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Sulphur and zinc fertilization for improving productivity and quality of mustard (*Brassica juncea* L. Czern)

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Abstract
A field experiment was conducted at Agronomy Research Field, College of Agriculture, Gwalior (M.P.) during *rabi* seasons of 2018-19 and 2019-20. The soil of the experimental field was alluvial and sandy clay loam in texture. Twenty four treatment combinations administered in mustard consisted of 4 sulphur levels (0, 20, 40 & 60 kg ha^{-1}), three Zn levels (0, 2.5 & 5 kg ha^{-1}) and two zinc solubilizing bacteria levels (without zinc solubilizer & with zinc solubilizer) were replicated three times in randomized block design (factorial). Higher value of growth parameters (like; plant height (cm), number of branches plant^{-1}, and dry matter accumulation plant^{-1}), yield attributes (*viz.*; number of silliquae plant^{-1}, and 1000 seeds weight), qualitative parameters (*viz.*; oil content and nutrient viz.; N, P, K, S & Zn content in seed) as well as computed parameters (*viz.*; seed yield, biological yield and HI) and gross return were recorded significantly under 60 kg ha^{-1} S level, which was statistically at par with 40 kg ha^{-1} S level; while lower value was noted under 0 kg ha^{-1} S level. Maximum value of various parameters were recorded under 5 kg ha^{-1} Zn level, which was statistically at par with 2.5 kg ha^{-1} Zn level; while significantly minimum value was noted under 0 kg ha^{-1} Zn level. Significantly superior value of different attributes was noted with zinc solubilizer; while minimum value was recorded without zinc solubilizer. In case of B:C ratio; higher B:C ratio was recorded significantly under 20 kg ha^{-1} S level + 5 kg ha^{-1} Zn level ((3.22), which was statistically at par with 40 kg ha^{-1} S level + 5 kg ha^{-1} Zn level (3.17); while lower value was noted under 60 kg ha^{-1} S level + 0 kg ha^{-1} Zn level (2.82).

Keywords: B:C ratio, HI, mustard, qualitative parameters, yield attributes

Introduction
Indian mustard (*Brassica juncea* L. Czern) is the most important *rabi* oilseed crops in India. About 18% of the nation's total oilseed production is made up of the crops rapeseed and mustard in India. The requirement of vegetable oil and fat will be the much higher in coming years in view of ever increasing population. Among the oilseed crop rapeseed mustard occupy rank next to soybean in acreage and production. Indian mustard, Brown and Yellow Sarson, Raya, and Toria Crop belong to the mustard-rapeseed species. Gujarat, Rajasthan, Madhya Pradesh, the United Provinces, Haryana, and several southern states including Andhra Pradesh, Karnataka, and Tamil Nadu are among the states that grow Indian mustard. Sulfur has recently come to be recognised as a crucial ingredient for improving the quality and production of all crops, particularly oilseeds and pulses. Sulfur has a crucial role in the synthesis of important amino acids like methionine, cysteine, and cysteine, as well as oils in oilseeds, and as such, it has an impact on the yield and quality of the crop. According to estimates, India is one of the top nations in the world for mustard production, coming in third in terms of area (19.3%) behind Canada (24.6%) and China (20.6%). (Anonymous, 2021b) [2].
Currently, in India, 7.39 M ha of land is planted to rapeseed and mustard, yielding an estimated 8.95 MT on an average of 1211 kg ha-1 (Anonymous, 2021a) [1].
Sulphur deficiency has recently been detected in more than 50% of Indian soils. Another obstacle that is restricting agricultural output is a lack of micronutrients in the soil. Due to intensive agriculture, the use of high analysis fertilisers, and farmers' inadequate or nonexistent usage of zinc fertilisers, zinc insufficiency appears to be the most widely prevalent. Tandon (2010) [13] reported that sulphur deficiency trends to affect adversely the growth and yield of oilseed crop, which reduces the crop yield to an extent of 10-30%. Highest Zn deficiency in alluvial soils may be attributed to very low organic carbon, very high sand content, large number of ravines and top soil losses through run-off (Yadav and Meena, 2009) [17].

Beside inorganic fertilizers sources of nutrients, bio-fertilizers such as rhizobium, azotobacter, azospirillum, PSB, AM etc. are being used to meet partially the nutrient requirement of crops. In this series of bio-fertilizers zinc solubilizer, a bio-fertilizer has been developed to improve the availability of native zinc in the soil. Zinc solubilizer is a new entry in the group of bio-fertilizers and no-work has been carried on its efficiency to substitute zinc requirement of crops under field conditions. Zinc has been reported to interact with other plant nutrient. Under Zn and S; synergistic, antagonistic and no interaction have been reported and the relationship between S and Zn is not clear-cut (Takkar and Colin, 1989) [12]. S and Zn interaction can be positive or absent depending on the degree of their deficiency and crop requirement.

Methodology

To carry out the investigation during *rabi* seasons of 2018-19 and 2019-20 at Agronomy Research Field, College of Agriculture, Gwalior (M.P.). The area was uniform topography. The experimental field was gentle slope provides free drainage of excessive water, which is an essential condition for mustard crop growing. Twenty four treatment combinations administered in mustard consisted of 4 sulphur levels (0, 20, 40 & 60 kg ha^{-1}), three Zn levels (0, 2.5 & 5 kg ha^{-1}) and two zinc solubilizing bacteria levels (without zinc solubilizer & with zinc solubilizer) were replicated three times in randomized block design (factorial). The 80 kg N, 40 kg P_2O_5 and 40 kg K_2O per hectare were optimum dose (100%) for NPK. Half dose of the N in the form of urea was applied as basal and remaining quantity of nitrogen was top dressed after first irrigation. The Complete Dose of P and K were applied by DAP and muriate of potash at the time of sowing. Mustard variety 'Rohini' was sown at row spacing of 30 cm with seed rate of 5 kg ha^{-1}. All recommended practices were followed during crop growing season. All parameters were statistically analyzed by null method as described by Fisher (1958) [3] and Panse and Sukhatme (1967) [5].

Results and Discussion

The results have revealed several points of interest are discussed in this chapter. During the course of discussion an effort has been made to establish relationship between various treatments and yield of the crop. All findings of research have been described as per pooled data.

The various treatments significantly affected the growth parameters like; plant height (cm), number of branches plant^{-1}, and dry matter accumulation plant^{-1} at all stages of crop growth except their interactions (Table 1). Significantly maximum value of growth parameters was recorded under 60 kg/ha S level, which was statistically at par with 40 kg/ha S level; while minimum value was observed under 0 kg/ha S level at all growth stages. Higher value of growth parameters was registered significantly under 5 kg/ha Zn level, which was statistically at par with 2.5 kg/ha Zn level; while lower value was recorded under 0 kg/ha Zn level at all growth stages. Superior value of growth parameters was noted with zinc solubilizer; while significantly minimum value was recorded without zinc solubilizer at all growth stages. The increase in growth attributes might be due to adequate availability of sulphur and zinc attributed to better nutritional environment for plant growth at active vegetative stages as a result of enhancement in cell multiplications, cell elongation and cell expression in the plant body. The results of present investigation are also in agreement with the findings of Singh *et al*. (2016) [10], Sahu *et al*. (2018) [7] and Verma *et al*. (2020) [16].

The yield attributes *viz*.; number of silliquae plant^{-1}and 1000 seeds weight were significantly affected by different treatments except their interactions (Table 1). Higher number of yield attributeswas recorded significantly under 60 kg ha^{-1} S level (254.50 and 3.81 g; respectively), which was statistically at par with 40 kg ha^{-1} S level (251.62and 3.77 g; respectively); while lower value was noted under 0 kg ha^{-1} S level (216.69 and 3.25 g; respectively). Significantly maximum number of yield attributes was registered under 5 kg ha^{-1} Zn level (250.78and3.76 g; respectively),which was statistically at par with 2.5 kg ha^{-1} Zn level (248.35and3.72 g; respectively); while minimum value was recorded under 0 kg ha^{-1} Zn level (227.19and3.40 g; respectively).Superior value of yield attributes was observed with zinc solubilizer (247.82and3.71 g; respectively); while significantly minimum value was recorded without zinc solubilizer (236.40and3.54 g; respectively).This may be due to efficient nutrients level combination provided congenial condition to the crop for proper development on its reproductive phase resulted in the enhancement of all yield contributing characters have also been reported by Singh *et al*. (2016) [10], Singh *et al*. (2017) [8, 9], Nath *et al*. (2018) [6], Meena *et al*. (2018) [4] and Rana *et al*. (2018) [6].

The qualitative parameters *viz*.; oil content and nutrient (N, P, K, S & Zn) content in seed were significantly influenced various treatments except Zinc solubilizing bacteria and all interactions (Table 1). Significantly higher qualitative parameters were recorded under 60 kg ha^{-1} S level, which was statistically at par with 40 kg ha^{-1} S level; while lower value was noted under 0 kg ha^{-1} S level. Maximum qualitative parameters were recorded under 5 kg ha^{-1} Zn level, which was statistically at par with 2.5 kg ha^{-1} Zn level; while significantly minimum value was observed under 0 kg ha^{-1} Zn level. Significantly superior value of N and K content in seed was noted with zinc solubilizer (2.897% and 0.668%; respectively); while minimum value was recorded without zinc solubilizer (2.856% and 0.658%; respectively). The increase in sulphur and zinc uptake might be due to increased concentration of sulphur and zinc in soil with the application of sulphur and zinc. The higher sulphur concentration in seed and stover resulted in greater uptake of sulphur and zinc in plant. The result of present investigation is corroborating with the findings of Sipai *et al*. (2016) [11] and Rana *et al*. (2018) [6].

The computed parameters *viz*.; seed yield, biological yield and HI were significantly influenced various treatments and S x Z & Z x I interactions except other interactions (Table 2, 3 & 4). Significantly higher value of computed parameters were registered under 60 kg ha^{-1} S level (1755 kg ha^{-1}, 5734 kg ha^{-1}and 30.631%; respectively), which was statistically at par with 40 kg ha^{-1} S level (1734 kg ha^{-1}, 5691 kg ha^{-1} and 30.480% respectively); while lower value was recorded under 0 kg ha^{-1} S level (1478 kg ha^{-1}, 5110 kg ha^{-1}and 28.923%; respectively). Maximum value of computed parameters were recorded under 5 kg ha^{-1} Zn level (1750 kg ha^{-1}, 5688 kg ha^{-1}and 30.736%; respectively),which was statistically at par with 2.5 kg ha^{-1} Zn level (1710 kg ha^{-1}, 5636 kg ha^{-1}and 30.313%; respectively); while significantly minimum value was noted under 0 kg ha^{-1} Zn level (1541 kg ha^{-1}, 5283 kg ha^{-1}and 29.218%; respectively).Significantly superior value of seed yield and biological yield were noted with zinc solubilizer (1696 kg ha^{-1} and 5613 kg ha^{-1}; respectively);

while minimum value was recorded without zinc solubilizer (1638 kg ha^{-1} and 5458 kg ha^{-1}; respectively).Higher value of seed yield was registered under 60 kg ha^{-1} S level + 5 kg ha^{-1} Zn level (1856 kg ha^{-1}),which was statistically at par with 40 kg ha^{-1} S level + 2.5 kg ha^{-1} Zn level (1837 kg ha^{-1}); while significantly lower value was recorded under 0 kg ha^{-1} S level + 0 kg ha^{-1} Zn level (1440 kg ha^{-1}).Significantly maximum seed yield was noted under 5 kg ha^{-1} Zn level + with zinc solubilizer (1758 kg ha^{-1}),which was statistically at par with 5 kg ha^{-1} Zn level + without zinc solubilizer (1742 kg ha^{-1}); while minimum value was recorded under 0 kg ha^{-1} Zn level + without zinc solubilizer (1481 kg ha^{-1}).Maximum harvest index was recorded under 5 kg ha^{-1} Zn level + without zinc solubilizer (30.961%), which was statistically at par with 5 kg ha^{-1} Zn level + with zinc solubilizer (30.512%); while significantly minimum value was registered under 0 kg ha^{-1} Zn level + without zinc solubilizer (28.609%).The increase in seed yield under adequate sulphur supply might be ascribed mainly due to the combined effect of higher number of siliquae/plant, more number of seeds siliqua^{-1} and higher 1000-seed weight, which was the result of better translocation of photosynthates from source to sink. Sulphur also stimulates the pod setting, seed formation and oil synthesis and seed to stover ratio in mustard and it increases the biological, seed, stover yields and harvest index of mustard. Singh *et al*. (2016) [10], Nath *et al*. (2018) [6] and Verma and Dawson (2018) [15] also reported the similar results.

The gross return and B:C ratio was significantly influenced by various treatments as well as interactions except S x I and S x Zn x I interactions(Table 2, 3 & 4). Significantly higher value of gross return was recorded under 60 kg ha^{-1} S level (Rs.72194 ha^{-1}), which was statistically at par with 40 kg ha^{-1} S level (Rs.71322 ha^{-1}); while lower value was registered under 0 kg ha^{-1} S level (Rs.60917 ha^{-1}). In case of B:C ratio; significantly higher B:C ratio was noted under 20 kg ha^{-1} S level (3.10), which was statistically at par with 40 kg ha^{-1} S level (3.06); while lower value was recorded under 0 kg ha^{-1} S level (2.88). Maximum value of gross return and B:C ratio was noted under 5 kg ha^{-1} Zn level (Rs.71971 ha^{-1} and 3.09; respectively),which was statistically at par with 2.5 kg ha^{-1} Zn level (Rs.70357 ha^{-1} and 3.06; respectively); while significantly minimum value was recorded under 0 kg ha^{-1} Zn level (Rs.63516 ha^{-1} and 2.88; respectively).Superior value of gross return was recorded significantly with zinc solubilizer (Rs.69783 ha^{-1}); while minimum value was registered without zinc solubilizer (Rs.67446 ha^{-1}). In case of B:C ratio; significantly superior B:C ratio was recorded without zinc solubilizer (3.01); while minimum value was noted without zinc solubilizer (3.00).

Significantly higher value of gross return was recorded under 60 kg ha^{-1} S level + 5 kg ha^{-1} Zn level (Rs.76264 ha^{-1}),which was statistically at par with 40 kg ha^{-1} S level + 2.5 kg ha^{-1} Zn level (Rs.75505 ha^{-1}); while lower value was registered under 0 kg ha^{-1} S level + 0 kg ha^{-1} Zn level (Rs.59408 ha^{-1}). In case of B:C ratio; higher B:C ratio was recorded significantly under 20 kg ha^{-1} S level + 5 kg ha^{-1} Zn level ((3.22), which was statistically at par with 40 kg ha^{-1} S level + 5 kg ha^{-1} Zn level (3.17); while lower value was noted under 60 kg ha^{-1} S level + 0 kg ha^{-1} Zn level (2.82). Maximum value of gross return was recorded under 5 kg ha^{-1} Zn level + with zinc solubilizer (Rs.72308 ha^{-1}), which was statistically at par with 5 kg ha^{-1} Zn level + without zinc solubilizer (Rs.71634 ha^{-1}); while significantly minimum value was noted under 0 kg ha^{-1} Zn level + without zinc solubilizer (Rs.61115 ha^{-1}). In case of B:C ratio; significantly maximum B:C ratio was recorded under 5 kg ha^{-1} Zn level + without zinc solubilizer (3.13), which was statistically at par with 2.5 kg ha^{-1} Zn level + without zinc solubilizer (3.08); while minimum value was noted under 0 kg ha^{-1} Zn level + without zinc solubilizer (2.83). These results are in tune with the findings of Singh and Pandey (2017) [8, 9], Sahu *et al*. (2018) [7] and Upadhyay *et al*. (2018a) [14].

Table 1: Effect of sulphur and zinc fertilization on growth, yield and qualitative parameters in mustard

Treatment	Plant height (cm)	No. of branches plant^{-1}	Dry matter accumulation plant^{-1} (g)	No. of Silliquae plant^{-1}	1000 seed weight (g)	Oil Content (%)	N (%)	P (%)	K (%)	S (%)	Zn (ppm)
Sulphur Level (S)											
0 kg ha^{-1}	160.03	7.04	25.43	216.69	3.25	40.17	2.767	0.567	0.638	1.140	20.44
20 kg ha^{-1}	181.45	7.98	28.83	245.62	3.68	42.04	2.897	0.594	0.667	1.193	21.40
40 kg ha^{-1}	185.47	8.16	29.53	251.62	3.77	42.30	2.914	0.597	0.672	1.200	21.53
60 kg ha^{-1}	188.19	8.28	29.87	254.50	3.81	42.50	2.928	0.600	0.675	1.206	21.63
SE(m)±	2.28	0.09	0.35	3.00	0.04	0.31	0.020	0.004	0.005	0.009	0.16
CD at 5%	6.46	0.27	1.00	8.49	0.11	0.89	0.057	0.012	0.013	0.025	0.46
Zinc Level (Z)											
0 kg ha^{-1}	168.25	7.40	26.67	227.19	3.40	40.94	2.821	0.578	0.650	1.161	20.84
2.5 kg ha^{-1}	183.28	8.06	29.15	248.35	3.72	42.08	2.900	0.594	0.668	1.194	21.42
5 kg ha^{-1}	184.81	8.13	29.43	250.78	3.76	42.23	2.910	0.596	0.670	1.198	21.50
SE(m)±	1.98	0.08	0.31	2.60	0.03	0.27	0.017	0.004	0.004	0.008	0.14
CD at 5%	5.60	0.23	0.86	7.35	0.10	0.77	0.049	0.011	0.012	0.022	0.40
Zinc Solubilizing Bacteria (I)											
Without Zinc Solubilizer	174.50	7.68	27.75	236.40	3.54	41.45	2.856	0.585	0.658	1.176	21.10
With Zinc Solubilizer	183.07	8.05	29.09	247.82	3.71	42.05	2.897	0.594	0.668	1.193	21.40
SE(m)±	1.62	0.07	0.25	2.12	0.03	0.22	0.014	0.003	0.003	0.006	0.11
CD at 5%	4.57	0.19	0.70	6.00	0.08	NS	0.040	NS	0.010	NS	NS
Interaction											
S x Z	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
S x I	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Z x I	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
S x Z x I	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 2: Effect of sulphur and zinc fertilization on computed parameters and economics in mustard

Treatment	Seed yield (kg ha^{-1})	Biological yield (kg ha^{-1})	HI (%)	Gross Return (Rs. ha^{-1})	B:C Ratio (Rs. ha^{-1})
Sulphur Level (S)					
0 kg ha^{-1}	1478	5110	28.923	60917	2.88
20 kg ha^{-1}	1702	5608	30.322	70026	3.10
40 kg ha^{-1}	1734	5691	30.480	71322	3.06
60 kg ha^{-1}	1755	5734	30.631	72194	2.99
SE(m)±	11	53	0.197	438	0.02
CD at 5%	30	150	0.556	1238	0.05
Zinc Level (Z)					
0 kg ha^{-1}	1541	5283	29.218	63516	2.88
2.5 kg ha^{-1}	1710	5636	30.313	70357	3.06
5 kg ha^{-1}	1750	5688	30.736	71971	3.09
SE(m)±	9	46	0.170	379	0.02
CD at 5%	26	130	0.481	1072	0.05
Zinc Solubilizing Bacteria (I)					
Without Zinc Solubilizer	1638	5458	29.988	67446	3.01
With Zinc Solubilizer	1696	5613	30.190	69783	3.00
SE(m)±	7	37	0.139	309	0.01
CD at 5%	21	106	NS	875	NS
Interaction					
S x Z	S	NS	NS	S	S
S x I	NS	NS	NS	NS	NS
Z x I	S	NS	S	S	S
S x Z x I	NS	NS	NS	NS	NS

Table 3: Interaction effect of sulphur and zinc fertilization on computed parameters and economics of mustard

Treatment	Seed yield (kg ha^{-1})				Gross Return (Rs. ha^{-1})				B:C Ratio (Rs. ha^{-1})			
S/Z	0 kg ha^{-1}	20 kg ha^{-1}	40 kg ha^{-1}	60 kg ha^{-1}	0 kg ha^{-1}	20 kg ha^{-1}	40 kg ha^{-1}	60 kg ha^{-1}	0 kg ha^{-1}	20 kg ha^{-1}	40 kg ha^{-1}	60 kg ha^{-1}
0 kg ha^{-1}	1440	1547	1579	1599	59408	63762	65045	65849	2.91	2.92	2.88	2.82
2.5 kg ha^{-1}	1489	1754	1785	1811	61384	72161	73415	74468	2.87	3.17	3.12	3.07
5 kg ha^{-1}	1503	1804	1837	1856	61960	74154	75505	76264	2.86	3.22	3.17	3.10
SE(m)±	18				758				0.03			
CD at 5%	52				2144				0.09			

Table 4: Interaction effect of zinc and zinc solubilizing bacteria fertilization on computed parameters and economics of mustard

Treatment	Seed yield (kg ha^{-1})			HI (%)			Gross Return (Rs. ha^{-1})			B:C Ratio (Rs. ha^{-1})		
Z/I	0 kg ha^{-1}	2.5 kg ha^{-1}	5 kg ha^{-1}	0 kg ha^{-1}	2.5 kg ha^{-1}	5 kg ha^{-1}	0 kg ha^{-1}	2.5 kg ha^{-1}	5 kg ha^{-1}	0 kg ha^{-1}	2.5 kg ha^{-1}	5 kg ha^{-1}
Without Zinc Solubilizer	1481	1691	1742	28.609	30.393	30.961	61115	69589	71634	2.83	3.08	3.13
With Zinc Solubilizer	1601	1728	1758	29.827	30.232	30.512	65916	71125	72308	2.93	3.04	3.04
SE(m)±	13			0.241			536			0.02		
CD at 5%	37			0.681			1516			0.07		

Conclusion

Higher value of growth parameters, yield attributes, qualitative parameters as well as computed parameters and gross return were recorded significantly under 60 kg ha^{-1} S level, which was statistically at par with 40 kg ha^{-1} S level; while lower value was noted under 0 kg ha^{-1} S level.

Maximum value of growth parameters, yield attributes, qualitative parameters as well as computed parameters, gross return and B:C ratio were recorded under 5 kg ha^{-1} Zn level, which was statistically at par with 2.5 kg ha^{-1} Zn level; while significantly minimum value was noted under 0 kg ha^{-1} Zn level.

Significantly superior value of growth parameters, yield attributes, qualitative parameters as well as computed parameters and gross return were noted with zinc solubilizer; while minimum value was recorded without zinc solubilizer.

In case of interaction (S x Zn) as per B:C ratio; higher B:C ratio was recorded significantly under 20 kg ha^{-1} S level + 5 kg ha^{-1} Zn level ((3.22), which was statistically at par with 40 kg ha^{-1} S level + 5 kg ha^{-1} Zn level (3.17); while lower value was noted under 60 kg ha^{-1} S level + 0 kg ha^{-1} Zn level (2.82).

In case of other interaction (Zn x Zinc solubilizing bacteria) as per B:C ratio; significantly maximum B:C ratio was recorded under 5 kg ha^{-1} Zn level + without zinc solubilizer (3.13), which was statistically at par with 2.5 kg ha^{-1} Zn level + without zinc solubilizer (3.08); while minimum value was noted under 0 kg ha^{-1} Zn level + without zinc solubilizer (2.83).

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Conflict of Interest

None

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