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INFLUENCE OF SULPHUR AND ZINC FERTILIZATION ON GROWTH AND YIELD OF INDIAN MUSTARD (*BRASSICA JUNCEA* L.) IN A VERTISOL

Vishakha Rai*, H. K. Rai, A. K. Upadhyay and Prinsu Singh
Department of Soil Science and Agricultural Chemistry, College of Agriculture Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh, India
*Corresponding Author E-mail: vishakharadha@gmail.com
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ABSTRACT

Field experiment was conducted during two successive *Rabi* seasons of 2022–23 and 2023–24 at research field of Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur to assess the effects of sulphur and zinc levels on the growth and yield of Indian mustard (*Brassica juncea* L.) grown in under maize-mustard cropping in a medium black soil characterized by high clay content and possess 12.78 mg kg^{-1} and 0.65 mg kg^{-1} available sulphur and zinc, respectively. The experiment was laid in split-plot design consisting of three levels of sulphur (0, 20, and 40 kg ha^{-1}) as main plot treatments and five levels of zinc (0, 2.5, 5, 7.5, and 10 kg ha^{-1}) as sub-plot treatments which had been replicated thrice. The results indicated that growth plant height and SPAD value), yield attributes (number of siliquae per plant and seed test weight) and yield (seed and stover) parameters of mustard were significantly affected by levels of sulphur and zinc application. Present study concluded that application of Sulphur (40 Kg ha^{-1}) and Zinc (10 Kg ha^{-1}) with recommended doses of fertilizers can increase the growth and yield of mustard.
***Keywords* :** Mustard, sulphur, zinc, growth, yield and SPAD value

Introduction

Indian mustard (*Brassica juncea* L.) is India's second-most important oilseed crop, following soybean, accounting for almost one-fourth of the country's oilseed cultivation area and production (Jat *et al.*, 2019). It is cultivated on 8.06 million hectares, producing 11.75 million tonnes, with an average yield of 1458 kg ha^{-1}. In Madhya Pradesh, mustard occupies about 1.23 million hectares, contributing an annual production of approximately 1.69 million tonnes (DOAC, 2023). However, mustard cultivation is increasingly shifting to marginal lands with low productivity due to competition with other food grain crops. Concurrently, the growing population has led to a continual rise in edible oil demand, necessitating a substantial increase in production to meet the requirements.

The suboptimal yield of mustard is attributed to various factors, including improper agronomic practices, imbalanced nutrient application, and soil nutrient depletion. Yield declines are often closely associated with soil degradation, particularly nutrient depletion caused by insufficient or imbalanced fertilizer use (Roy *et al.*, 2003; Haque *et al.*, 2014; Tan *et al.*, 2005; Chaudhary *et al.*, 2007). Fertilizer application plays a critical role in improving crop productivity, and efficient nutrient management is vital for sustaining and enhancing yield (Sultana *et al.*, 2019; Sultana *et al*., 2015).

Sulphur (S) is a vital nutrient for mustard, contributing significantly to yield, quality, and resistance to abiotic and biotic stresses. It is essential for chlorophyll synthesis, nitrogen metabolism, and the production of sulphur-containing amino acids such as methionine (21% S), cysteine (26% S), and cystine (27% S), which collectively account for approximately 90% of plant sulphur content. Sulphur also aids in synthesizing glucosinolates, contributing to mustard oil's characteristic flavor, and activates various enzymatic processes (Kumar *et al.*, 2018). The indiscriminate use of high-analysis fertilizers with little or no sulphur content has led to widespread sulphur deficiencies in Indian soils, particularly under intensive cropping systems. Research indicates that sulphur application under irrigated conditions can enhance mustard yields by up to 50% (Aulakh, 2003).

Zinc (Zn), a crucial micronutrient, plays an indispensable role in maintaining metabolic processes such as photosynthesis, sugar synthesis, auxin production, and protein formation. It also enhances disease resistance, seed yield, and tolerance to environmental stresses like heat and salinity (Nadaf and Chandranath, 2019; Solanki *et al.*, 2016; Peck and McDonald, 2010; Tavallali *et al.,* 2010). However, Zn deficiency has become prevalent in mustard due to intensive cropping systems and the absence of Zn in standard NPK fertilizers. Symptoms of Zn deficiency include stunted growth, delayed maturity, and reduced yields, underscoring the importance of incorporating zinc into nutrient management (Islam *et al.*, 2017; Alloway, 2004; Maqsood *et al.,* 2009). Adequate Zn levels improve water-use efficiency, branching, stover yield, and grain production (Asad and Rafique, 2000; Torun *et al.,* 2000; Maqsood *et al.,* 2009).

Considering the significant roles of sulphur and zinc in improving mustard growth, yield, and quality, this study was undertaken to evaluate the influence of sulphur and zinc fertilization on Indian mustard in Vertisol, aiming to optimize productivity while maintaining soil health.

Materials and Methods

The present study was done during two consecutive Rabi seasons of 2022–2023 and 2023–2024 at the experimental farm, Department of Soil Science and Agricultural Science, JNKVV, Jabalpur. This location geographically is situated at a latitude of $23^0$13' N and a longitude of $79^0$57' E and an elevation of 411.78 meters above the mean sea level in the southeastern region of Madhya Pradesh. At physiological maturity, observations about growth parameters, such as plant height, branches per plant, and the number of Siliquae per plant, were recorded by averaging the values of the five plants in each plot. The height of the plant was measured with the help of a meter scale from the base to the tip of the plant which was estimated at 30, 60, 90 DAS and at the time of harvesting. Average plant height was computed and expressed in cm. The total number of siliqua per plant was also counted manually. Chlorophyll content was recorded with the help of a Chlorophyll meter (SPAD) at 30, 60 and 90 DAS and expressed as SPAD unit.

Experimental setup

The experiment consisted of included three levels of sulphur, (0, 20, and 40 kg ha^{-1}), while the subplot treatments incorporated five zinc levels (0, 2.5, 5, 7.5, and 10 kg ha^{-1}) each with 15 treatment combinations arranged in a split-plot design with 3 replications.

Statistical analysis

Recorded data were analyzed using the appropriate 'Analysis of Variance (ANOVA)' method given by Gomez and Gomez (1984). The mean significant differences were compared by Tukey's HSD test at $p < .05$.

Result and Discussion

Plant height

Sulphur application significantly enhanced mustard plant height at all growth stages during 2022-23 and 2023-24 (Table 1 and Figure 1). Among the sulphur levels tested, the application of 40 kg ha^{-1} sulphur resulted in the highest plant height. This treatment was significantly superior to the 0 kg ha^{-1} sulphur level across both years of the study. Additionally, the 20 kg ha^{-1} sulphur level is significantly superior to the 0 kg ha^{-1} level and was statistically at par with the 40 kg ha^{-1} level, this suggests that sulphur, likely through its role in protein synthesis and enzymatic activities, is crucial for promoting mustard growth. The application of sulphur, had a significant impact on mustard growth, promoting enhanced vegetative development and height. This is consistent with previous findings where sulphur, application enhanced plant metabolic functions, including enzyme activation and protein synthesis, which contributed to taller plants (Anupma, V. (2024); Kumar *et al.,* (2018); Verma *et al.,* (2018); Singh and Singh (2017)).

Among the zinc levels tested, significant variation was observed, with the application of 10 kg ha^{-1}zinc showing the best performance. This treatment resulted in significantly higher plant height at all growth stages as compared to the 0 kg ha^{-1} zinc level in the first and second years of research, respectively. The enhanced growth at higher zinc levels can be attributed to zinc's role in enzyme activation and hormone regulation. These findings are in agreement with previous research showing that zinc plays a critical role in promoting plant growth by influencing auxin synthesis and chlorophyll formation, both of which are vital for cell division and elongation (Anupama, V. (2024); Kumar *et al.,* (2018); Verma *et al.,* (2018); Singh and Singh (2017).

Table 1: Effect of Sulphur and zinc levels on temporal change in plant height of mustard

	Plant height (cm)							
	30 DAS		60 DAS		90 DAS		At harvest	
	2022-23	2023-24	2022-23	2023-24	2022-23	2023-24	2022-23	2023-24
Main plot treatments: S-levels (kg ha^{-1})								
0.0	17.3	23.5	126.1	112.7	142.1	143.2	147.3	151.9
20.0	18.9	25.2	133.1	122.8	151.9	156.1	156.8	160.9
40.0	19.5	27.1	139.3	133.2	163.9	165.9	167.2	169.6
S Em +	0.23	0.18	0.90	1.45	1.67	1.70	1.52	1.59
CD (*p=0.05*)	0.64	0.52	2.55	4.09	4.73	4.80	4.23	4.50
Sub-plot treatments: Zn-levels (kg ha^{-1})								
0.0	17.2	23.3	126.6	115.8	146.8	147.7	150.2	154.4
2.5	17.4	24.0	131.5	118.3	150.7	150.6	153.4	157.3
5.0	19.2	25.2	133.4	122.1	153.3	155.9	158.7	161.5
7.5	19.4	26.4	134.8	128.5	155.3	158.4	160.9	164.8
10.0	19.5	27.4	137.9	129.7	157.1	162.8	162.3	165.9
S Em +	0.69	0.22	1.95	1.09	1.96	1.20	1.45	1.39
CD (*p=0.05*)	1.96	0.61	5.52	3.07	5.54	3.39	4.09	3.93
Interaction (Main x Sub): Comparison of main plot at the same level of sub plot treatments								
S Em +	1.20	0.38	3.38	1.88	3.39	2.08	2.50	2.40
CD (*p=0.05*)	NS	NS	NS	NS	NS	NS	NS	NS
Interaction (Main x Sub): Comparison of sub plot at the same or different levels of main plot treatments								
S Em +	1.16	0.50	3.52	3.35	4.52	3.87	3.74	3.84
CD (*p=0.05*)	NS	NS	NS	NS	NS	NS	NS	NS

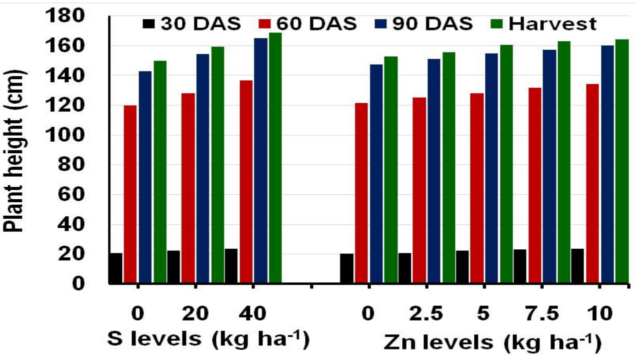

Fig. 1: Effect of Sulphur and zinc levels on temporal change in plant height of mustard (pooled value)

Chlorophyll Index (SPAD)

At 30 DAS, the highest SPAD value was observed with 40 kg S ha^{-1} (38.55 in 2022-23 and 36.72 in 2023-24). The control treatment (0 kg S ha^{-1}) had the lowest SPAD values, indicating the importance of sulphur in promoting early chlorophyll formation (Table 2 and Figure 2). At 60 DAS, SPAD values increased with S levels, with the highest value (44.29 in 2022-23 and 42.2 in 2023-24) at 40 kg S ha^{-1}, demonstrating improved plant vigor and photosynthetic capacity at mid-growth. At 90 DAS, the trend remained consistent, with 40 kg S ha^{-1} showing the highest SPAD values (36.35 in 2022-23 and 34.38 in 2023-24), reflecting sustained chlorophyll content due to adequate sulphur nutrition. The increase in SPAD values with sulphur application suggests improved photosynthetic efficiency. Rubisco/soluble protein ratio and protein synthesis enhanced crop photosynthetic capacity and chlorophyll formation, adequate sulphur supply is required for carbohydrate formation as it plays a vital role in photosynthesis by influencing the formation of chlorophyll which ultimately improves the growth and development of crop (Bhinda *et al.,* 2023).

Zinc application also had a positive and statistically significant effect on SPAD values at all stages. At 30 DAS, SPAD values increased from 32.85 (control, 0 kg Zn ha^{-1}) to 35.2 (10 kg Zn ha^{-1}) in 2022-23, and from 31.83 to 35.21 in 2023-24, suggesting that zinc contributes to early chlorophyll synthesis. At 60 DAS, the highest SPAD value was recorded at 10 kg Zn ha^{-1} (43.12 in 2022-23 and 40.84 in 2023-24), showing improved plant photosynthetic activity during peak growth. By 90 DAS, the trend remained similar, with 10 kg Zn ha^{-1} showing the highest SPAD values (35.57 in 2022-23 and 34.28 in 2023-24). Zinc plays a critical role in chlorophyll production and maintaining plant health. The increase in chlorophyll content was due to the increased concentration of Zn in the plant system, which is a constituent of photosynthetic and N-assimilating enzymes. These enzymes helped ultimately in chlorophyll formation (Alloway, 2008).

Table 2: Effect of Sulphur and zinc levels of mustard on SPAD Value

	Chlorophyll Index (SPAD)					
	30 DAS		**60 DAS**		**90 DAS**	
	2022-23	**2023-24**	**2022-23**	**2023-24**	**2022-23**	**2023-24**
Main plot treatments: S-levels (kg ha^{-1})						
0.0	26.55	29.87	38.43	30.08	28.46	29.33
20.0	36.53	33.61	41.42	39.91	34.07	33.52
40.0	38.55	36.72	44.29	42.20	36.35	34.38
S Em +	1.08	1.11	0.93	1.11	1.07	0.79
CD (*p=0.05*)	3.44	4.36	2.87	4.34	3.78	2.44
Sub-plot treatments: Zn-levels (kg ha^{-1})						
0.0	32.85	31.83	39.57	33.66	30.99	30.44
2.5	33.29	32.90	40.47	36.26	31.57	31.71
5.0	33.57	33.37	41.55	37.62	32.90	32.62
7.5	34.47	33.69	42.19	38.61	33.77	33.00
10.0	35.20	35.21	43.12	40.84	35.57	34.28
S Em +	0.43	0.36	0.87	0.59	0.68	0.75
CD (*p=0.05*)	1.26	1.04	2.56	1.72	1.97	2.19
Interaction (Main x Sub): Comparison of main plot at the same level of sub plot treatments						
S Em +	0.75	0.62	1.51	1.03	1.17	1.31
CD (*p=0.05*)	NS	NS	NS	NS	NS	NS
Interaction (Main x Sub): Comparison of sub plot at the same or different levels of main plot treatments						
S Em +	1.88	2.29	1.99	2.40	2.20	1.71
CD (*p=0.05*)	NS	NS	NS	NS	NS	NS

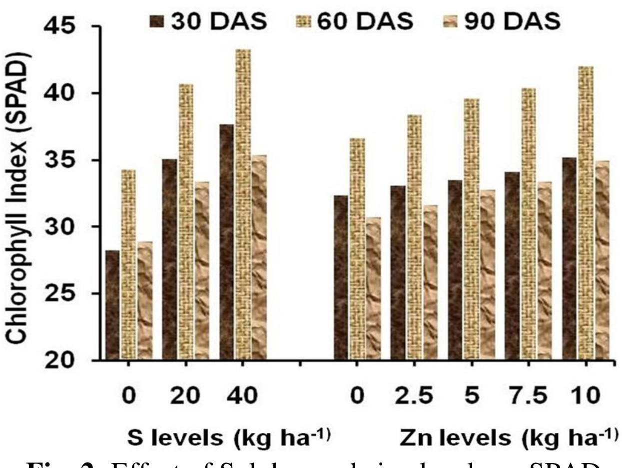

Fig. 2: Effect of Sulphur and zinc levels on SPAD Value of Mustard (pooled Value)

Yield and Yield attributes

A significant effect of treatments was noted on the yield constituents of mustard ((Table 3 and Figure 3). Among the sulphur levels, an increase in sulphur application led to successive improvements in yield attributes, namely, the number of siliquae per plant, 1000-seed weight, and the Seed and stover yield of mustard. The maximum values for these traits were observed with the application of 40 kg ha^{-1} sulphur, which was significantly superior to the 0 kg ha^{-1} sulphur level but remained statistically at par with the 20 kg ha^{-1} sulphur level during both years of research. The results are also substantiated by the findings reported by Rana *et al.*, 2020, Kumar *et al.*, 2018, Singh *et al.* 2015, Sultana *et al.*, 2015, Tripathi *et al.*, 2010, Verma *et al.*, 2020, Verma *et al.*, 2018

Similarly, zinc application at 10 kg ha^{-1} produced the highest number of siliquae per plant, test weight and seed and stover yield compared to lower values observed in the untreated control. However, there was no significant interaction between sulphur and zinc levels, indicating that their individual effects were more pronounced in enhancing growth and yield parameters. The results are also substantiated by the findings reported by Rana *et al.*, 2020, Kumar *et al.*, 2018, Singh *et al.*, 2015, Sultana *et al.*, 2015, Tripathi *et al.*, 2010, Verma *et al.*, 2020, Verma *et al.*, 2018.

Table 3: Effect of Sulphur and zinc levels Yield attributes and Seed and stover yield of mustard

	Siliquae per plant		**Test weight (g)**		**Seed Yield (kg ha^{-1})**		**Stover Yield (kg ha^{-1})**	
	2022-23	**2023-24**	**2022-23**	**2023-24**	**2022-23**	**2023-24**	**2022-23**	**2023-24**
Main plot treatments: S-levels (kg ha^{-1})								
0.0	211.3	215.6	4.87	4.92	1110	1376	2433	2454
20.0	240.3	244.8	5.05	5.14	1345	1482	2694	2993
40.0	255.5	263.1	5.14	5.20	1458	1522	2830	3124
S Em +	7.14	7.09	0.01	0.04	27.55	26.40	47.01	61.29
CD (*p=0.05*)	21.77	21.54	0.04	0.10	82.85	80.10	145.3	185.7
Sub-plot treatments: Zn-levels (kg ha^{-1})								
0.0	217.6	224.0	4.87	4.88	1115	1353	2424	2726
2.5	229.4	234.6	4.92	5.01	1196	1427	2583	2780
5.0	235.0	239.6	5.08	5.15	1328	1459	2632	2892
7.5	242.4	247.2	5.11	5.19	1400	1506	2777	2909
10.0	253.7	260.3	5.12	5.21	1483	1555	2848	2979
S Em +	4.03	4.58	0.05	0.03	68.50	19.03	90.63	36.92
CD (*p=0.05*)	12.08	14.83	0.15	0.08	208.7	58.19	273.3	113.6
Interaction (Main x Sub): Comparison of main plot at the same level of sub plot treatments								
S Em +	7.22	8.80	0.09	0.05	123.9	34.53	162.2	67.41
CD (*p=0.05*)	NS	NS	NS	NS	NS	NS	NS	NS
Interaction (Main x Sub): Comparison of sub plot at the same or different levels of main plot treatments								
S Em +	12.79	13.51	0.08	0.08	118.5	47.89	162.8	112.2
CD (*p=0.05*)	NS	NS	NS	NS	NS	NS	NS	NS

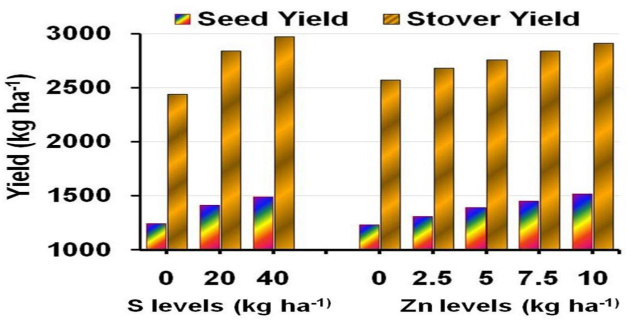

Fig. 3a: Effect of Sulphur and zinc levels on Seed and stover yield of Mustard (Pooled Value)

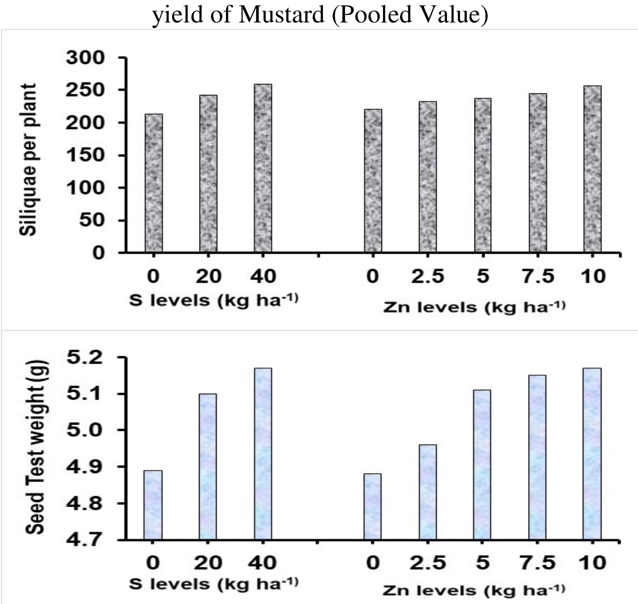

Fig. 3b: Effect of Sulphur and zinc levels on siliquae plant^{-1} and 1000 seed weight of Mustard (Pooled Value)

Conclusion

The present study concludes that the application of sulphur at 40 kg ha^{-1} and zinc at 10 kg ha^{-1} led to notable improvements in agronomic traits and yield components, resulting in the higher seed and stover yield. The increasing levels of sulphur and zinc showed a marked positive impact on growth traits and yield compared to the absence of these nutrients across both years of experimentation. Specifically, the application of 40 kg ha^{-1} of sulphur and 10 kg ha^{-1} of zinc significantly enhanced plant height at all growth stages, the number of siliquae per plant, 1000-seed weight, chlorophyll index (SPAD value), and ultimately the seed and stover yield. However, these effects were statistically at par with the treatment combination of 20 kg S and 7.5 kg Zn ha^{-1}, suggesting that these treatments were also highly effective in promoting growth and yield compared to other treatment combinations.

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