ₃ -(Zinc 15 kg/ha)	Mean S
S ₀ - (Sulphur 0 kg/ha)	14.30	14.70	14.70	17.14	15.21	76.57	79.29	76.81	78.05	77.68
S ₁ - (Sulphur 15 kg/ha)	19.43	18.83	19.90	17.46	18.25	77.54	83.89	85.49	86.55	83.37
S ₂ - (Sulphur 35 kg/ha)	18.46	19.43	19.65	19.62	19.64	74.48	89.76	90.47	92.22	86.73
S ₃ - (Sulphur 55 kg/ha)	17.33	20.13	20.40	22.25	19.84	75.37	92.40	93.50	94.82	89.02
Mean Z	17.38	17.78	17.93	19.85		75.99	86.33	86.57	87.91	
Factors		Factor S	Factor Z	Factor (S x Z)			Factor S	Factor Z	Factor (S x Z)	
'F' Test		S	S	NS			S	S	S	
SE. m (±)		0.39	0.39	0.78			0.51	0.51	1.02	
CD 0.05		1.13	1.13	-			1.47	1.47	2.95	

Plant height (cm) at 90 DAS					
Treatments	Z ₀ -(Zinc 0 kg/ha)	Z ₁ -(Zinc 5 kg/ha)	Z ₂ -(Zinc 10 kg/ha)	Z ₃ -(Zinc 15 kg/ha)	Mean S
S ₀ - (Sulphur 0 kg/ha)	112.57	117.68	121.67	124.58	119.12
S ₁ - (Sulphur 15 kg/ha)	119.44	124.69	125.82	125.80	123.94
S ₂ - (Sulphur 35 kg/ha)	118.81	129.13	132.30	137.75	129.50
S ₃ - (Sulphur 55 kg/ha)	121.83	142.35	146.24	150.82	140.31
Mean Z	118.16	128.46	131.51	134.74	
Factors		Factor S	Factor Z	Factor (S x Z)	
'F' Test		S	S	S	
SE. m (±)		0.64	0.64	1.29	
CD 0.05		1.87	1.87	3.74	

3.1.3 Dry matter accumulation (g/m²)

Dry matter accumulation increased significantly with higher levels of sulphur and zinc at all growth stages. At 30 DAS, the highest accumulation was observed in S3 (55 kg/ha sulphur) at 14.20 g/m², while the lowest was in S0 (no sulphur) at 11.46 g/m². Among zinc treatments, Z3 (15 kg/ha) recorded 13.14

g/m², and Z0 (no zinc) had 12.55 g/m². The combination S3Z3 gave the highest dry matter (14.69 g/m²), while S0Z0 had the lowest (11.06 g/m²). At 60 DAS, S3 and Z3 again showed maximum dry matter (138.06 g/m² and 133.37 g/m² respectively), with S3Z3 reaching 145.05 g/m². S0Z0 remained the lowest at 110.57 g/m². At 90 DAS, S3 and Z3 recorded

286.57 g/m² and 279.78 g/m², respectively. The highest value was seen in S3Z3 (306.23 g/m²), and the lowest in S0Z0 (252.11

g/m²). Overall, sulphur and zinc applications improved dry matter accumulation significantly.

Dry matter accumulation (g/m ²) at 30 DAS						Dry matter accumulation (g/m ²) at 60 DAS				
Treatments	Z ₀ -(Zinc 0 kg/ha)	Z ₁ -(Zinc 5 kg/ha)	Z ₂ -(Zinc 10 kg/ha)	Z ₃ -(Zinc 15 kg/ha)	Mean S	Z ₀ -(Zinc 0 kg/ha)	Z ₁ -(Zinc 5 kg/ha)	Z ₂ -(Zinc 10 kg/ha)	Z ₃ -(Zinc 15 kg/ha)	Mean S
S ₀ - (Sulphur 0 kg/ha)	11.06	11.52	11.62	11.65	11.46	110.57	118.13	121.70	124.04	118.61
S ₁ - (Sulphur 15 kg/ha)	12.29	12.43	12.50	12.92	12.53	120.95	124.62	124.55	128.63	124.69
S ₂ - (Sulphur 35 kg/ha)	13.32	13.52	13.78	13.72	13.59	122.96	127.88	132.28	135.77	129.72
S ₃ - (Sulphur 55 kg/ha)	13.53	14.29	14.31	14.69	14.20	124.92	138.91	143.34	145.05	138.06
Mean Z	12.55	12.94	13.14	13.15		119.85	127.39	130.47	133.37	
Factors		Factor S	Factor Z	Factor (S x Z)			Factor S	Factor Z	Factor (S x Z)	
'F' Test		S	S	NS			S	S	S	
SE. m (±)		0.08	0.08	0.16			0.56	0.56	1.11	
CD _{0.05}		0.23	0.23	-			1.61	1.61	3.22	

Dry matter accumulation (g/m ²) at 90 DAS					
Treatments	Z ₀ -(Zinc 0 kg/ha)	Z ₁ -(Zinc 5 kg/ha)	Z ₂ -(Zinc 10 kg/ha)	Z ₃ -(Zinc 15 kg/ha)	Mean S
S ₀ - (Sulphur 0 kg/ha)	252.11	254.01	255.77	259.38	255.32
S ₁ - (Sulphur 15 kg/ha)	264.78	267.35	271.46	274.04	269.41
S ₂ - (Sulphur 35 kg/ha)	267.21	273.43	275.12	279.46	273.80
S ₃ - (Sulphur 55 kg/ha)	264.71	277.77	297.56	306.23	286.57
Mean Z	262.20	268.14	274.98	279.78	
Factors		Factor S	Factor Z	Factor (S x Z)	
'F' Test		S	S	S	
SE. m (±)		0.78	0.78	1.56	
CD _{0.05}		2.27	2.27	4.54	

3.1.4 Leaf area index

Leaf area index (LAI) increased significantly with higher levels of sulphur and zinc at all growth stages. At 30 DAS, the maximum LAI was observed with 55 kg/ha sulphur (S₃) at 1.40, followed by 35 kg/ha sulphur (S₂) at 1.28, while the lowest was in the control (S₀) at 0.80. Among zinc treatments, 15 kg/ha zinc (Z₃) recorded the highest LAI of 1.27, followed by 10 kg/ha zinc (Z₂) at 1.26, and the lowest in Z₀ (0.91). The interaction S₃Z₃ gave the highest LAI of 1.53, while S₀Z₀ recorded the minimum (0.75). At 60 DAS, S₃ and Z₃ showed the highest LAI

values of 5.52 and 4.97, respectively. The S₃Z₃ treatment again resulted in the maximum LAI of 5.78, while the minimum (3.30) was recorded in S₀Z₀. At 90 DAS, the highest LAI was recorded in S₃ (4.05) and Z₃ (3.85), while the lowest was in S₀ (2.74) and Z₀ (3.14). The combined S₃Z₃ treatment produced the highest LAI (4.27), followed by S₃Z₂ (4.12), with the lowest in S₀Z₀ (2.38). Overall, the data clearly indicate that leaf area index improved progressively with increasing sulphur and zinc levels, especially when both were applied in combination

Leaf area index at 30 DAS						Leaf area index at 60 DAS				
Treatments	Z ₀ -(Zinc 0 kg/ha)	Z ₁ -(Zinc 5 kg/ha)	Z ₂ -(Zinc 10 kg/ha)	Z ₃ -(Zinc 15 kg/ha)	Mean S	Z ₀ -(Zinc 0 kg/ha)	Z ₁ -(Zinc 5 kg/ha)	Z ₂ -(Zinc 10 kg/ha)	Z ₃ -(Zinc 15 kg/ha)	Mean S
S ₀ - (Sulphur 0 kg/ha)	0.75	0.79	0.84	0.82	0.80	3.30	3.61	3.40	3.85	3.54
S ₁ - (Sulphur 15 kg/ha)	0.88	1.22	1.27	1.33	1.18	4.15	4.52	4.64	4.94	4.56
S ₂ - (Sulphur 35 kg/ha)	0.94	1.37	1.39	1.43	1.28	4.39	5.09	5.21	5.32	5.00
S ₃ - (Sulphur 55 kg/ha)	1.06	1.50	1.51	1.53	1.40	5.23	5.54	5.53	5.78	5.52
Mean Z	0.91	1.22	1.26	1.27		4.27	4.69	4.70	4.97	
Factors		Factor S	Factor Z	Factor (S x Z)			Factor S	Factor Z	Factor (S x Z)	
'F' Test		S	S	NS			S	S	NS	
SE. m (±)		0.02	0.02	0.03			0.05	0.05	0.09	
CD _{0.05}		0.05	0.05	-			0.14	0.14	-	

Leaf area index at 90 DAS					
Treatments	Z ₀ -(Zinc 0 kg/ha)	Z ₁ -(Zinc 5 kg/ha)	Z ₂ -(Zinc 10 kg/ha)	Z ₃ -(Zinc 15 kg/ha)	Mean S
S ₀ - (Sulphur 0 kg/ha)	2.38	2.49	2.64	3.43	2.74
S ₁ - (Sulphur 15 kg/ha)	3.33	3.33	3.49	3.65	3.45
S ₂ - (Sulphur 35 kg/ha)	3.11	3.77	3.64	4.04	3.64
S ₃ - (Sulphur 55 kg/ha)	3.72	4.10	4.12	4.27	4.05
Mean Z	3.14	3.42	3.47	3.85	
Factors		Factor S	Factor Z	Factor (S x Z)	
'F' Test		S	S	S	
SE. m (±)		0.06	0.06	0.11	
CD _{0.05}		0.16	0.16	0.33	

3.2 Effect of sulphur and zinc on Yield Attribute of Indian mustard

3.2.1 Number of siliquea per plant

The application of sulphur and zinc significantly influenced the number of siliquea per plant in Indian mustard. Among sulphur treatments, the highest number of siliquea (281.93) was recorded with S3 (55 kg/ha), followed by S2 (35 kg/ha) with 269.22, while the lowest (232.58) was observed in the control (S0). Similarly, zinc levels had a strong impact, with Z3 (15 kg/ha) producing the most siliquea (274.78), followed by Z2 (10 kg/ha)

with 269.56, and the minimum (230.31) under Z0 (0 kg/ha). The combined application of sulphur and zinc also showed significant interaction effects. The maximum number of siliquea per plant (297.79) was found in the S3Z3 treatment (55 kg/ha sulphur + 15 kg/ha zinc), closely followed by S3Z2 (293.70). The lowest siliquea count (212.74) occurred in the S0Z0 treatment. These results indicate that higher levels of sulphur and zinc, especially in combination, greatly enhance siliquea formation and yield potential.

Number of siliquea per plant					
Treatments	Z ₀ -(Zinc 0 kg/ha)	Z ₁ -(Zinc 5 kg/ha)	Z ₂ -(Zinc 10 kg/ha)	Z ₃ -(Zinc 15 kg/ha)	Mean S
S ₀ - (Sulphur 0 kg/ha)	212.74	233.41	240.08	244.08	232.58
S ₁ - (Sulphur 15 kg/ha)	221.21	265.08	267.93	272.15	256.59
S ₂ - (Sulphur 35 kg/ha)	241.53	273.75	276.53	285.08	269.22
S ₃ - (Sulphur 55 kg/ha)	245.75	290.47	293.70	297.79	281.93
Mean Z	230.31	265.68	269.56	274.78	
Factors		Factor S	Factor Z	Factor (S x Z)	
'F' Test		S	S	S	
SE. m (±)		0.69	0.69	1.38	
CD 0.05		2.00	2.00	4.00	

3.2.2 Siliquea length

Application of different sulphur and zinc levels significantly affected siliquea length in Indian mustard. The highest siliquea length (5.99 cm) was recorded with 55 kg/ha sulphur (S3), followed by 5.75 cm in S2 (35 kg/ha), while the lowest (4.46 cm) was observed in the control (S0). Among zinc treatments,

Z3 (15 kg/ha) resulted in the longest siliquea (5.95 cm), followed by Z2 (10 kg/ha) at 5.65 cm, and the shortest (4.48 cm) in Z0. The combined treatment S3Z3 showed the maximum siliquea length (6.48 cm), whereas S0Z0 recorded the minimum (3.99 cm), highlighting the benefit of combined application.

Siliquea length					
Treatments	Z ₀ -(Zinc 0 kg/ha)	Z ₁ -(Zinc 5 kg/ha)	Z ₂ -(Zinc 10 kg/ha)	Z ₃ -(Zinc 15 kg/ha)	Mean S
S ₀ - (Sulphur 0 kg/ha)	3.99	4.23	4.40	5.21	4.46
S ₁ - (Sulphur 15 kg/ha)	4.44	5.51	5.70	5.93	5.40
S ₂ - (Sulphur 35 kg/ha)	4.64	6.03	6.11	6.20	5.75
S ₃ - (Sulphur 55 kg/ha)	4.84	6.27	6.39	6.48	5.99
Mean Z	4.48	5.51	5.65	5.96	
Factors		Factor S	Factor Z	Factor (S x Z)	
'F' Test		S	S	S	
SE. m (±)		0.01	0.01	0.01	
CD 0.05		0.02	0.02	0.04	

3.2.3 Number of seed per siliquea

Different levels of sulphur and zinc significantly influenced the number of seeds per siliquea in Indian mustard. The highest seeds per siliquea (14.53) were recorded with 55 kg/ha sulphur (S3), followed by 13.94 seeds at 35 kg/ha (S2), while the lowest (11.00) was in the control (S0). Among zinc treatments, 15

kg/ha zinc (Z3) yielded the highest seeds per siliquea (13.96), followed by 13.70 seeds at 10 kg/ha (Z2), and the lowest (12.08) in the control (Z0). The combined S3Z3 treatment produced the maximum number of seeds per siliquea (15.36), while the control combination S0Z0 had the minimum (9.45).

Number of seeds per siliquea					
Treatments	Z ₀ -(Zinc 0 kg/ha)	Z ₁ -(Zinc 5 kg/ha)	Z ₂ -(Zinc 10 kg/ha)	Z ₃ -(Zinc 15 kg/ha)	Mean S
S ₀ - (Sulphur 0 kg/ha)	9.45	10.63	11.84	12.08	11.00
S ₁ - (Sulphur 15 kg/ha)	12.83	13.44	13.63	13.88	13.44
S ₂ - (Sulphur 35 kg/ha)	12.63	14.29	14.29	14.53	13.94
S ₃ - (Sulphur 55 kg/ha)	13.42	14.31	15.02	15.36	14.53
Mean Z	12.08	13.17	13.70	13.96	
Factors		Factor S	Factor Z	Factor (S x Z)	
'F' Test		S	S	S	
SE. m (±)		0.12	0.12	0.24	
CD 0.05		0.35	0.35	0.70	

3.2.4 Test weight

The application of sulphur and zinc significantly affected the test weight of Indian mustard seeds. The highest test weight (5.58 grams) was recorded with 55 kg/ha sulphur (S3), followed by 5.26 grams at 35 kg/ha (S2), while the lowest (4.44 grams) was in the control (S0). Among zinc treatments, 15 kg/ha zinc (Z3)

resulted in the highest test weight (5.46 grams), followed by 5.32 grams at 10 kg/ha (Z2), with the minimum (4.36 grams) in the control (Z0). The combined S3Z3 treatment produced the maximum test weight (5.95 grams), whereas the control combination S0Z0 recorded the minimum (4.07 grams).

Test weight (grams)					
Treatments	Z ₀ -(Zinc 0 kg/ha)	Z ₁ -(Zinc 5 kg/ha)	Z ₂ -(Zinc 10 kg/ha)	Z ₃ -(Zinc 15 kg/ha)	Mean S
S ₀ - (Sulphur 0 kg/ha)	4.07	4.28	4.58	4.82	4.44
S ₁ - (Sulphur 15 kg/ha)	4.37	5.10	5.26	5.36	5.02
S ₂ - (Sulphur 35 kg/ha)	4.22	5.54	5.60	5.68	5.26
S ₃ - (Sulphur 55 kg/ha)	4.76	5.75	5.85	5.95	5.58
Mean Z	4.36	5.17	5.32	5.46	
Factors		Factor S	Factor Z	Factor (S x Z)	
'F' Test		S	S	S	
SE. m (±)		0.02	0.02	0.04	
CD _{0.05}		0.05	0.05	0.11	

3.2.5 Seed yield

The highest seed yield per plot (2.67 kg) was recorded with 55 kg/ha sulphur (S₃), followed by 2.44 kg at 35 kg/ha (S₂), while the lowest yield (1.89 kg) occurred in the control (S₀). For zinc, 15 kg/ha (Z₃) resulted in the maximum yield (2.57 kg), followed

by 2.44 kg at 10 kg/ha (Z₂), with the minimum (1.86 kg) in the control (Z₀). The combined application of sulphur and zinc showed that S₃Z₃ produced the highest seed yield (3.02 kg), followed by S₃Z₂ with 2.87 kg, while the lowest yield (1.65 kg) was found in the untreated control S₀Z₀.

Seed yield per plot (kg/plot)					
Treatments	Z ₀ -(Zinc 0 kg/ha)	Z ₁ -(Zinc 5 kg/ha)	Z ₂ -(Zinc 10 kg/ha)	Z ₃ -(Zinc 15 kg/ha)	Mean S
S ₀ - (Sulphur 0 kg/ha)	1.65	1.84	1.93	2.14	1.89
S ₁ - (Sulphur 15 kg/ha)	1.85	2.28	2.36	2.38	2.22
S ₂ - (Sulphur 35 kg/ha)	1.94	2.50	2.61	2.73	2.44
S ₃ - (Sulphur 55 kg/ha)	2.01	2.78	2.87	3.02	2.67
Mean Z	1.86	2.35	2.44	2.57	
Factors		Factor S	Factor Z	Factor (S x Z)	
'F' Test		S	S	S	
SE. m (±)		0.01	0.01	0.03	
CD _{0.05}		0.04	0.04	0.08	

3.2.6 Biological yield

The highest biological yield per plot (9.10 kg) was recorded with 55 kg/ha sulphur (S₃), followed by 8.34 kg at 35 kg/ha (S₂), while the lowest yield (5.74 kg) was observed in the control (S₀). For zinc, 15 kg/ha (Z₃) produced the maximum biological yield (8.45 kg), followed by 7.75 kg at 10 kg/ha (Z₂), with the

minimum (6.12 kg) in the control (Z₀). The combined application of sulphur and zinc showed that S₃Z₃ yielded the highest biological output (9.70 kg), followed by S₃Z₂ with 8.34 kg, while the lowest (5.20 kg) was found in the untreated control S₀Z₀.

Biological yield per plot (kg/plot)					
Treatments	Z ₀ -(Zinc 0 kg/ha)	Z ₁ -(Zinc 5 kg/ha)	Z ₂ -(Zinc 10 kg/ha)	Z ₃ -(Zinc 15 kg/ha)	Mean S
S ₀ - (Sulphur 0 kg/ha)	5.20	5.58	5.82	6.36	5.74
S ₁ - (Sulphur 15 kg/ha)	5.35	6.61	6.80	8.19	6.74
S ₂ - (Sulphur 35 kg/ha)	6.56	8.56	8.68	9.56	8.34
S ₃ - (Sulphur 55 kg/ha)	7.36	9.63	9.70	9.70	9.10
Mean Z	6.12	7.60	7.75	8.45	
Factors		Factor S	Factor Z	Factor (S x Z)	
'F' Test		S	S	S	
SE. m (±)		0.08	0.08	0.16	
CD _{0.05}		0.23	0.23	0.47	

3.2.7 Harvest index

The highest harvest index (33.60%) was recorded with 55 kg/ha sulphur (S₃), followed by 32.32% at 15 kg/ha (S₁), while the lowest (27.03%) occurred in the control (S₀). Among zinc treatments, 15 kg/ha (Z₃) showed the highest harvest index

(31.86%), followed by 10 kg/ha (Z₂) with 31.26%, and the minimum was in the control (Z₀). The combined sulphur and zinc application resulted in the highest harvest index of 34.50% in S₃Z₃, followed by 33.63% in S₃Z₂. The lowest harvest index (22.28%) was observed in the untreated control S₀Z₀.

Harvest index per plot (%)					
Treatments	Z ₀ -(Zinc 0 kg/ha)	Z ₁ -(Zinc 5 kg/ha)	Z ₂ -(Zinc 10 kg/ha)	Z ₃ -(Zinc 15 kg/ha)	Mean S
S ₀ - (Sulphur 0 kg/ha)	22.28	27.26	28.87	29.69	27.03
S ₁ - (Sulphur 15 kg/ha)	31.18	34.42	31.56	29.05	32.32
S ₂ - (Sulphur 35 kg/ha)	29.53	29.15	30.12	31.83	30.16
S ₃ - (Sulphur 55 kg/ha)	33.02	33.24	33.63	34.50	33.60
Mean Z	29.00	31.02	31.26	31.86	
Factors		Factor S	Factor Z	Factor (S x Z)	
'F' Test		S	S	S	
SE. m (±)		0.33	0.33	0.66	
CD _{0.05}		0.96	0.96	1.92	

3.3 Effect of sulphur and zinc on Quality Attribute of Indian mustard

3.3.1 Nitrogen uptake

Nitrogen uptake in mustard seeds and stover improved significantly with varying levels of sulphur and zinc application. In seeds, the highest nitrogen uptake (67.21 kg/ha) was observed with S3 (55 kg/ha sulphur), followed by S2 (59.16 kg/ha), while the lowest was recorded in S0 (43.52 kg/ha). Among zinc treatments, Z3 (15 kg/ha) showed the highest uptake (59.51 kg/ha), and Z0 the lowest (48.56 kg/ha). The combined

effect of sulphur and zinc was more pronounced, with S3Z3 yielding the highest nitrogen uptake in seeds (75.09 kg/ha), while S0Z0 had the minimum (41.36 kg/ha). A similar trend was found in stover, where S3 (76.45 kg/ha) and Z3 (67.98 kg/ha) showed maximum uptake, and S0 and Z0 recorded the lowest. The interaction effect again confirmed the highest nitrogen uptake (84.32 kg/ha) in S3Z3 and the lowest (48.95 kg/ha) in S0Z0. These findings indicate that the combined application of sulphur and zinc significantly boosts nitrogen uptake in mustard, improving nutrient utilization and crop productivity.

Nitrogen uptake (kg/ha) in seed						Nitrogen uptake (kg/ha) in stover				
Treatments	Z ₀ -(Zinc 0 kg/ha)	Z ₁ -(Zinc 5 kg/ha)	Z ₂ -(Zinc 10 kg/ha)	Z ₃ -(Zinc 15 kg/ha)	Mean S	Z ₀ -(Zinc 0 kg/ha)	Z ₁ -(Zinc 5 kg/ha)	Z ₂ -(Zinc 10 kg/ha)	Z ₃ -(Zinc 15 kg/ha)	Mean S
S ₀ - (Zinc 0 kg/ha)	41.36	43.16	43.90	45.67	43.52	48.95	50.74	51.48	53.25	51.11
S ₁ - (Zinc 15 kg/ha)	43.14	46.06	46.33	54.23	47.44	50.73	53.65	53.92	62.05	55.09
S ₂ - (Zinc 35 kg/ha)	50.89	60.89	61.78	63.06	59.16	59.83	70.13	71.02	72.29	68.32
S ₃ - (Zinc 55 kg/ha)	58.86	64.91	69.99	75.09	67.21	68.10	74.14	79.22	84.32	76.45
Mean Z	48.56	53.75	55.50	59.51		56.90	62.17	63.91	67.98	
Factors		Factor S	Factor Z	Factor (S x Z)			Factor S	Factor Z	Factor (S x Z)	
'F' Test		S	S	NS			S	S	NS	
SE. m (±)		1.69	1.69	3.37			1.78	1.78	3.55	
CD 0.05		4.89	4.89	-			5.15	5.15	-	

3.3.2 Phosphorus uptake

Phosphorus uptake in mustard seeds and stover significantly increased with higher zinc and sulphur treatments. In seeds, the highest phosphorus uptake (19.20 kg/ha) occurred under S3 (55 kg/ha zinc), followed by S2 (35 kg/ha) with 17.34 kg/ha, while the control S0 registered the lowest at 13.16 kg/ha. Among zinc levels, Z3 (15 kg/ha) showed the greatest uptake (17.35 kg/ha), followed closely by Z2 (16.98 kg/ha), with the minimum (11.41 kg/ha) under Z0 (0 kg/ha). The interaction of

both nutrients further enhanced uptake—S3Z3 (55 kg/ha zinc + 15 kg/ha zinc) produced the maximum seed phosphorus uptake of 21.35 kg/ha, closely followed by S3Z2 at 19.87 kg/ha. The lowest value, 11.41 kg/ha, was recorded in S0Z0. In stover, phosphorus uptake peaked at 20.41 kg/ha under S3 and 19.20 kg/ha under Z3, with the lowest values in S0 (14.47 kg/ha) and Z0 (15.15 kg/ha). The S3Z3 combination again achieved the highest uptake at 23.90 kg/ha, followed by 21.24 kg/ha in S3Z2, while S0Z0 recorded the minimum of 11.94 kg/ha.

Phosphorus uptake (kg/ha) in seed						Phosphorus uptake (kg/ha) in stover				
Treatments	Z ₀ -(Zinc 0 kg/ha)	Z ₁ -(Zinc 5 kg/ha)	Z ₂ -(Zinc 10 kg/ha)	Z ₃ -(Zinc 15 kg/ha)	Mean S	Z ₀ -(Zinc 0 kg/ha)	Z ₁ -(Zinc 5 kg/ha)	Z ₂ -(Zinc 10 kg/ha)	Z ₃ -(Zinc 15 kg/ha)	Mean S
S ₀ - (Zinc 0 kg/ha)	11.41	13.82	14.39	13.00	13.16	11.94	15.54	15.42	14.99	14.47
S ₁ - (Zinc 15 kg/ha)	12.90	15.43	17.84	16.06	15.56	14.73	16.71	18.42	17.27	16.78
S ₂ - (Zinc 35 kg/ha)	16.88	17.65	15.83	19.00	17.34	16.35	18.77	17.38	20.65	18.29
S ₃ - (Zinc 55 kg/ha)	16.83	18.76	19.87	21.35	19.20	17.59	18.89	21.24	23.90	20.41
Mean Z	14.50	16.42	16.98	17.35		15.15	17.48	18.11	19.20	
Factors		Factor S	Factor Z	Factor (S x Z)			Factor S	Factor Z	Factor (S x Z)	
'F' Test		S	S	S			S	S	S	
SE. m (±)		0.21	0.21	0.42			0.21	0.21	0.41	
CD 0.05		0.61	0.61	1.23			0.60	0.60	1.20	

3.3.3 Potassium uptake

Potassium uptake in mustard seeds and stover significantly improved with the application of sulphur and zinc at varying levels. In seeds, the highest potassium uptake (13.64 kg/ha) was observed under S3 (55 kg/ha sulphur), followed by S2 (12.23 kg/ha), while the lowest (10.84 kg/ha) was noted in the control (S0). Among zinc treatments, Z3 (15 kg/ha) led to the highest uptake (12.76 kg/ha), followed by Z2 (12.30 kg/ha), and the lowest was in Z0 (11.06 kg/ha). The interaction of both

nutrients showed that the S3Z3 combination resulted in the maximum uptake (15.23 kg/ha), while S0Z0 had the lowest (10.31 kg/ha). Similarly, in mustard stover, potassium uptake peaked under S3 (30.29 kg/ha), followed by S2 (26.97 kg/ha), and was lowest in S0 (23.50 kg/ha). Among zinc levels, Z3 showed the highest uptake (27.99 kg/ha), while Z0 had the lowest (24.90 kg/ha). The S3Z3 interaction treatment resulted in the highest potassium uptake in stover (35.06 kg/ha), whereas S0Z0 recorded the minimum (21.06 kg/ha).

Potassium uptake (kg/ha) in seed						Potassium uptake (kg/ha) in stover				
Treatments	Z ₀ -(Zinc 0 kg/ha)	Z ₁ -(Zinc 5 kg/ha)	Z ₂ -(Zinc 10 kg/ha)	Z ₃ -(Zinc 15 kg/ha)	Mean S	Z ₀ -(Zinc 0 kg/ha)	Z ₁ -(Zinc 5 kg/ha)	Z ₂ -(Zinc 10 kg/ha)	Z ₃ -(Zinc 15 kg/ha)	Mean S
S ₀ - (Zinc 0 kg/ha)	10.31	10.75	10.93	11.38	10.84	21.06	23.88	25.51	23.54	23.50
S ₁ - (Zinc 15 kg/ha)	10.75	11.48	11.54	11.64	11.35	24.52	26.60	26.48	25.54	25.79
S ₂ - (Zinc 35 kg/ha)	11.22	12.35	12.53	12.79	12.23	26.34	27.13	26.60	27.82	26.97
S ₃ - (Zinc 55 kg/ha)	11.94	13.17	14.20	15.23	13.64	27.70	28.30	30.12	35.06	30.29
Mean Z	11.06	11.94	12.30	12.76		24.90	26.48	27.17	27.99	
Factors		Factor S	Factor Z	Factor (S x Z)			Factor S	Factor Z	Factor (S x Z)	
'F' Test		S	S	S			S	S	S	
SE. m (±)		0.39	0.39	0.78			0.30	0.30	0.60	
CD 0.05		1.14	1.14	2.27			0.87	0.87	1.74	

3.3.4 Sulphur uptake

Sulphur uptake in mustard seeds and stover increased significantly with the application of sulphur and zinc. In seeds, the highest sulphur uptake (10.18 kg/ha) was recorded under S₃ (55 kg/ha sulphur), followed by S₂ (35 kg/ha) with 8.74 kg/ha, while the lowest (5.28 kg/ha) was observed in the control S₀. Among zinc treatments, Z₃ (15 kg/ha zinc) recorded the highest uptake (8.84 kg/ha), followed by Z₂ (8.48 kg/ha), with the minimum (4.68 kg/ha) in Z₀. The combined application (S₃Z₃)

resulted in the maximum sulphur uptake (10.73 kg/ha), while the minimum (4.40 kg/ha) was in S₀Z₀. In stover, the maximum sulphur uptake (14.35 kg/ha) was observed in S₃, followed by S₂ (12.90 kg/ha), and the lowest (8.29 kg/ha) in S₀. Zinc application also improved uptake, with Z₃ (12.07 kg/ha) highest, followed by Z₂ (11.71 kg/ha), and the lowest (7.63 kg/ha) in Z₀. The combined treatment S₃Z₃ recorded the highest sulphur uptake in stover (14.90 kg/ha), while the lowest (7.05 kg/ha) was seen in S₀Z₀.

Sulphur uptake (kg/ha) in seed						Sulphur uptake (kg/ha) in stover				
Treatments	Z ₀ -(Zinc 0 kg/ha)	Z ₁ -(Zinc 5 kg/ha)	Z ₂ -(Zinc 10 kg/ha)	Z ₃ -(Zinc 15 kg/ha)	Mean S	Z ₀ -(Zinc 0 kg/ha)	Z ₁ -(Zinc 5 kg/ha)	Z ₂ -(Zinc 10 kg/ha)	Z ₃ -(Zinc 15 kg/ha)	Mean S
S ₀ - (Zinc 0 kg/ha)	4.40	5.94	5.15	5.62	5.28	7.05	8.95	8.16	8.63	8.29
S ₁ - (Zinc 15 kg/ha)	4.55	6.85	8.17	7.87	7.32	7.50	9.86	11.18	10.88	10.33
S ₂ - (Zinc 35 kg/ha)	4.70	9.04	8.78	9.71	8.74	7.87	13.21	12.94	13.88	12.90
S ₃ - (Zinc 55 kg/ha)	5.05	9.84	10.38	10.73	10.18	8.09	14.01	14.54	14.90	14.35
Mean Z	4.68	7.92	8.12	8.48		7.63	11.51	11.71	12.07	
Factors		Factor S	Factor Z	Factor (S x Z)			Factor S	Factor Z	Factor (S x Z)	
'F' Test		S	S	S			S	S	S	
SE. m (±)		0.06	0.06	0.11			0.07	0.07	0.14	
CD _{0.05}		0.16	0.16	0.32			0.20	0.20	0.41	

3.3.5 Zinc uptake

Zinc uptake in mustard seeds and stover improved significantly with the application of sulphur and zinc. In seeds, the highest zinc uptake (111.69 g/ha) was recorded under S₃ (55 kg/ha sulphur), followed by S₂ (100.77 g/ha), while the lowest (66.10 g/ha) was in S₀ (0 kg/ha). Among zinc levels, Z₃ (15 kg/ha zinc) led to the highest uptake (106.96 g/ha), followed by Z₂ (102.46 g/ha), with the lowest in Z₀ (53.88 g/ha). The

interaction treatment S₃Z₃ (55 kg/ha sulphur + 15 kg/ha zinc) gave the maximum seed zinc uptake (135.77 g/ha), and S₀Z₀ had the least (55.15 g/ha). In stover, zinc uptake was also highest with S₃ (162.88 g/ha) and Z₃ (158.15 g/ha), while the lowest uptake was under S₀ (117.28 g/ha) and Z₀ (105.06 g/ha). The combined treatment S₃Z₃ recorded the highest zinc uptake (186.96 g/ha), followed by S₃Z₂ (182.73 g/ha), while the lowest uptake (106.34 g/ha) was observed in the control (S₀Z₀).

Zinc uptake (g/ha) in seed						Zinc uptake (g/ha) in stover				
Treatments	Z ₀ -(Zinc 0 g/ha)	Z ₁ -(Zinc 5 g/ha)	Z ₂ -(Zinc 10 g/ha)	Z ₃ -(Zinc 15 g/ha)	Mean S	Z ₀ -(Zinc 0 g/ha)	Z ₁ -(Zinc 5 g/ha)	Z ₂ -(Zinc 10 g/ha)	Z ₃ -(Zinc 15 g/ha)	Mean S
S ₀ - (Zinc 0 g/ha)	55.15	74.43	64.52	70.29	66.10	106.34	125.61	115.70	121.47	117.28
S ₁ - (Zinc 15 g/ha)	52.10	85.86	102.37	98.53	84.71	103.28	137.05	153.55	149.71	135.90
S ₂ - (Zinc 35 g/ha)	53.73	114.67	111.41	123.26	100.77	104.91	165.86	162.60	174.45	151.95
S ₃ - (Zinc 55 g/ha)	54.54	124.92	131.54	135.77	111.69	105.72	176.11	182.73	186.96	162.88
Mean Z	53.88	99.97	102.46	106.96		105.06	151.16	153.64	158.15	
Factors		Factor S	Factor Z	Factor (S x Z)			Factor S	Factor Z	Factor (S x Z)	
'F' Test		S	S	S			S	S	S	
SE. m (±)		1.25	1.25	2.51			1.25	1.25	2.51	
CD _{0.05}		3.64	3.64	7.28			3.64	3.64	7.28	

3.4 Economic parameters

3.4.1 Cost of cultivation

Maximum cost of cultivation was recorded in treatment S₃Z₃ (Sulphur 55 kg/ha + Zinc 15 kg/ha) with Rs 1,01,105 ha⁻¹ followed by S₃Z₂ (Sulphur 55 kg/ha + Zinc 10 kg/ha) with Rs 99,805 ha⁻¹ and the minimum (Rs 89,505 ha⁻¹) was recorded in treatment S₀Z₀ (Sulphur 0 kg/ha + Zinc 0 kg/ha).

3.4.2 Gross return

Maximum gross returns were recorded in treatment S₃Z₃ (Sulphur 55 kg/ha + Zinc 15 kg/ha) with (Rs 2,04,621 ha⁻¹) followed by S₃Z₂ (Sulphur 55 kg/ha + Zinc 10 kg/ha) with (Rs 94,898 ha⁻¹) and the minimum (Rs 1,12,146 ha⁻¹) was recorded in treatment S₀Z₀ (Sulphur 0 kg/ha + Zinc 0 kg/ha).

3.4.3 Net Return

Maximum net returns were recorded in treatment S₃Z₃ (Sulphur 55 kg/ha + Zinc 15 kg/ha) with (Rs 1,03,516 ha⁻¹) followed by S₃Z₂ (Sulphur 55 kg/ha + Zinc 10 kg/ha) with (Rs 95,093 ha⁻¹) and the minimum (Rs 22,641 ha⁻¹) was recorded in treatment S₀Z₀ (Sulphur 0 kg/ha + Zinc 0 kg/ha).

3.4.4 Benefits cost ratio

Maximum benefit cost ratio was recorded in treatment S₃Z₃ (Sulphur 55 kg/ha + Zinc 15 kg/ha) with 2.02 ha⁻¹ followed by S₃Z₂ (Sulphur 55 kg/ha + Zinc 10 kg/ha) with 1.95 ha⁻¹ and the minimum (1.25 ha⁻¹) was recorded in treatment S₀Z₀ (Sulphur 0 kg/ha + Zinc 0 kg/ha).

Treatment	Sulphur dose	Zinc dose	Total cost of cultivation (INR)	Seed yield (t/ha)	Gross return (INR)	Net return (INR)	BC ratio
S ₀ Z ₀	0 kg/ha	0 kg/ha	89505	1.88	1,12,146	22,641	1.25
S ₀ Z ₁		5 kg/ha	90805	2.10	1,25,033	34,228	1.38
S ₀ Z ₂		10 kg/ha	92105	2.20	1,31,138	39,033	1.42
S ₀ Z ₃		15 kg/ha	93405	2.44	1,44,930	51,525	1.55
S ₁ Z ₀	15 kg/ha	0 kg/ha	91605	2.11	1,25,259	33,654	1.37
S ₁ Z ₁		5 kg/ha	92905	2.60	1,54,426	61,521	1.66
S ₁ Z ₂		10 kg/ha	94205	2.69	1,59,853	65,648	1.70
S ₁ Z ₃		15 kg/ha	95505	2.71	1,61,435	65,930	1.69
S ₂ Z ₀	35 kg/ha	0 kg/ha	94405	2.21	1,31,364	36,959	1.39
S ₂ Z ₁		5 kg/ha	95705	2.85	1,69,349	73,644	1.77
S ₂ Z ₂		10 kg/ha	97005	2.98	1,77,262	80,257	1.83
S ₂ Z ₃		15 kg/ha	98305	3.11	1,84,950	86,645	1.88
S ₃ Z ₀	55 kg/ha	0 kg/ha	97205	2.29	1,36,112	38,907	1.40
S ₃ Z ₁		5 kg/ha	98505	3.17	1,88,341	89,836	1.91
S ₃ Z ₂		10 kg/ha	99805	3.28	1,94,898	95,093	1.95
S ₃ Z ₃		15 kg/ha	101105	3.44	2,04,621	1,03,516	2.02

4. Conclusion

The combined application of sulphur at 55 kg/ha and zinc at 15 kg/ha (S3Z3) was the most effective treatment for enhancing mustard crop performance. This treatment resulted in the maximum plant height of 165.47 cm, significantly higher than all other treatments, due to sulphur and zinc promoting meristematic activity and cell elongation for vigorous growth. The highest number of branches per plant (9.62) was also recorded under S3Z3, indicating improved plant structure and photosynthetic capacity. Additionally, S3Z3 produced the greatest number of siliques per plant (356.83), contributing to better reproductive success. Seed yield peaked at 24.38 q/ha with S3Z3, showcasing the synergistic effect of sulphur and zinc in nutrient use efficiency and assimilate partitioning. The harvest index was highest (35.42%), reflecting improved biomass conversion into economic yield. The treatment also recorded the highest oil content at 41.27%, highlighting sulphur's role in oil biosynthesis and zinc's role in enzyme activation during lipid metabolism. Economically, S3Z3 provided the highest gross returns (Rs 2,04,621/ha) and the best benefit-cost ratio, emphasizing its profitability. Overall, the S3Z3 treatment significantly enhanced mustard growth, yield, quality, and economic returns, underscoring the importance of balanced sulphur and zinc nutrition for optimal crop production.

5. References

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