

Effect of Sulfur and Zinc on Yield, Growth Parameters, Nutrient Uptake and Content and Quality Characteristics of Linseed (*Linum usitatissimum* L.)

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Abstract A pot experiment was carried out to study the effect of sulfur and zinc nutrition on growth, yield, nutrient uptake and quality of linseed crop on sandy loam soil during *rabi* season of 2013-14 and 2014-15. The results indicated that application of 40 ppm S pot⁻¹ and 5.0 ppm Zn pot⁻¹ improved the growth parameters like plant height, number of branches plant⁻¹ and yield components viz., number of capsules plant⁻¹ number of seeds capsules⁻¹, seed weight pod⁻¹, 1000-seed weight (test wt), seed and stover yield as compared to other treatments. However, the yield values were statistically at par at 40 and 60 ppm S levels and 5.0 and 7.5 ppm Zn levels. The content of sulfur increased with its application

upto 60 ppm S and 2.5 ppm Zn, while, uptake of S increased upto 40 ppm and 2.5 ppm Zn levels and thereafter, decreased. However, the zinc content increased upto 20 ppm S and 7.5 ppm Zn. On the other hand, zinc uptake increased upto 40 ppm S and 7.5 ppm Zn. The results also exhibited that oil and protein content of seed increased with the application of sulfur and zinc upto their highest levels. The oil and protein contents in seeds increased upto 60 ppm S and 5.0 ppm Zn respectively. However, increase was higher magnitude at higher level and of sulfur in comparison to zinc.

Keywords Sulfur and zinc, Linseed, Nutrient content and uptake, Yield attributes, Quality characteristics.

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Introduction

Linseed (*Linum usitatissimum* L.) is an important oilseed crop of the world. In India, it is grown in winter season in the Deccan *rabi* zone and accounts 21.42 lakh hac of total area, with an average production and productivity of 2.12 lakh tonnes and 403 kg ha⁻¹ respectively during 2014-15 (Directorate of economics and Statistics, 2014-15). Seed of linseed contain about 35-47% oil. It contains 35-70% linolenic acid, (omega-3 fatty acid) the factor which re-

duces blood cholesterol concentration and cardiovascular benefits by affecting prostaglandins and leukotriens related to blood clotting and inflammatory disorder like rheumatoid arthritis [1]. Linseed is a natural source of lignin which has anti-carcinogenic properties and also provide protection against certain form of cancer due to estrogenic and anti-estrogenic activities inside the body [1]. Moreover, due to high content of unsaturated fatty acids and it is being used as an excellent drying oil for use in paints, varnishes, printing ink, coating oils, oil cloths, lanolin and soap industries and similar other products. The deficiency of secondary and micro nutrients is wide spread in many parts of the country due to cultivation of high yielding varieties, intensive agricultural practices and increasing use of sulfur free fertilizers in large quantities with concomitant decrease in use of organic manures. This necessitates rational application of these elements as they have becoming limiting factor for obtaining higher yields of several oil seed crops including linseed crop.

Sulfur is now recognized as the fourth major nutrient next to N, P and K. It plays a vital role in formation of chlorophyll, activation of enzymes and improvement in both crop yield and oil yield. Sulfur is involved in the synthesis of chlorophyll and is also required for the synthesis of oil. Nutritionally, oil-seed rape and Brassicaspecies in general require sulfur during their growth for the synthesis of both protein and naturally occurring glucosinolates. Glucosinolates are a group of secondary metabolites containing β - thioglucose, a sulfonated oxime moiety and a side chain, their concentration is closely related to the sulfur supply, what is not surprising, since each glucosinolate molecule contains two or three sulfur atoms [2]. Both sulfur uptake and sulfur translocation in linseed crop (oilseed) vary as a function of growth stage and plant part. Application of sulfur and zinc significantly increased yield as well as quality [3].

Materials and Methods

The experiments to evaluate the effect of sulfur and zinc on yield attributes, yield and uptake of nutrients and quality parameters of linseed were con-

ducted under irrigated conditions during *rabi* season 2014-15 on sandy loam soil (Inceptisols) at pot culture house of the department of soil Science and Agricultural Chemistry, CS Azad University of Agriculture and Technology, Kanpur. The soil of experimental site contained 62.50% sand, 21.10% silt, 14.40% clay, had pH 7.8 Ec 0.56 dsm⁻¹, organic carbon 0.41%, available N, P and K was 240, 10.10 and 108 kg ha⁻¹, respectively and available sulfur and zinc was 9.20 and 0.53 mg kg⁻¹ respectively. The treatments comprising of four levels of sulfur (0, 20, 40 and 60 ppm through gypsum) and four levels of zinc (0, 2.5, 5.0 and 7.5 ppm through ZnO) replicated four times in a randomized complete block design. All the sixteen treatments were given a uniform recommended doses of N, P and K (80 kg N, 60 kg P₂O₅ and 40 kg K₂O). Nitrogen was applied in the form of urea, phosphorus in the form of diammonium phosphate and potash in the form of muriate of potash. Half dose of N as basal and half as top dressing. The amount of N present in DAP was adjusted while applying N through urea. Sulfur and zinc were applied as per treatment through gypsum (at the time of sowing) and zinc oxide as solution form taken at 15 days after sowing. The seeds were sown during third week of November. At maturity plants are harvested manually. Harvested plants were tied in small bundles and kept up right with wall for sun drying for five days. After drying plants were thrashed manually. Seed yield was recorded on pot basis and then converted into hectare basis. Soil of experimental site was taken and analyzed as per standard method. The growth and yield attributing characters i.e. plant height, number of branches plant⁻¹, number of capsules plant⁻¹, number of seeds capsules⁻¹ and 1000-grains weight were recorded at maturity. The recorded data were subjected to statistical analysis appropriate to randomized complete block design by using M. Stat. Freed and Eisen Smith [4]. Means were compared for significance at 5% probability level using LSD Steel and Torrie [5]. Plant samples were collected at harvesting stage and grain samples were analyzed for oil content. The oil content in seeds estimated by Nuclear Magnetic Resonance (NMR) Spectrophotometer. The nitrogen content was estimated by modified Kjeldahl's method. The protein content was calculated by multiplying the nitrogen content (%) with a factor 6.25 Tai and Young [6].

Table 1. Effect of sulfur and zinc on growth parameters and yield of linseed (mean of two years).

Treatments	Plant height (cm)	No. of branches plant ⁻¹	No. of capsules plant ⁻¹	No. of seeds capsules ⁻¹	1000-seed wt (g)	Yield (g pot ⁻¹) seed	stover
S-levels (ppm)							
S ₀	62.41	4.92	46.02	7.05	7.19	11.16	16.15
S ₂₀	65.04	5.92	52.67	8.07	8.5	13.26	19.20
S ₄₀	66.13	6.35	55.80	8.40	8.60	14.33	20.75
S ₆₀	65.97	6.25	54.50	8.27	8.50	13.84	20.70
CD (p=0.05)	1.668	0.387	1.876	0.384	0.317	0.730	1.001
Zn-levels (ppm)							
Zn ₀	63.34	5.35	48.62	7.52	7.55	11.82	17.30
Zn _{2.5}	65.12	5.90	52.43	8.00	8.15	13.29	19.31
Zn _{5.0}	65.77	6.30	54.47	8.35	8.55	13.91	20.45
Zn _{7.5}	65.33	5.90	53.60	7.95	8.09	13.56	19.74
CD (p=0.05)	1.668	0.387	1.876	0.384	0.317	0.730	1.001

Results and Discussion

Yield attributes

Table 1 shows that levels of sulfur and zinc had significant influence on yield attributes i.e. plant height, number of branches plant⁻¹, number of capsules plant⁻¹, number of seeds capsules⁻¹ and test weight of 1000 seeds and seed and stover yields of linseed crop. The yield attributed and yield increased concordantly with increase in both sulfur and zinc levels. Among the sulfur levels, application of 40 ppm S registered the highest plant height, number of branches plant⁻¹, number of capsules plant⁻¹, number of seeds capsules⁻¹ and test weight. It was significantly superior over 20 ppm S and control levels. The increase in yield attributes on addition of sulfur might be due to its deficiency in experimental soil. The crop receiving 40 ppm sulfur might have been helped in terms of vigorous root growth formation of chlorophyll, resulting in higher photosynthesis. Similar results were reported by Tripathi et al. [7] and Charan et al. [8].

Likewise, sulfur, zinc application also enhanced the yield attributes in the linear order upto 5.0 ppm zinc level. However, in general, these values of yield attributes at 5.0 ppm and 7.5 ppm levels were recorded statistically at par. This beneficial effect might

be due to the interaction effect of sulfur and zinc and their role in the synthesis of IAA, metabolism of auxin and formation of chlorophyll synthesis. It has been also reported by a number of research workers that zinc application has a positive effect on yield attributes Singh and Pal [9].

Yield

The yield determining components such as number of capsules plant⁻¹, number of seeds capsules⁻¹, 1000-seed weight and seed and stover yields were significantly influenced by the levels of sulfur and zinc (Table 1). On an average, the seed and stover yield increase upto 40 ppm levels of sulfur and 5.0 ppm levels of zinc. However, the yield values were statistically at par at 40 and 60 ppm S levels and 5.0 and 7.5 ppm Zn levels. It has been observed that, on an average, the highest seed and stover yield of 14.33 g pot⁻¹ and 20.75 g pot⁻¹ at 40 ppm S were found 28.40% and 28.48% higher in comparison to lowest seed and stover yield of 11.16 g pot⁻¹ and 16.15 g pot⁻¹ at control, respectively. Likewise, the highest seed and stover yield on an average, 13.91 g pot⁻¹ and 20.45 g pot⁻¹ recorded at 5.0 ppm Zn were computed 17.68% and 18.21% higher in comparison to lowest seed and stover yield of 11.82 g pot⁻¹ and 17.30 g pot⁻¹ are recorded at control (0 ppm Zn).

Table 2. Effect of sulfur and zinc on its content and uptake in seed and stover (mean of two years).

Treatments	S-content (%)		S-uptake (mg pot ⁻¹)		Zn-content (%)		Zn-uptake (mg pot ⁻¹)	
	Seed	Stover	Seed	Stover	Seed	Stover	Seed	Stover
S-levels (ppm)								
S ₀	0.29	0.12	32.42	20.17	74.82	36.60	0.85	0.60
S ₂₀	0.37	0.15	49.42	29.23	101.65	49.77	1.37	0.97
S ₄₀	0.41	0.17	58.71	36.35	99.45	48.72	1.43	1.02
S ₆₀	0.42	0.17	58.47	35.26	93.32	47.65	1.29	0.98
CD (<i>p</i> =0.05)	0.036	0.011	2.149	1.330	2.151	1.580	0.100	0.065
Zn-levels (ppm)								
Zn ₀	0.37	0.15	45.29	27.37	57.77	28.12	0.69	0.49
Zn _{2.5}	0.39	0.17	55.65	33.24	97.35	46.67	1.30	0.90
Zn _{5.0}	0.37	0.15	52.24	31.96	105.17	52.62	1.47	1.08
Zn _{7.5}	0.35	0.14	48.88	28.44	108.95	55.32	1.48	1.10
CD (<i>p</i> =0.05)	0.036	0.011	2.149	1.330	2.151	1.580	0.100	0.065

The results are in conformity with the findings of Jat and Mehra [10] and Kumar et al. [11].

Content and uptake of nutrients

Content and uptake of sulfur the data on nutrient content and uptake (Table 2) in both seed and stover indicates that application of sulfur and zinc increased the uptake of sulfur and zinc significantly. From the Table 2, it is obvious that content of sulfur in both seed and stover increased with an increase in sulfur level, being lowest at control and highest at 60 ppm S level. This shows synergistic effect of sulfur application with its absorption. The uptake is affected by yield parameters and therefore, the yield being highest at 40 ppm S level affected the uptake of sulfur. However, the sulfur uptake values in both seed and stover at 40 and 60 ppm levels were statistically at par. Therefore, the uptake of sulfur in both seed and stover were recorded higher at 40 ppm sulfur levels. The increase in sulfur content on its addition might be attributed to increase its availability on its addition, resulting in higher content of sulfur at its higher at its higher level i.e. 60 ppm sulfur. The increase in content and uptake of sulfur, these results are in conformity with the findings of Singh et al. [12] and Tomar [13]. Unlike sulfur, addition of zinc had depressing effect on sulfur content and uptake

in both seed and stover, resulting in highest at 2.5 ppm and lowest at 7.5 ppm Zn and at control levels respectively. The value of sulfur uptake at 2.5 and 5.0 ppm were found statistically at par. The zinc addition had significant negative effect on the absorption of sulfur and higher concentration of sulfur was observed at 2.5 ppm and lowest at control. Content and uptake of zinc the data depicted in Table 2 exhibit that application of increasing doses of zinc showed synergistic effect on content and uptake in both seed and stover resulting in, on an average, highest content and uptake at 7.5 ppm Zn levels. The higher concentration of zinc at its higher level is attributed to increase in its availability on its addition, causing higher concentration at higher level of zinc. The values of zinc uptake and content at 5.0 and 7.5 ppm were statistically at par. The uptake of nutrients (zinc) is the resultant product of content and yield. Therefore, in accordance with content and yield the higher uptake at higher levels of zinc application i.e. 7.5 ppm zinc was recorded. These results are supported by the findings of Verma et al. [14] and Trivedi et al. [15]. It is also revealed from the data that the addition of sulfur, in general has depressing effect on the absorption of zinc. The zinc content increase by the addition of sulfur, on an average, significantly only upto 20 ppm sulfur level and thereafter, showed declining trend upto 60 ppm sulfur level in both seed and stover. While uptake of zinc increased by the application of sulfur upto 40 ppm levels significantly.

Table 3. Effect of sulfur and zinc on its oil and protein content (%) in seed (mean of two years).

Treatments	Oil yield (%)	Protein content (%)
S-levels (ppm)		
S ₀	39.08	19.06
S ₂₀	40.32	19.62
S ₄₀	40.80	20.06
S ₆₀	40.85	20.12
CD ($p=0.05$)	0.198	0.233
Zn-levels (ppm)		
Zn ₀	39.56	19.43
Zn _{2.5}	40.26	19.73
Zn _{5.0}	40.70	19.87
Zn _{7.5}	40.53	19.82
CD ($p=0.05$)	0.198	0.233

Quality characteristics

Oil content

The data on the oil content (Table 3) showed that significant differences were manifested in the oil content of seeds due to sulfur application. The application of sulfur increased the oil content in seed in linear order, being lowest at control and highest at 60 ppm sulfur level is 40.85% was recorded. On an average, an increase of 4.53% in oil content was recorded at 60 ppm sulfur in comparison to control. This might be due to role of sulfur in synthesis of oil, sulfur is involved in the formation of glucosides and glucosinolates (mustard oil) and sulphydril-linkage and activation of enzymes, which aid in biochemical reaction within the plant. This confirms the findings of Mishra and Agarwal [16] in soybean. The increase in oil content on addition of sulfur might be associated with increase in Acetyl-CoA and carboxylase activity through the enhancement of Acetyl-CoA concentration Ahmad et al. [17]. On the other hand, though the zinc application also increased the oil content in the seed but increase was not remarkable as like sulfur, the increase was observed only upto 5.0 ppm and thereafter, decreased at 7.5 ppm level. The increase in oil content on addition of sulfur in oilseed crop has also reported by Varun et al. [18]

Table 4. Effect of sulfur and zinc on oil content (%) in seeds of linseed.

Levels of S (ppm)	Levels of Zn (ppm)				Mean
	0.0	2.5	5.0	7.5	
0.0	38.02	39.00	39.60	39.70	39.08
20	39.69	40.64	40.80	40.18	40.32
40	40.18	40.62	41.23	41.18	40.80
60	40.37	40.80	41.20	41.06	40.85
Mean	39.56	40.26	40.70	40.53	
		S	Zn	S × Zn	
SE (diff)		0.097	0.097	0.194	
CD ($p=0.05$)		0.198	0.198	0.397	

and Dash et al. [19]. The increase in oil content of seed on addition of zinc is supported by the findings of Krishna et al. [20] and Trivedi et al. [15]. The combined application of sulfur and zinc had significant influence on oil content. Application of 40 ppm sulfur + 5.0 ppm zinc was recorded in the highest oil content (41.23%) over the other treatments. This may be due to the interaction effect of S × Zn. Zinc involved in the synthesis of oil in plant and also enzyme activity in the plant cell.

Protein content

Results revealed (Table 3) that S and Zn application increased the protein content in seed significantly in comparison to control. Though, the protein content increased in linear order with the increasing both sulfur and zinc levels being highest at 60 ppm S and 5.0 ppm Zn levels but the increases were found non-significant. This might be due to role of sulfur in protein synthesis. Sulfur is a constituent of essential amino acids viz. methionine, cysteine and cystine. It also helps in conversion of these amino acids into high quality protein. Appropriate structure is essential for protein formation and sulfur provides di-sulfide chains and thus helps in increasing the protein content of linseed. Similar increase in protein content of seed on addition of sulfur has also been reported by Prasad and Singh [22]. Likewise, zinc is a constituent of essential component of variety of dehydrogenase, proteinases, which might have

resulted in increasing protein content of seed. The increase in protein content on addition of zinc is agreeable with the findings of Singh and Pal [9] and Verma et al. [14].

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