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EFFECT OF SULPHUR AND ZINC ON GROWTH AND YIELD ATTRIBUTES OF MUSTARD UNDER RAINFED CONDITION IN BUNDELKHAND REGIONS OF INDIA

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ABSTRACT

A field experiment was conducted during *rabi* season 2025-26 at Attara P.G. College Attara (U.P.) under the Bundelkhand University Jhansi. To find out the effect of soil sulphur and zinc for enhancing the productivity of mustard and evaluate the economics of applied treatments. The experiment conducted in Randomized block design (RBD), with three replications and 9 treatments. The result revealed that T_9 [(NPK (100%) + S (40 kg) Zn (5kg)] was recorded significantly the highest growth parameters viz., plant height (139.70 cm), Branches plant^{-1} (14.95 branches plant^{-1}), Dry weight (43.59 g) at harvest. Yield attributes and Yields, the maximum number of siliqua plant^{-1} (284.19), Number of seeds siliqua^{-1} (11.00) and Test weight (6.34 g) was recorded under treatment T_9 [NPK (100%) + S (40 kg ha^{-1}) + Zn (5 kg ha^{-1})], which was statistically at par with T_6 [NPK (100%) + S (40 kg ha^{-1}) + Zn (2.5 kg ha^{-1})] and T_8 [NPK (100%) + S (20 kg ha^{-1}) + Zn (5 kg ha^{-1})], while the minimum was recorded under T_1 - NPK (100%) alone. Similarly, the economics of mustard cultivation were significantly influenced by different levels of sulphur and zinc application. the maximum cost cultivation (Rs. 35657 ha^{-1}), gross return (Rs. 126,798 ha^{-1}), net return (Rs. 91,140 ha^{-1}) and B:C ratio (3.56) was registered under the treatment T_9 - NPK (100%) + S (40 kg) Zn (5kg) which was followed by T_6 NPK (100%) + S (40kg) Zn (2.5kg) (35208 Rs/ha) which was superior over T_1. As a result, this treatment was advised for achieving increased productivity and profitability.

***Keywords*:** Economics, Growth parameters, Productivity, Profitability, Yield attributes and Yields.

Introduction

Indian mustard (*Brassica juncea* L.) popularly known as Rai, which is cultivated throughout the world belongs to family Brassicaceae. Mustard is the major *rabi* oil seed crop of India, occupying a place next to groundnut in area and production. It is a major source of edible oil and contributes significantly to meeting the domestic demand for vegetable oils. India is among the leading producers of rapeseed-mustard in the world. Mustard is cultivated in the state of Rajasthan, Madhya Pradesh and Uttar Pradesh. The mustard seed oil content range between 10-20 % protein, 8-10 % fibres, 6-10% moisture, and 10-12 % extractable substance with higher nutritive value (Pandey *et al.*, 2013). India contributes as the third largest producer of oil seed crop in the world and Mustard requires well-drained sandy loam soil. It is a fast-growing plant which has good yield potential, wide adaptability and possesses high oil content of good quality (Shekhwat *et al.*, 2012).

Globally, rapeseed-mustard is cultivated over 42.86 million hectares, contributing 87.85 million tonnes to the global oilseed basket, with an average yield of 2049.6 kg/ha (FAOSTAT, 2024). Indian mustard production in India is highly concentrated in a few major states, which together contribute the bulk of national output. Among these, Rajasthan occupies the leading position, contributing more than 40 per cent of the total production followed by Uttar Pradesh (19.02 %) and Haryana (11.32 %). Other important mustard-growing states include Madhya Pradesh (about 8-9%), West Bengal (6-7%), Gujarat, Assam and Jharkhand (each contributing around 3-4%), whereas Bihar, Punjab and other states contribute relatively smaller shares (less than 2%) to the total production. Within India, the crop occupies 8.65 M ha, producing 12.66 Mt with an average yield of 1463 kg/ha. In Madhya Pradesh, the area occupied under rapeseed-mustard is 1.63 m ha with the annual production of 2.41 million tonnes and average productivity of 1474 kg/ha (Anonymous, 2024-25). This uneven distribution highlights the regional concentration of mustard cultivation and indicates the potential for increasing productivity in other states through improved agronomic practices and nutrient management strategies.

The combined application of sulphur and zinc has been reported to improve nutrient uptake, dry matter accumulation, yield attributes and oil content of mustard. Adequate sulphur and zinc nutrition also enhances nutrient use efficiency and helps in maintaining long-term soil health under intensive cropping systems (Chandel *et al*., 2026). Sulphur and zinc nutrition are closely associated with oilseed metabolism and their combined application often produces synergistic effects on crop growth and productivity. Balanced application of sulphur and zinc improves nutrient use efficiency, enhances photosynthetic activity and promotes better translocation of assimilates towards reproductive organs. Several researchers observed that integrated use of sulphur and zinc significantly increased plant height, number of branches, siliqua per plant, seeds per siliqua, test weight, seed yield, stover yield and oil content in mustard crop (Bhambu *et al*., 2025). To achieve high growth, productivity and profitability in a sustainable manner it is important to adjust the dosages of zinc and sulphur especially when reducing the amount of fertilizer used. The aim of the study was to assess the growth productivity, and profitability of mustard. Thus, realizing the importance of sulphur and zinc application and limited availability of research on these aspects in Bundelkhand region.

Method and Materials

The present field experiment was carried out during *rabi* season 2025-26 at Attara P.G. College Attara (U.P.) under the Bundelkhand University Jhansi. lies between 25.29^o North latitude and 80.56^o East longitude with an altitude of 124 to 134 m from mean sea level. The experiment was laid out in simple randomized block design (RBD) with three replications. The climatic condition extremely hot during summer and enjoy very cold during winter. Weekly meteorological data showed that the maximum temperature ranged from 18.0°C to 40.0°C. Whereas minimum temperature ranged from 8.0°C to 30.0°C. The minimum and maximum relative humidity was observed in 6% in March and 100 % in November 2025 and January, 2026 respectively. The soil of experimental area was Sandy clay loam, with 6.8 pH, 230.6 kg ha^{-1} available N, 26.8 kg ha^{-1} available P and 240.3 kg ha^{-1} available K. 5 kg ha^{-1} seeds were sown manually in line, having row spacing of 45 cm × 10cm at 18 November 2025. 80 kg ha^{-1} nitrogen, 40 kg ha^{-1} phosphorus and 40 kg ha^{-1} potash., P & K were applied as basal dose nitrogen was applied in split dose. Gross return was obtained by the formula,

$$\text{Gross returns} = \text{seed yield} \times \text{minimum support price}$$

while stover returns were calculated using the sold price at local market. Net returns were obtained by formula

$$\text{Net returns} = \text{Gross return} - \text{total cost of cultivation}$$

The BCR was calculated by formula

$$\text{BCR} = \frac{\text{Gross return}}{\text{Cost of cultivation}}.$$

Statistical analysis was done with the help of window-based SPSS based on ANOVA (F-test) as per the method suggested by Gomez and Gomez (1984) and critical difference (CD) was work out at 0.05 level of significance for comparison.

Details of the treatment

S. No	Symbol	Treatment
01	T_1	T_1 NPK (100%)
02	T_2	T_2 NPK (100%) + S (20kg.) Zn (0kg)
03	T_3	T_3 NPK (100%) + S (40kg) Zn (0kg)
04	T_4	T_4 NPK (100%) + S (0kg) Zn (2.5kg)
05	T_5	T_5 NPK (100%) + S (20kg) Zn (2.5kg)
06	T_6	T_6 NPK (100%) + S (40kg) Zn (2.5kg)
07	T_7	T_7 NPK (100%) + S (0kg) Zn (5kg)
08	T_8	T_8 NPK (100%) + S (20kg) Zn (5kg)
09	T_9	T_9 NPK (100%) + S (40kg) Zn (5kg)

Result and Discussion

Effect of sulphur and zinc on growth

The data on account of growth parameter viz., plant height (cm), number of branches and dry weight at harvest was significantly influenced by the application of sulphur and zinc and presented in Table -1.

The present investigation revealed that the combined application of sulphur and zinc along with the recommended dose of NPK fertilizers significantly improved plant height, number of branches per plant, and dry matter accumulation of mustard at harvest. Among the various treatments, T_9- NPK (100%) + S

(40 kg) Zn (5kg) recorded the highest plant height (139.70 cm), branches per plant (14.95), and dry weight (43.59 g plant^{-1}), which remained statistically at par with T_8 - NPK (100%) + S (20kg) Zn (5 kg) (135.91 cm), T_6 NPK (100%) + S (40 kg) Zn (2.5 kg) (134.59 cm), T_5 NPK (100%) + S (20 kg) Zn (2.5kg) and T_7 NPK (100%) + S (0 kg) Zn (5 kg). The lowest values of plant height (121.97 cm), branches per plant (9.37) and dry matter accumulation (27.60 g plant^{-1}) were observed under T_1 **-** NPK (100%). It might due the increased plant height, number of branches/plant and dry matter accumulation under combined application of sulphur and zinc might be due to the synergistic effect of the nutrients in regulating different physiological and biochemical processes in mustard. Sulphur is an important component of sulphur amino acids, proteins, chlorophyll and enzymes that improve photosynthetic efficiency, nutrient uptake and the production of plant metabolites. Zinc is important for the synthesis of auxin, protein metabolism, activation of enzyme and cell division and hence helps in stem elongation, branching and overall growth of the plant. Balanced supply of sulphur and zinc improves metabolic activities, nitrogen utilization and growth of photosynthetically active tissues resulting in better source-sink relationships. Under adequate sulphur and zinc nutrition, higher accumulation of dry matter and production of biomass were due to increased chlorophyll content, rate of photosynthesis and efficient translocation of photosynthates from source to sink. Thus, synergistic interaction of sulphur and zinc enhanced nutrient use efficiency and overall growth performance of mustard. Similar beneficial effects of sulphur and zinc on plant height and number of branches/plant in mustard were also reported by Sipai *et al.* (2017), Singh *et al.* (2020), Saini *et al.* (2024), Jaiswal *et al*. (2025) and furthermore Rai *et al*. (2025) observed that application of 40 kg S ha^{-1} along with higher zinc levels significantly improved dry biomass accumulation in mustard due to enhanced nutrient metabolism and photosynthetic efficiency.

Effect of sulphur and zinc on yield attributes and yield

The data on account of yield attributes viz., number of siliqua plant^{-1}, number of siliqua^{-1} and test weight (g) and yield viz., seed yield, straw yield and harvest index was significantly influenced by the application of sulphur and zinc and presented in Table-2.

The present investigation revealed that the number of siliqua plant^{-1} was significantly influenced by the combined application of sulphur and zinc along with NPK. The maximum number of siliqua plant^{-1} (284.19), Number of seeds siliqua^{-1} (11.00) and Test weight (6.34 g) was recorded under treatment T_9 [NPK (100%) + S (40 kg ha^{-1}) + Zn (5 kg ha^{-1})], which was statistically at par with T_6 [NPK (100%) + S (40 kg ha^{-1}) + Zn (2.5 kg ha^{-1})] and T_8 [NPK (100%) + S (20 kg ha^{-1}) + Zn (5 kg ha^{-1})], while the minimum was recorded under T_1 - NPK (100%) alone. It might due the increase in number of siliqua plant^{-1}, number of seeds siliqua^{-1} and test weight due to combined application of sulphur and zinc may be attributed to the improved nutritional and physiological status of mustard plants. Sulphur is essential for the synthesis of sulphur-containing amino acids, proteins and oils, while zinc plays a role in enzyme activation, auxin synthesis and reproductive development. Adequate supply of both nutrients enhanced the photosynthetic activity, assimilate production and translocation towards reproductive sinks leading to better flower retention, siliqua formation and seed development. The higher test weight under sulphur and zinc fertilization might be attributed to better seed filling and accumulation of photosynthates during the grain development stage. Hence, the synergistic interaction of sulphur and zinc improved the source-sink relationship and reproductive efficiency leading to better yield attributes in mustard. These results are in close conformity with the findings Dubey *et al.* (2013), Singh and Singh (2017), Verma *et al.* (2020), Ramya *et al.* (2022), Singh *et al.* (2023), Saini *et al.* (2024), Jaiswal *et al.* (2025) and Bhambu *et al.* (2025).

The seed yield, straw yield and harvest index of mustard were significantly influenced by different levels of sulphur and zinc application. Yield is the cumulative effect of various growth and yield contributing characters and largely depends upon balanced nutrient availability throughout the crop growth period. In the present investigation, the data revealed that the maximum seed yield (2047 kg ha^{-1}), straw yield (4981 kg ha^{-1}) biological yield (7029 kg ha^{-1}) and harvest index (29.09 %) was recorded under the treatment T_9 **-** NPK (100%) + S (40 kg) Zn (5kg) which was statistical at par with, T_6 NPK (100%) + S (40kg) Zn (2.5kg) and T_8 - NPK (100%) + S (20kg) Zn (5kg). Whereas, the table also revealed that the minimum seed yield was recorded under the treatment T_1 **-** NPK (100%). The combined application of sulphur and zinc enhanced nutrient uptake and metabolic efficiency, resulting in increased number of siliqua plant^{-1}, seeds siliqua^{-1} and test weight, which ultimately contributed to higher seed yield. The increase in straw yield under sulphur and zinc treatments may be due to vigorous vegetative growth and greater biomass accumulation resulting from balanced nutrition.

Sulphur improves protein synthesis and chlorophyll formation, while zinc enhances growth hormone production and metabolic activities, thereby promoting plant height, branching and dry matter accumulation. Consequently, treatments receiving higher sulphur and zinc levels produced greater vegetative biomass and straw yield compared to RDF alone. The maximum harvest index recorded under T_9 indicates more efficient conversion of total biomass into economic yield. Balanced sulphur and zinc nutrition improved reproductive efficiency and assimilate partitioning towards seed development, resulting in higher harvest index. The comparatively lower harvest index under T_1 may be due to poor nutrient utilization and reduced reproductive growth caused by deficiency of sulphur and zinc. The present findings are in close conformity with those reported by Tiwari *et al.* (2021), Rathore *et al.* (2022), Saini *et al.* (2024), Bhambu *et al.* (2025), Jaiswal *et al.* (2025).

Effect of sulphur and zinc on economics

The data on account of economics viz., cost of cultivation, gross return, net return and B:C ratio was significantly influenced by the application of sulphur and zinc and presented in Table 2.

The economics of mustard cultivation were significantly influenced by different levels of sulphur and zinc application. the maximum cost cultivation (35657 Rs/ha), gross return (Rs. 126,798 ha^{-1}), net return (Rs. 91,140 ha^{-1}) and B:C ratio (3.56) was registered under the treatment T_9 - NPK (100%) + S (40 kg) Zn (5kg) which was followed by T_6 NPK (100%) + S (40kg) Zn (2.5kg) (35208 Rs/ha) which was superior over $T_{1.}$ The higher cost of cultivation under T_9 and T_6 was mainly due to additional expenditure incurred on sulphur and zinc fertilizers. However, the increase in cultivation cost was compensated by substantially higher seed and biological yield, resulting in superior economic returns over RDF alone. The higher gross return and net return recorded under T_9 may be attributed to enhanced seed yield, straw yield and improved yield attributes resulting from balanced sulphur and zinc nutrition. Sulphur plays a vital role in chlorophyll synthesis, protein formation and oil biosynthesis, while zinc regulates enzymatic activity, auxin synthesis and carbohydrate metabolism. Adequate supply of these nutrients improved photosynthetic efficiency, dry matter accumulation and assimilate translocation towards reproductive organs, thereby increasing economic yield and gross income. Similarly, higher straw yield under balanced nutrition also contributed towards increased gross return. The benefit: cost ratio was also highest under T_9, indicating better economic efficiency and profitability of sulphur and zinc application. Higher B:C ratio under integrated nutrient management reflects the fact that additional expenditure on sulphur and zinc fertilizers generated proportionately greater economic returns through increased yield and biomass production. The comparatively lower B:C ratio under T_1 might be due to nutrient imbalance and lower productivity resulting from absence of sulphur and zinc supplementation. The present findings are in close conformance with the results reported by Sipai *et al.* (2017), who observed significant improvement in gross return, net return and benefit: cost ratio of mustard under combined sulphur and zinc fertilization. Similar findings were also reported by Saini *et al.* (2024), who stated that balanced application of sulphur and zinc significantly enhanced profitability and economic efficiency of mustard cultivation through improvement in yield and nutrient uptake efficiency. Jaiswal *et al.* (2025) also reported that integrated sulphur and zinc nutrition resulted in higher economic returns due to improved growth, yield attributes and seed productivity in Indian mustard. Similar findings were also reported by Singh *et al.* (2010).

Conclusion

From the above investigation, it is concluded that sulphur and zinc fertilization had a sustainable influence growth, productivity and profitability of mustard. The present study found consistent evidence that the application of NPK (100%) + S (40 kg) Zn (5kg) offers substantial agronomic and economic advantages. Based on the findings of one year investigation it may be concluded that for higher productivity and profitability.

Table 1: Effect of sulphur and zinc on growth, yield attributes of mustard

Treatments	Plant height at harvest	Number of branches $plant^{-1}$	Dry weight (g)	Number of silique $plant^{-1}$	Number of seeds $siliqua^{-1}$	Test weight (g)
T_1 NPK (100%)	121.97	9.37	27.60	158.93	8.65	5.42
T_2 NPK (100%) + S (20kg.) Zn 0kg	127.68	10.49	29.95	225.17	9.22	5.98
T_3 NPK (100%) + S (40kg) Zn (0kg)	130.75	11.88	32.45	245.30	9.40	6.10
T_4 NPK (100%) + S (0kg) Zn (2.5kg)	129.44	11.13	30.61	222.67	9.14	5.92
T_5 NPK (100%) + S (20kg) Zn (2.5kg)	133.39	12.22	38.47	252.48	9.67	6.11

T_6 NPK (100%) + S (40kg) Zn (2.5kg)	134.59	14.49	40.72	269.18	10.21	6.22
T_7 NPK (100%) + S (0kg) Zn (5kg)	132.13	12.10	37.83	242.28	9.28	6.08
T_8 NPK (100%) + S (20kg) Zn (5kg)	135.91	13.12	38.58	256.66	9.74	6.15
T_9 NPK (100%) + S (40kg) Zn (5kg)	139.70	14.95	43.59	284.19	11.00	6.34
S.E(m)±	**2.69**	**0.22**	**0.08**	**9.98**	**0.31**	**0.03**
C.D. at 5%	**8.06**	**0.67**	**0.24**	**29.93**	**0.94**	**0.09**

Table 2: Effect of sulphur and zinc on yield and economics of mustard

Treatments	Seed yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest index (%)	Cost of cultivation (Rs./ha)	Gross return (Rs./ha)	Net return (Rs./ha)	B: C ratio
T_1 NPK (100%)	1172	3070	27.76	31919	72785	40865	2.28
T_2 NPK (100%) + S (20kg.) Zn 0kg	1553	3899	28.50	33336	96322	62986	2.89
T_3 NPK (100%) + S (40kg) Zn (0kg)	1663	4155	28.59	34753	103123	68370	2.97
T_4 NPK (100%) + S (0kg) Zn (2.5kg)	1333	3371	28.40	32451	82704	50253	2.55
T_5 NPK (100%) + S (20kg) Zn (2.5kg)	1740	4329	28.67	33792	107839	74047	3.19
T_6 NPK (100%) + S (40kg) Zn (2.5kg)	1890	4678	28.77	35208	117133	81925	3.33
T_7 NPK (100%) + S (0kg) Zn (5kg)	1413	3634	28.17	32983	87727	54744	2.66
T_8 NPK (100%) + S (20kg) Zn (5kg)	1813	4581	28.37	34241	112475	78234	3.28
T_9 NPK (100%) + S (40kg) Zn (5kg)	2047	4981	29.09	35657	126798	91140	3.56
S.E(m)±	**57.41**	**136.27**	**1.04**	**--**	**3442.83**	**3442.83**	**0.10**
C.D. at 5%	**172.12**	**408.52**	**NS**	**--**	**10321.47**	**10321.47**	**0.30**

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