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Residual effect of varying levels of sulphur, zinc and boron on yield, yield attributing characters, nutrient uptake and quality in mustard *(Brassica juncea* L.*)* grown after cluster bean in a Mollisol

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ABSTRACT

A field experiment was conducted at G.B.P.U.A.T, Pantnagar, to study the residual effect of varying levels of sulphur, zinc and boron in mustard grown after cluster bean crop in a Mollisol. The experiment was conducted with 13 treatments comprising of soil as well as foliar application. The highest seed yield (1.74 t ha^{-1}) and stover yield (5.25 t ha^{-1}) were recorded from 40 kg and 60 S ha^{-1}, respectively. The highest total B uptake (91.48 g ha^{-1}was observed under 1.5 kg B ha^{-1}. The highest total Zn uptake by the pods (86.07 g ha^{-1}) was observed under combined foliar applications of 0.25% Zn and 0.20% borax. However, the highest total S uptake (35.43 kg ha^{-1} was observed under 60 kg S ha^{-1}. It was concluded that with application of 4 kg Zn ha^{-1}, 1.5 kg B ha^{-1}, and 40 kg S ha^{-1}, a better yield of the mustard and B, Zn, and S absorption can be attained.

Keywords: Mustard, boron, zinc, sulphur, seed, stover, yield, oil, content and uptake.

INTRODUCTION

Indian mustard (*Brassica juncea* L.) belongs to the family Brassicaceae and commonly called as rai or Indian mustard. It contains good amount of oil usually 30–38% (Thomas *et al.*, 2004). The mustard oil contains low amount of saturated fatty acids among vegetable oils. It is a good source of essential fatty acids (EFA) viz. linolenic acid 2 and linoleic acid. It has also anti-cancer properties due to presence of antioxidant (tocopherol) in oil and glucosinolates (e.g., indolyl glucosinolate) in seed meal. The nutrient management helps to increase the productivity of mustard crop up to 18 to 73% over the traditional packages and practices (Kumar, 2012). Intensification of agriculture and imbalanced nutrient management in crop production are responsible for multinutrient deficiencies in Indian soils particularly macronutrients namely N, P, K, S and micronutrients namely Zn and B , thus yield of mustard is significantly influenced by application of S, Zn and B. Sulphur application enhances mustard yield both under irrigated and rainfed conditions by 12–48% and 17–124%, respectively (Aulakh and Pasricha, 1988). Sulphur is essential for synthesis of cystine (27% S), cysteine (26% S) and methionine (21% S) amino acids which contain 90% of total sulphur (Havlin *et al.*, 2013). It is also an essential component for chlorophyll formation, activation of various enzymes and sulphydryl (SH-) linkages, protein and oil synthesis (Rathore *et al.*, 2015). Zn plays an important role in the activation of several enzymes, such as carbonic anhydrase, dehydrogenase, aldolase, alkaline phosphatase, ribulose bi-phosphate carboxylase, RNA polymerase and phospholipase which regulate various metabolic processes in the plants (Srivastava and Gupta, 1996). Being an essential component of tryptophane, Zn is required for the biosynthesis of indole acetic acid (IAA), which governs auxin production (Alloway, 2008). Mustard as a Brassica group generally has a high B requirement (Mengel and Kirkby, 1987). A positive response of mustard to B fertilization has been reported (Saha *et al.,* 2003). The presence of B is mainly associated with meristematic activity, auxin, cell wall, and protein and pectin metabolism, maintaining correct water relations within the plant, sugar translocation, fruiting processes, and so on (Kandil *et al.*, 2020).

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MATERIALS AND METHODS

The experiment was conducted at Norman E. Borlaug Crop Research Centre, G.B.P.U.A.T, Pantnagar, Uttarakhand during Rabi season of 2021-22. The basal treatments of S, Zn and B were applied in Kharif of 2021 under cluster bean cv *Guar Sarita.* The soil of the experimental field was loam in texture having soil OC, EC, pH, available N, P, and K were 0.75%, 0.34 dSm^{-1}, 6.9, 233 kg ha^{-1}, 9.3 kg ha^{-1} and 230 kg ha^{-1}, respectively. Boron, sulphur and zinc content in soil were low. The experiment was conducted with 13 treatments comprised of; T_1 = Control, T_2 =2.0 kg Zn ha^{-1}, T_3 = 4.0 kg Zn ha^{-1}, T_4 = 6.0 kg Zn ha^{-1}, T_5 = 1.0 kg B ha^{-1}, T_6 = 1.5 kg B ha^{-1}, T_7 =2.0 kg B ha^{-1}, T_8 = 20 kg S ha^{-1}, T_9 = 40 kg S ha^{-1}, T_{10} = 60 kg S ha^{-1}, T_{11} = Foliar application of B at 30, 45 and 60 days after emergence(0.20%B/L), T_{12} = Foliar application of Zn at 30, 45 and 60 days after emergence (0.25% Zn+ Lime), T_{13} = T_{11} + T_{12} were tested in randomized block design replicated 3 times. After the harvest of cluster bean, mustard crop (cv PR-15) was grown for this experiment. Only recommended dose of fertilizer N, P_2O_5, K_2O (120:40:40) was applied through NPK (12:32:16) in mustard crop.

At maturity, plant samples were collected and finely ground seeds and stover samples were digested in di-acid (3:1 HNO_3 and $HClO_4$, v/v) and estimated for Zn by atomic absorption spectrophotometer) and S concentration by turbidimetry method (Chesnin and Yien, 1951). For the estimation of boron plant samples were dry ashed in a muffle furnace at *550 °C* and ash was dissolved in *2N HCl* acid and used for estimating B concentration by azomethine–H (John *et al.,* 1975). The statistical analysis of the experimental data was done according to the procedure prescribed in Gomez and Gomez (1984) with the help of R-studio software. The significance was tested at a 5 % level of significance ($p \leq 0.05$).

RESULTS AND DISCUSSION

Grain yield

The seed yield ranges from 1.25 to 1.74 t ha^{-1}. It was observed that residual effect of treatment T_3, T_6 and T_9 gave statistically at par and significantly higher value of seed yield 1.61, 1.65 and 1.74 t ha^{-1} which were 29.07, 31.73 and 39.47 percent, respectively, higher over control. In the case of zinc treatments there was a progressive increase in seed yield with increasing levels of zinc, but beyond 4 kg Zn ha^{-1} there was a decline in response. A similar pattern was observed with boron and sulphur application with a decline in response beyond 1.5 kg B ha^{-1} and 40 kg S ha^{-1}, respectively. On the other hand, effect of foliar application of B and Zn was also studied in mustard where T_{11}, T_{12} and T_{13} gave yields which were 24.53, 25.87 and 34.67 percent, respectively, higher over control. It is also due to higher chlorophyll formation, protein synthesis, carbohydrate metabolism and translocation of photosynthates with S application (Thompson *et al.*, 1986). According to Alloway (2008), Zn fertilization helped in enhancing the activity of various enzymes related to photosynthesis, CO_2 assimilation, starch formation and protein synthesis while B helped in the development of reproductive structures and translocation of photosynthates toward sink (Shireen *et al.*, 2018).

Stover yield

The stover yield ranges from 3.46 to 5.25 t ha^{-1}. It was observed that residual effect of treatment T_6, T_9 and T_{10} gave statistically at par and significantly higher values of stover yield 5.1, 4.94 and 5.25 t ha^{-1} which were 47.30, 42.77 and 51.73 percent, respectively, higher over control. The foliar treatments T_{11}, T_{12} and T_{13} were 20.23, 37.28 and 50.1 percent, respectively, higher over control. Singh *et al.,* (2010) reported that significant increment in 1000-seed weight, seed yield and stover yield was noticed up to 30 kg S ha^{-1}. Dubey *et al.,* (2013) found that application of 40 kg S ha^{-1}had significantly higher seed and stover yield. It may be due to enhanced photosynthetic capacity of the crop with S application, which helped in the formation of chlorophyll, protein synthesis and efficient nitrogen utilization and responsible for higher plant growth and dry matter accumulation of mustard crop (Thompson *et al.*, 1986; Ahmad and Abdin, 2000).

Oil content and yield

Perusal of data revealed that oil content of the mustard seed increased significantly with increasing levels of sulphur. Oil content was significantly higher under T_9 (40.1%), which was at par with with T_8 and T_{10} (37.17 and 39.40%) and were 15.9, 7.42 and 13.87 percent respectively, higher to control. Data indicates that levels of S significantly improved the oil yield. Maximum oil yield was obtained with application of T_9 (699.94 kg ha^{-1}), which was statistically at par with T_3, T_{10} and T_{13}. This increment in oil yield may be due to better seed yield and oil content under higher S, Zn and B application level.

This was due to adequate availability of S, because S is a structural component of glucosinolate, glycosidase enzyme (Thompson *et al.*, 1986), constituent of acetyl-CoA carboxylase and glycerol, responsible for higher fatty acid and oil synthesis in mustard (Fazli *et al.*, 2005). Varying soil levels as well foliar spray of Zn and B markedly influenced oil content. This might be due to activation of several enzymes such as cysteine desulphydrase, NADPH dehydrogenase, glycyl-glycine dipeptidase and dihydropeptodase and higher assimilate supply to seeds responsible for higher fat synthesis and oil content in mustard crop with Zn application (Iweive and Weiner, 1972; Havlin, *et al.*, 2013).

Table 1: Effect of varying levels of S, Zn and B on yield, harvest index, oil content and yield in mustard

Treatment	Seed yield (t ha^{-1})	Stover yield (t ha^{-1})	HI (%)	Oil content (%)	Oil yield (Kg ha^{-1})
T_1 0 kg B	1.25^{e}	3.46^{g}	36.06^{ab}	34.6^{e}	430.63^{f}
T_2 2 kg Zn	1.38^{de}	3.79^{fg}	36.66^{ab}	37.4^{abcde}	520^{def}
T_3 4 kg Zn	1.61^{ab}	4.29^{de}	37.6^{a}	39.1^{ab}	632.03^{abc}
T_4 6 kg Zn	1.51^{bcd}	4.08^{def}	37.02^{ab}	38.6^{abc}	583.03^{bcde}
T_5 1 kg B	1.4^{cde}	3.86^{efg}	36.4^{ab}	35.6^{cde}	499.53^{ef}
T_6 1.5kg B	1.65^{ab}	5.1^{ab}	32.38^{ab}	36.8^{bcde}	605.8^{bcd}
T_7 2kg B	1.5^{bcd}	4.07^{def}	36.97^{ab}	36.3^{bcde}	545.51^{cde}
T_8 20 kg S	1.58^{ab}	4.41^{cd}	35.77^{ab}	37.17^{abcde}	586.7^{bcde}
T_9 40kg S	1.74^{a}	4.94^{ab}	35.33^{ab}	40.1^{a}	699.94^{a}
T_{10} 60 kg S	1.59^{ab}	5.25^{a}	30.59^{b}	39.4^{ab}	627.56^{abc}
T_{11} foliar(0.2%B/L)	1.56^{abc}	4.16^{def}	37.41^{a}	35.4^{de}	550.96^{bcde}
T_{12} foliar Zn (0.25%)	1.57^{abc}	4.75^{bc}	33.45^{ab}	37.6^{abcde}	591.05^{bcde}
T_{13} T_{11}+ T_{12}	1.68^{ab}	5.19^{ab}	32.55^{ab}	38.1^{abcd}	641.45^{ab}

**Means followed by same letters do not differ significantly ($p \leq 0.05$)*

Yield attributing characters

Zn, S and B application did not bring any significant variation in height. The number of primary branches range from 4.56 to 7.19. It was observed that treatment T_6, T_9 and T_{10} gave statistically at par and significantly higher number of primary branches 6.89, 7.19 and 6.79 which were 21.1, 57.68 and 48.83 percent, respectively, higher over control. On the other hand, effect of foliar application of B and Zn was also studied in mustard where treatments T_{11}, T_{12} and T_{13} gave number of primary branches which were 42.62, 46.71 and 55.56 percent, respectively, higher over control. The secondary branches range from 10.46 to 16.46. It was observed that treatment T_6, T_9 and T_{10} gave statistically at par and significantly higher number of secondary branches 15.76, 16.46 and 16.13 which were 50.64, 57.36 and 54.24 percent, respectively, higher over control. Application of foliar treatments T_{11}, T_{12} and T_{13} gave number of secondary branches which were 44.96, 53.57 and 55.80 percent, respectively, higher over control.

The number of total siliquae range from 158.67 to 263. It was observed that residual effect of treatment T_9 gave significantly higher total siliqua 263 which was 65.41 percent higher over control. On the other hand application of foliar treatments T_{11}, T_{12} and T_{13} gave number of total siliquae which were 46.54, 41.51 and 61.43 percent, respectively, higher over control. The number of main shoot siliquae range from 34.98 to 56.98 while that of primary branch siliquae range from 45.52 to 67.84. The number of secondary branch siliquae range from 78.17 to 146.87. Thousand seed weight range from 4.21

to 5.16. Majority of the treatments were at par and significantly higher over control with regards to thousand grain weight. The number of seeds per siliquae range from 7.67 to 11.83. Singh *et al.*, (2010) reported that siliquae/plant and seeds/siliqua increased significantly with application of 60 kg S ha^{-1}. Hossain *et al.*, (2011) observed that application of 1.0 kg B ha^{-1} gave maximum values of yield attributes (siliquae/plant, seed/siliqua and 1000-seed weight). Kour *et al.*, (2017) reported that maximum value of plant height and primary branches increased significantly with recommended dose of fertilser (RDF) + 10 kg Zn + 2 kg B ha^{-1}. The pronounced effect of S application on secondary branches was due to adequate supply of S throughout the crop growth period, which has significant role in cell division, elongation and meristematic tissue development and ultimately resulted in more numbers of secondary branches (Thompson *et al.*, 1986). It may be also due to increased levels of aldolase and fructose 1-5 diphosphate with Zn application, which helps in the transportation of photosynthates to the developing branches (Sharma *et al.*, 2019).

Table 2: Effect of varying levels of S, Zn and B on yield attributing characters in mustard

Treatment	Height (cm)	No of primary branches	No of secondary branches	Total siliqua	Main shoot siliqua	Primary branch siliqua	Secondary branch siliqua	1000 grain weight	Seeds/ siliqua
T_1 0 kg B	158.5^{a}	4.56^{g}	10.46^{e}	158.67^{h}	34.98^{f}	45.52^{i}	78.17^{f}	4.21^{d}	7.67^{f}
T_2 2 kg Zn	159^{a}	5.59^{f}	14.59^{cd}	207^{g}	41.64^{e}	50.69^{hi}	114.66^{e}	4.7^{c}	10.5^{de}
T_3 4 kg Zn	162.2^{a}	6.09^{def}	14.96^{bcd}	234^{de}	46.64^{cd}	57.85^{defg}	129.51^{bcd}	4.91^{abc}	11.3^{bc}
T_4 6 kg Zn	163.8^{a}	5.7^{ef}	14.3^{d}	222^{f}	45.31^{de}	53.84^{fgh}	122.85^{cde}	4.87^{abc}	10.7^{de}
T_5 1 kg B	162.2^{a}	6.19^{cde}	14.89^{bcd}	217.34^{f}	43.33^{de}	53.85^{fgh}	120.16^{de}	4.84^{abc}	10.2^{e}
T_6 1.5kg B	162.7^{a}	6.89^{ab}	15.76^{abcd}	243^{cd}	52.98^{ab}	64.85^{abc}	125.18^{cde}	5.07^{ab}	10.9^{cd}
T_7 2kg B	161.7^{a}	6.38^{bcd}	15.2^{abcd}	221^{f}	47.98^{cd}	59.18^{cdef}	113.84^{e}	4.81^{bc}	10.43^{de}
T_8 20 kg S	163.5^{a}	6.2^{cde}	15.49^{abcd}	238^{d}	44^{de}	62.69^{abcd}	131.31^{bcd}	5.01^{abc}	11.4^{ab}
T_9 40kg S	164.5^{a}	7.19^{a}	16.46^{a}	263^{a}	56.98^{a}	67.84^{a}	138.19^{ab}	5.16^{a}	11.83^{a}
T_{10} 60 kg S	164.2^{a}	6.79^{ab}	16.13^{ab}	249^{bc}	47.29^{cd}	66.85^{ab}	134.86^{abc}	5.12^{ab}	11.6^{ab}
T_{11} foliar (0.2%B/L)	162.4^{a}	6.5^{bcd}	15.16^{abcd}	233^{de}	50.98^{bc}	61.18^{bcde}	120.85^{de}	4.83^{bc}	10.6^{de}
T_{12} foliar Zn (0.25%)	162.8^{a}	6.69^{abc}	16.06^{abc}	225^{ef}	48^{cd}	53^{gh}	124.01^{cde}	4.92^{abc}	10.67^{de}
T_{13} T_{11}+ T_{12}	163.1^{a}	7.09^{a}	16.3^{ab}	256.67^{ab}	53.8^{ab}	56^{efgh}	146.87^{a}	5.12^{ab}	11.66^{ab}

**Means followed by same letters do not differ significantly ($p \leq 0.05$)*

Boron content in seed and stover

The boron content in the seed ranges from 19.4 to 28.5 mg kg^{-1}. It was observed that residual effect of treatments T_6 and T_7 produced the greatest value of B content in seed (28.5 and 27.6 mg kg^{-1}), which was statistically at par and considerably higher than control by 46.91 and 42.27 percent, respectively. There was a steady rise in B content as zinc and sulphur levels rise. When comparing B content in the seed, foliar treatments T_{13} was superior over T_{10} and T_{11}.

The boron content in stover ranges from 6.37 to 9.17 mg kg^{-1}. It was found that residual effect of treatment T_6 and T_7 considerably increased the B content in the stover to 9.03 and 9.17 mg kg^{-1} which were 41.81 and 43.90 percent more than control. With increasing levels, the B content in stover increased in the case of the zinc and sulphur treatments. Regarding the B content in stover, among the foliar treatments T_{13} outperformed other treatments. Studies developed by Mariano *et al.,* (2000) and Souza *et al.,* (2011) also furnished that B increase in the soil led to higher absorption and accumulation of B by the crop, in agreement with the results observed in this work. Cikili *et al.,* (2015) reported that even in the absence of added boron, the B content of the shoots of peanut was increased by supplying Zn to the soil. Flores *et al.,* (2018) also observed a higher B accumulation after B application on common beans with the highest B accumulation observed at a rate of 4 kg ha^{-1} of B.

Zinc content in grain and stover

The zinc content in the grain ranges from 26.20 to 42.20 mg kg^{-1}. Residual effect of treatment T_3 and T_4 gave at par significantly the higher value of Zn content (34.0 and 34.7 mg kg^{-1}) in grain which were 29.77 and 32.44 percent, higher over control. With regards to boron and sulphur treatments, there was a progressive increase in Zn content with increasing levels. The foliar treatment T_{12} and T_{13} were statistically at par with each other with regards to Zn content in grain and 61.07 and 59.67 percent, respectively, higher over control.

The zinc content in stover ranges from 1.79 to 3.01 mg kg^{-1}. It is evident that treatment T_3 and T_4 were statistically at par and considerably enhanced the content of zinc in the stover (2.82 and 2.92 mg kg^{-1}), or 57.36 and 63.13 percent, more over the control. With increasing quantities of boron and sulphur treatments, there was a steady rise in Zn content. Among foliar treatments Zn content in stover was statistically superior in T_{13}. Cui and Wang (2005) reported a significant increase in Zn concentration in spring wheat with the application of sulphur. On the other hand, Cikili *et al.,* (2015) reported that the Zn content of the peanut shoots was enhanced and ranged from 8.9 to 64.1 µg g^{-1} with the increased additions of both B and Zn to the soil.

Sulphur content in seed and stover

The sulphur content in the seed ranges from 0.71 to 0.89 %. It was observed that residual effect of treatment T_9 and T_{10} gave statistically at par and significantly highest value of S content in seed 0.86 and 0.89 % which were 21.13 and 25.35 percent, respectively, higher over control. The foliar treatment T_{11}, T_{12} and T_{13} were statistically at par with each other with regards to S content in seed.

The sulphur content in stover ranges from 0.26 to 0.40 percent. It was observed that treatment T_{10} gave significantly highest value of S content in stover 0.40 % which was 55.13 percent, over control. The foliar treatment T_{11}, T_{12} and T_{13} were statistically at par with each other with regards to S content in stover were 30.77, 34.62 and 30.77 percent, respectively over control. The increase in sulphur content in soyabean and mustard was due to rapid absorption and translocation of sulphur by plants with adequate sulphur from the soil (Shrivastava *et al.,* 2000). Bhupenchandra *et al.,* (2022) reported that direct fertilization with 2 kg B ha^{-1}improved the sulfur content to 0.48% in the curd of cauliflower while its residual effect recorded an increase of sulfur content to the highest by 0.57% in the pod of cowpea and 0.46% in the fruit of okra.

Table 3: Effect of varying levels of S, Zn and B on nutrient content in mustard

Treatment	Boron content (mg kg^{-1})		Zinc content (mg kg^{-1})		Sulphur content (%)	
	Seed	Stover	Seed	Stover	Seed	Stover
T_1 0 kg B	19.4^{h}	6.37^{g}	26.2^{f}	1.79^{h}	0.71^{g}	0.26^{i}
T_2 2 kg Zn	21.5^{g}	7.23^{ef}	32.3^{d}	2.47^{e}	0.79^{f}	0.3^{h}
T_3 4 kg Zn	22.9^{ef}	7.37^{ef}	34^{bc}	2.82^{bc}	0.83^{bcde}	0.33^{fg}
T_4 6 kg Zn	23.2^{ef}	7.5^{e}	34.7^{b}	2.92^{ab}	0.84^{bcd}	0.34^{ef}
T_5 1 kg B	25.97^{b}	8.6^{cd}	26.23^{f}	2.06^{g}	0.8^{ef}	0.32^{g}
T_6 1.5kg B	27.6^{a}	9.03^{ab}	26.53^{f}	2.23^{f}	0.81^{def}	0.35^{de}
T_7 2 kg B	28.5^{a}	9.17^{a}	29.2^{e}	2.39^{e}	0.83^{bcde}	0.36^{cd}
T_8 20 kg S	22.27^{fg}	7.2^{ef}	31.63^{d}	2.25^{f}	0.85^{bc}	0.37^{bc}
T_9 40 kg S	23.6^{de}	7.23^{ef}	33.1^{cd}	2.35^{ef}	0.86^{ab}	0.38^{b}
T_{10} 60 kg S	24.9^{bc}	7.37^{ef}	34.63^{b}	2.63^{d}	0.89^{a}	0.4^{a}
T_{11} foliar (0.2%B/L)	24.33^{cd}	8.37^{d}	32.37^{d}	2.38^{e}	0.83^{bcde}	0.34^{ef}
T_{12} foliar Zn (0.25%)	21.7^{g}	7.1^{f}	42.2^{a}	2.73^{cd}	0.84^{bcd}	0.35^{de}
T_{13} T_{11}+ T_{12}	25.6^{b}	8.77^{bc}	41.83^{a}	3.01^{a}	0.82^{cdef}	0.34^{ef}

Means followed by same letters do not differ significantly ($p \leq 0.05$)

Boron uptake

The range of the total boron was is 46.24 to 91.48 g ha^{-1}. It was found that residual effect of treatments T_6 and produced significantly higher total B uptake values in mustard (91.48 g ha^{-1}) among different levels of boron, which was 97.84 percent higher than control. Regarding B uptake, T_{13} was statistically superior among foliar treatments. Kushwaha *et al.,* (2009) recorded that the total boron uptake by lentil increased significantly with an increase in levels of boron up to 4.0 kg ha^{-1}. Longkumer (2017) observed that total boron uptake by soybean plants increased up to 40 kg ha^{-1} S and 1.0 to 1.5 kg ha^{-1} B application, with the highest values being associated with the conjoint application of 40 kg S and 1.5 kg B/ha.

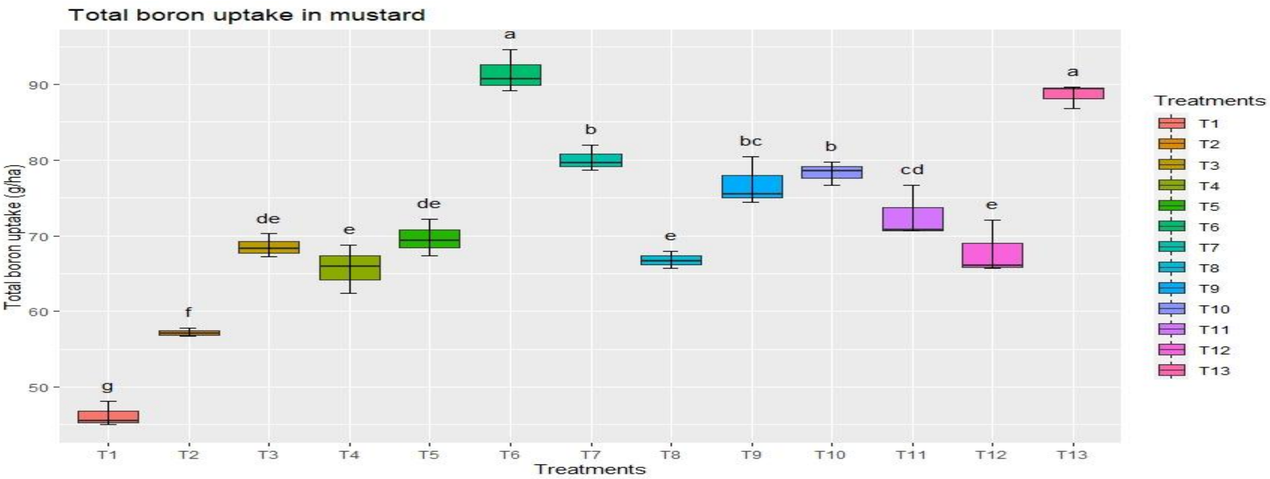

Figure1: Effect of varying levels of S, Zn and B on total boron uptake in mustard

Zinc uptake

From 38.86 to 86.07 g ha^{-1}, on average, total zinc was uptake. The greatest value of total Zn uptake, 86.07 g ha^{-1}, was obtained in treatment T_{13}, which was observed to be 121.48 percent higher than control. With increasing levels of sulphur, Zn uptake increased gradually but beyond 40 kg S application response declined. Zn uptake was increased by 55.19 and 104.42 percent, respectively over control in the foliar treatments T_{11}, T_{12}, respectively. The uptake of zinc by chickpea grain and straw increased significantly with increasing levels of zinc over the control due to an increase in yield and zinc content as a result of zinc application (Singh and Singh, 2012). Saha *et al.,* (2015) observed that there was a 29 and 93% increase in Zn uptake by groundnut upon application of 5 and 10 kg Zn ha^{-1}, respectively over the control while among the S levels, 50 kg S ha^{-1} showed the highest Zn uptake in groundnut (0.26 kg ha^{-1}) over the level 25 kg S ha^{-1} (0.22 kg ha^{-1}) and 0 kg S ha^{-1} (0.14 kg ha^{-1}).

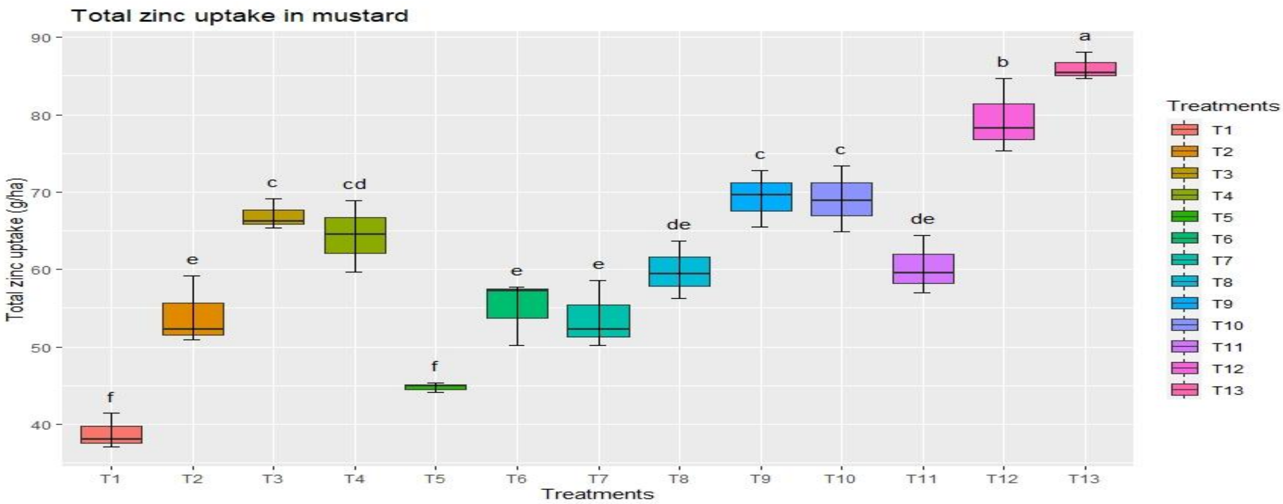

Figure 2: Effect of varying levels of S, Zn and B on total zinc uptake in mustard

Sulphur uptake

Total sulphur uptake varies from 17.98 to 35.43 kg ha^{-1} in total. It was found that residual effect of treatment T_{10} considerably increased the amount of total S uptake in mustard (35.43 kg ha^{-1}), resulting in a 97.04 percent increase compared to control. In comparison to control, the total S uptake in foliar treatments T_{11}, T_{12}, and T_{13} was 50.52, 65.81, and 75.10 percent, respectively. Nadaf and Chidanandappa (2015) reported significant increase in S uptake from 20.54 to 26.27 kg ha^{-1} as the levels of zinc sulphate application increased from 5 to 20 kg ha^{-1}. The increase in S uptake may be ascribed to the higher grain and straw production as well as improvement in S content with its addition (Singh and Sharma, 2016). Bhupenchandra *et al.,* (2022) observed that B fertilization @ 2 kg B ha^{-1} had a significant impact on the S uptake. The direct effect of 2 kg B ha^{-1} fertilization augmented the S uptake up to 0.24 kg B ha^{-1}.

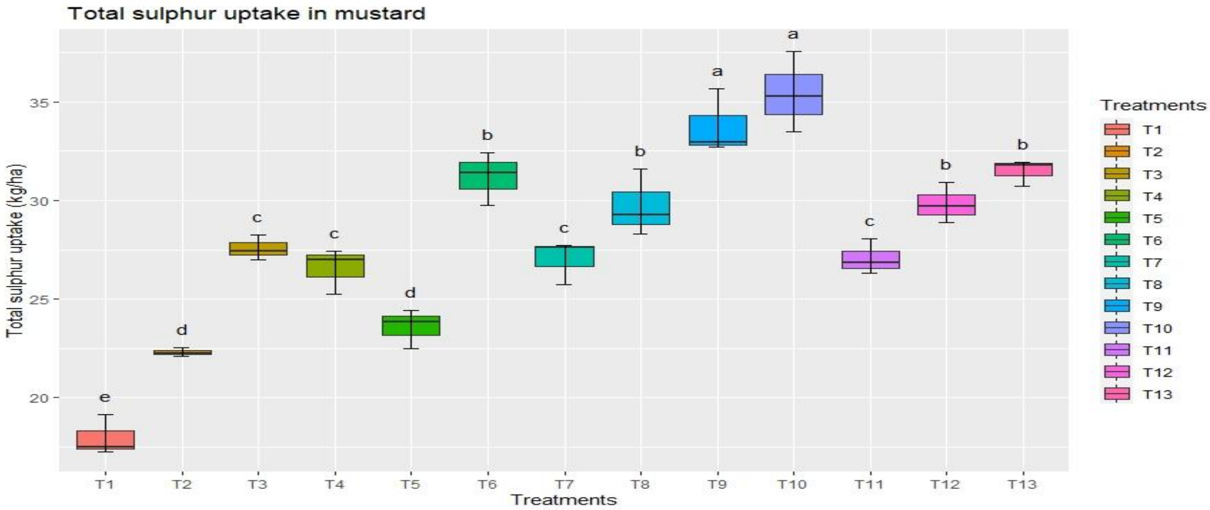

Figure 3: Effect of varying levels of S, Zn and B on total sulphur uptake in mustard

Relationship among seed yield, stover yield, B, Zn and S content in pods and stover and total B, Zn and S uptake

Positive correlations were observed between B, Zn and S content in seed and seed yield (r = 0.410, 0.489 and 0.754**). On similar lines, B, Zn and S content in stover and green forage yield showed positive correlations of corresponding values (r = 0.247, 0.467 and 0.756**). S content in seeds was strongly correlated with oil content (0.714**) and oil yield (0.788**) Statistical analysis demonstrated that the changes in seed yield of mustard with treatment application were positively correlated with the changes in total uptake of B (0.784**), Zn (0.758**) and S (0.91***). It was also inferred that the changes in stover yield of a mustard with treatment application were positively correlated with the changes in total uptake of B (0.794**), Zn (0.746**) and S (0.941***).

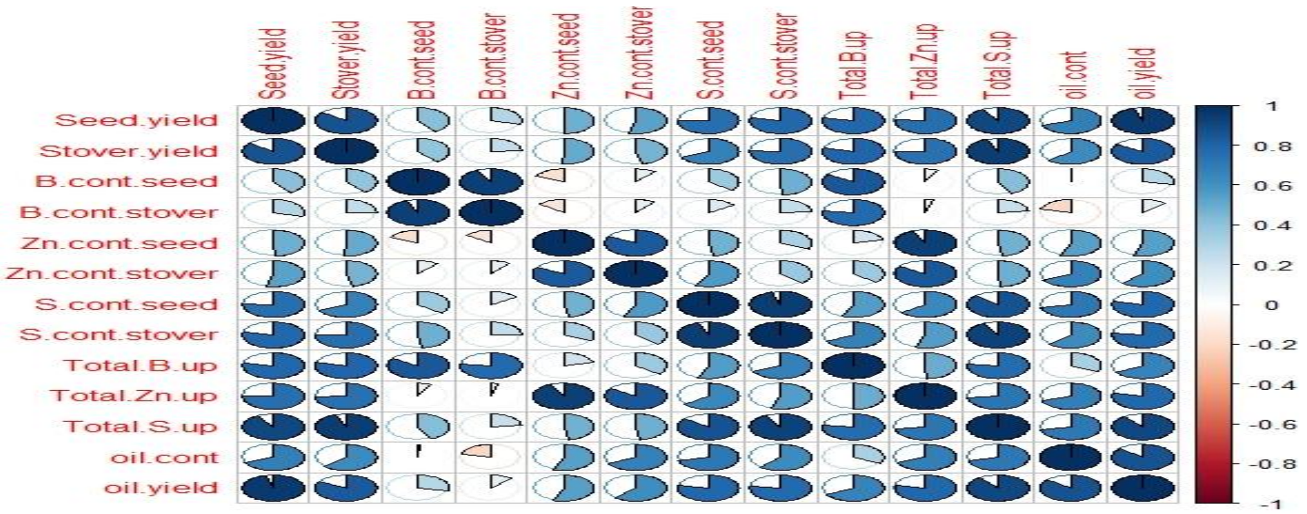

Figure 4: Pearson's correlation coefficient correlogram

Principal component analysis (PCA)

Since boron, zinc and sulphur application tangibly affected the yield, nutrient content and uptake in clusterbean it is obligatory to screen out the corresponding “highly weighted” variables to be retained and include in the minimum data set (MDS) from the eigenvector weight value or factor loadings. So, multivariate analysis i.e., principal component analysis (PCA) was carried out on the yield, nutrient content and uptake in mustard. Results of PCA (Figure 5) accomplished in respect of mustard crop generated two principal components which explained 62 % and 20.6% of total variance for PC1 and PC2, respectively. The corresponding loadings plot (Figure 5) revealed that PC1 had large positive loading on S content in seed and stover, total S, B and Zn uptake, seed yield, and stover yield, oil content and oil yield while PC2 had greater loading on B content in seed and stover, total S uptake, Zn content in seed.

Table 4: Results of principal components analysis of yield, nutrient content, uptake, oil content and oil yield in mustard

	PC1	PC2
Standard deviation	2.83	1.63
% of variance	61.96	20.57
Cumulative %	61.96	82.53
Factor loadings		
Parameters	PC1	PC2
Seed yield	0.330	0.041
Stover yield	0.317	0.043
B content seed	0.156	0.525
B content stover	0.102	0.525
Zn content seed	0.220	-0.356
Zn content stover	0.244	-0.230
S content seed	0.305	-0.017
S content stover	0.303	0.097
Total B uptake	0.276	0.357
Total Zn uptake	0.299	-0.235
Total S uptake	0.337	0.042

**Extraction Method: Principal Component Analysis

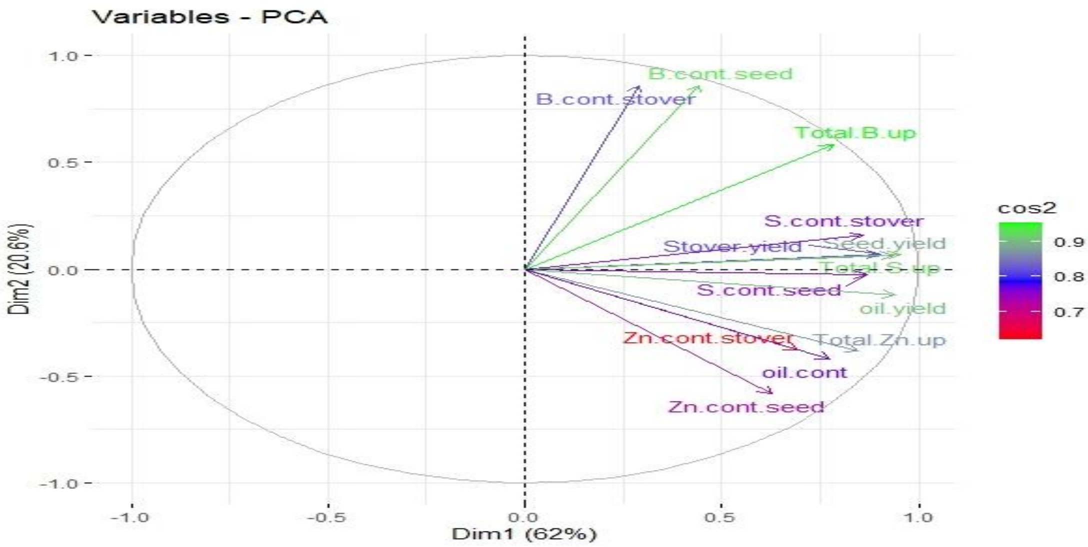

Figure 5: Loading’s plot formed by principal components 1 and 2 with different parameters of mustard

CONCLUSION

Based on this field study, it may be deduced that mustard crop responds to residual effect of B, Zn and S application and better yield of the seed and stover can be obtained under the soil application of 4 kg Zn ha^{-1}, 1.5 kg B ha^{-1} and 40 kg S ha^{-1}. Though combined foliar applications of 0.25% Zn and 0.20% borax were effective in increasing yield, concentration and uptake by both seed and stover of mustard due to ready translocation yet gave slightly lower but comparable seed yields in comparison to soil application S @ 40 kg ha^{-1}. However, considering the lesser consumption of B and Zn fertilizer in 3 foliar sprays of 0.20% borax and 0.25% Zn at 30 and 45 and 60 days after emergence it could be an attractive option to get higher grain yields of mustard on soils marginally deficient in B and Zn. The PCA and correlation matrix also confirmed the role of boron, sulphur and zinc application in the augmentation of yield improvement.

REFERENCES

Ahmad A. and Abdin M.Z. (2000). Photosynthesis and its related physiological variables in the leaves of Brassica genotypes as influenced by sulphur fertilization. *Physiologia Plantarum*, **110**: 144-149.

Alloway, B.J. (2008) Zinc in Soils and Crop Nutrition (Second Edition). IZA and IFA Pubication.

Aulakh, M.S. and Pasricha, N.S. (1988) Sulphur fertilization of oilseeds for yield and quality. In: Sulphur in Indian Agriculture, Chapter II.3, 1-14.

Bhupenchandra, I., Basumatary, A., Dutta, S., Nabachandra Singh, L., Das, A., Singh, L..K. and Premabati Devi, C. (2022) Direct and residual impact of boron fertilization improves the crop yield, nutrient contents, nutrient uptake, and nutrient use efficiencies in cauliflower–cowpea–okra sequence in an acidic Inceptisol of North East. India. *Journal of Plant Nutrition* **45**(7): 963-983.

Chesnin, L. and Yien, C.H. (1951) Turbidimetric determination of available sulfate. *Soil Science Society of America, Proceedings* **15**: 149-151.

Çikili, Y., Samet, H. and Dursun, S. (2015) Mutual effects of boron and zinc on peanut (*Arachis hypogaea* L.) growth and mineral nutrition. *Communications in Soil Science and Plant Analysis* **46**(5): 641-651.

Cui, Y. and Wang, Q. (2005) Interaction effect of zinc and elemental sulphur on their uptake by spring wheat. *Journal of Plant Nutrition* **28**: 39-649.

Dubey, S.K., Tripathi, S.K. and Singh, B. (2013) Effect of sulphur and zinc levels on growth, yield and quality of mustard [Brassica juncea (L.) czern. & coss.]. Research & Reviews: *Journal of Crop Science and Technology* **2**(1): 1–10.

Fazli, I.S., Abdin, M.Z., Jamal, A. and Ahmad, S. (2005) Interactive effect of sulphur and nitrogen on lipid accumulation, acetyl-CoA concentration and acetyl-CoA carboxylase activity in developing seeds of oilseed crops (Brassica campestris L. and Eruca sativa Mill.). *Plant Science* **168**: 29-36.

Flores, R.A., Silva, T.V., Damin, V., Marques Carvalho, R.D.C., Pereira, D.R.M. and Souza Junior, J.P.D. (2018) Common bean productivity following diverse boron applications on soil. *Communications in Soil Science and Plant Analysis* **49**(6): 725-734.

Gomez, K.A. and Gomez, A.A. (1984) Randomized complete block design analysis. Statistical procedures for agricultural research. John Willey and Sons, New York.

Havlin, J.L., Tisdale, S.L., Nelson, W.L. and Beaton. J.D. (2013) Soil Fertility and Fertilizers: An Introduction to Nutrient Management (Eighth Edition). Pearson India Education Services Pvt. Ltd.

Hossain, M.A., Jahiruddin, M. and Khatun, F. (2011) Effect of boron on yield and mineral nutrition of mustard (Brassica napus). *Bangladesh Journal of Agricultural Research* **36(**1): 63-73.

Hussain, M.J., Sarker, M.M.R., Sarker, M.H., Ali, M. and Salim, M.M.R. (2008) Effect of different levels of boron on the yield and yield attributes of mustard in Surma Kushiara Flood Plain Soil (AEZ 30). *Journal of Soil and Nature* **2**(3): 6-9.

Iweive, I. and Weiner, H. (1972) Effect of iron and zinc application on yield, oil content and their uptake by sesame. *Journal of the Indian Society of Soil Science* **38**: 171 – 173.

Jat, J.S., Rathore, B.S., and Chaudhary, M.G. (2012) Effect of sulphur and zinc on growth, chlorophyll content, yield attributes and yields of mustard (*Brassica juncea*) on clay loam soil of Rajasthan. *AGRES-An International e- Journals* **1**(1): 42-52.

John, M.K., Chuah, H.H. and Neufeld, J.H. (1975) Application of improved azomethine−H method to the determination of boron in soils and plants. *Analytical Letters* **8**: 559-568.

Kandil, E.E., Abdelsalam, N.R., Aziz, A.A.E., Ali, H.M. and Siddiqui, M.H. (2020) Efficacy of nanofertilizer, fulvic acid and boron fertilizer on sugar beet (Beta vulgaris L.) yield and quality. *Sugar Tech* **22**: 782–

791.

Kour, S., Gupta, M., Kachroo, D. and Bharat, R. (2017) Direct and residual effect of zinc and boron on productivity, nutrient uptake and quality on mustard (Brassica juncea) and succeeding maize (Zea mays) in subtropical Inceptisols of Jammu. *Journal of the Indian Society of Soil Science* **65**(3): 334-340.

Kumar, A. (2012) Production barriers and technological options for sustainable production of rapeseed-mustard in India. *Journal of Oilseed Brassica* **3**(2): 67-77.

Kushwaha, A.K., Singh, S. and Singh, R.N. (2009) Available nutrients and response of lentil (*Lens esculenta*) to boron application in rainfed upland soil of Ranchi. *Journal of the Indian Society of Soil Science* **57**(2): 219-222.

Longkumer, L.T., Singh, A.K., Jamir, Z. and Kumar, M. (2017) Effect of sulfur and boron nutrition on yield and quality of soybean (*Glycine max* L.) grown in an acid soil. *Communications in Soil Science and Plant Analysis* **48**(4): 405-411.

Mariano, E.D., V. Faquin, A.E., Furtini Neto, A.T., Andrade, and I.O.S. Mariano. (2000) Critical levels of boron in lowland soils for culture of bean. *Pesquisa Agropecuária Brasileira* **35**:1637–44.

Mengel, K. and Kirkby, E.A. (1987) Principles of Plant Nutrition. International Potash Institute, Switzerland.

Nadaf, S.A. and Chidanandappa, H.M. (2015) Content and uptake of macronutrients by groundnut (*Arachis hypogaea* L.) as influenced by soil application of zinc and boron in sandy loam soils of Karnataka, India. *Legume Research* **38**(3): 363-366.

Rathore, S.S., Shekhawat, K., Kandpal, B. K., Premi, O. P., Singh, S. P., Singh, G. C. and Singh, D. (2015) Sulphur management for increased productivity of Indian mustard: A review. *Annals of Plant and Soil Research* **17**(1), 1-12.

Saha, B., Saha, S., Saha, R., Hazra, G.C. and Mandal, B. (2015) Influence of Zn, B and S on the yield and quality of groundnut (*Arachis hypogea* L.). *Legume Research* **38**(6): 832-836.

Saha, P.K., Saleque, M.A. Zaman S.K. and Bhuiyan, N.J. (2003) Response of mustard to S, Zn and B in calcareous soil. *Bangladesh Journal of Agricultural Research* **28**: 633-636.

Sharma, V., Sharma, B. L., Sharma, G. D., Porte, S. S. and Dubey, A. (2018). Studies on impact of sulphur with and without FYM on yield, uptake and methionine content in mustard. *International Journal of Current Microbiology and Applied Sciences*. **7**: 723-731.

Shireen, F., Nawaz, M. A., Chen, C., Zhang, Q., Zheng, Z., Sohail, H., Sun, Jingyu, S., Cao, H., Huang, Y., & Bie, Z. (2018). Boron: Functions and approaches to enhance its availability in plants for sustainable agriculture. *International Journal of Molecular Science*. **19**: 1856.

Shrivastava, U.K., Rajput, R.L. and Diwivedi, M.L. (2000) Response of soybean-mustard cropping system to sulphur and biofertilizers on farmer's field. *Legume Research* **23**: 277-278.

Singh, D. and Singh, H. (2012) Effect of phosphorus and zinc nutrition on yield, nutrient uptake and quality of chickpea. *Annals of Plant and Soil Research* **14**(1): 71-74.

Singh, Y., Singh, T., Singh, U.N. and Rajput, P.K. (2010) Effect of nutrient management on yield, quality and economics of irrigated Indian mustard (Brassica juncea). *Indian Journal of Agricultural Sciences* **80**(8): 691–694.

Souza, H.A.D., Natale, W., Rozane, D.E., Hernandes, A. and Romualdo, L.M. (2011) Liming and fertilization with boron in production of bean. *Revista Ciencia Agronomica* **42**: 249–57.

Srivastava, P.C. and Gupta, U.C. (1996) Trace elements in crop production. Lebanon, NH: Science Publishers.

Thomas, J., Kuruvilla, K.M. and Hirdeek T.K., (2004) Mustard. In Handbook of Herbs and Spices, 2, 196–205

Thompson, J.F., Smith, I.K. and Madison, J.T. (1986) Sulfur Metabolism in Plants. Sulfur in Agriculture, M.A. Tabatabai (Ed.). 57-121.