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INTERACTIVE EFFECTS OF CROP GEOMETRY AND SULPHUR LEVELS ON GROWTH AND YIELD OF LINSEED (*Linum usitatissimum* L.)

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ABSTRACT

A field experiment was conducted during rabi 2025-26 at Agricultural Research Farm, School of Agricultural Sciences, Jaipur National University, Jaipur, Rajasthan to evaluate the Effect of Sulphur Levels and Spacing on Growth, Yield and Quality of Linseed (*Linum usitatissimum* L.). Result revealed that among different spacing treatments, closer spacing of 30 cm × 10 cm recorded significantly higher plant height throughout the crop growth period, whereas wider spacing of 45 cm × 15 cm produced the maximum number of branches plant^{-1} and dry matter accumulation plant^{-1}. The maximum number of capsules plant^{-1}, seeds capsule^{-1} and test weight were recorded under 45 cm × 15 cm spacing. However, the highest seed yield (1145 kg ha^{-1}), straw yield (2240 kg ha^{-1}) and biological yield (3385 kg ha^{-1}) were obtained with 30 cm × 10 cm spacing. Among the sulphur level, the application of 30 kg S ha^{-1} gave significantly higher growth parameters viz., plant height, number of branches, DMA; maximum yield attributes and yield viz., number of capsules plant^{-1}, number of seeds capsules^{-1}, test weight, seed yield (1054 kg ha^{-1}), straw yield (2055 kg ha^{-1}) and biological yield (3109 kg ha^{-1}) and harvest index.
The interaction between spacing and sulphur levels significantly influenced plant height, number of branches plant^{-1}, dry matter accumulation, capsules plant^{-1}, seed yield and straw yield. The combination of 30 cm × 10 cm spacing with 30 kg S ha^{-1} recorded the highest seed yield (1250 kg ha^{-1}) and straw yield (2450 kg ha^{-1}).
***Keywords* :** Linseed, Spacing, Sulphur, Growth, Yield.

Introduction

Linseed (*Linum usitatissimum* L.), commonly known as flax and locally referred to as *Tisi* in Hindi, is among the oldest cultivated crops in the world and belongs to the family Linaceae. It is a multipurpose crop valued for both its oil and fibre. Historically, linseed has been cultivated primarily for oil extraction in many countries, including India and North America (Sharma *et al.*, 2021). In India, the crop is mainly grown for seed production, which yields high-quality oil with diverse industrial and nutritional applications. Indian linseed cultivars are broadly categorized into two groups: peninsular types, characterized by a deep root system, and alluvial types, which possess shallow roots and exhibit profuse tillering (Loro *et al.*, 2022).

Based on their utilization, linseed is classified into three types: fibre type, seed type, and dual-purpose type. Fibre-type flax produces superior-quality fibre with high tensile strength but contains relatively lower oil content. The fibre is stronger and more durable than cotton and is widely used in the textile industry for manufacturing fine fabrics, suiting, shirting, and household textiles such as bed sheets (Ganvit *et al.*, 2019). After fibre extraction, the residual stalks serve as raw material for producing pulp used in high-quality paper, including cigarette paper, bond paper, and security paper employed in currency note production.

Owing to the wide range of uses of its various plant parts, linseed is considered an economically important crop. The oil, because of its excellent drying properties, is extensively utilized in the manufacture of paints, varnishes, printing inks, and polymers (Jatwa *et al.*, 2025).

Globally, flax is cultivated on nearly 12 million acres, with major production concentrated in northern Europe and Russia. Canada ranks first in global flax production, whereas India is the second-largest country in terms of area under cultivation and ranks fourth in production. In India, linseed occupies approximately 179.91 thousand hectares, producing about 120.66 thousand tonnes annually with an average productivity of 574 kg ha^{-1} (Anonymous, 2025). Major linseed-growing states include Madhya Pradesh, Uttar Pradesh, Chhattisgarh, Bihar, Rajasthan, Odisha, and Karnataka. In Maharashtra, the crop covers about 5.49 thousand hectares with an annual production of 1.94 thousand tonnes and an average productivity of 353 kg ha^{-1} (Anonymous, 2025).

Linseed is an annual herbaceous crop that grows between 30 and 120 cm in height. Fibre types are generally taller and less branched than seed types. The plant develops a well-established fibrous root system with numerous lateral roots. Its fruit is a globular capsule, usually indehiscent, containing shiny, flattened seeds that vary from yellow to light brown in colour. Seed-type cultivars, owing to their branching habit, generally exhibit a lower harvest index compared to fibre types. The harvest index typically ranges from 0.19 to 0.31, while the thousand-seed weight averages around 6.5 g. The number of capsules per unit area is a major yield-contributing factor influencing both productivity and seed quality. Linseed is predominantly a cool-season (*rabi*) crop and performs best under moderate climatic conditions. The crop requires temperatures ranging from approximately 10°C to 38°C for optimum growth and development (Diwan *et al.*, 2019). Consequently, sowing is generally carried out during October and November, depending on soil moisture availability. Linseed oil extracted from the seeds is widely used as a protective coating for wood due to its drying characteristics, which enable it to polymerize into a solid film. Although edible, its strong flavour and odour limit its direct consumption. The oil cake remaining after extraction serves as a valuable organic manure and nutritious livestock feed. Linseed also finds applications in the paper and plastic industries and possesses several medicinal properties. The oil is particularly rich in alpha-linolenic acid (40–60%), an omega-3 fatty acid known for its anti-inflammatory effects and beneficial role in reducing blood cholesterol levels. Furthermore, lignans present in linseed exhibit antioxidant and potential anti-carcinogenic properties. In India, linseed cultivation is largely rainfed (63%), followed by utera cropping systems (25%) and irrigated conditions (12%), generally under low-input management practices (Singh *et al.*, 2013).

Among the essential plant nutrients, sulphur (S) plays a crucial role in enhancing the growth, yield, and quality of oilseed crops, including linseed. Sulphur is a key constituent of amino acids, proteins, vitamins, and chlorophyll and is therefore indispensable for normal plant metabolism. The widespread use of sulphur-free fertilizers has resulted in sulphur deficiencies in many Indian soils. Consequently, balanced nutrient management that includes adequate sulphur application has become essential for sustaining crop productivity and improving oil quality. Studies have demonstrated that sulphur application in the range of 20-60 kg ha^{-1} significantly enhances crop growth, nutrient uptake, yield, and economic returns. Sulphur also contributes to the synthesis of proteins, chlorophyll, and oils, thereby improving both the quantity and quality of produce (Singh and Singh, 2007).

With increasing pressure on agricultural land resources and the growing demand for food and industrial products, intensive crop production systems have become necessary. Improving crop productivity through efficient nutrient management is therefore of paramount importance (Chaudhary, 2009). Oilseed crops generally require sulphur in quantities comparable to phosphorus, making it a critical nutrient for achieving higher yields. Sulphur influences flowering, seed development, and oil quality, while its deficiency adversely affects nitrogen metabolism, reduces protein synthesis, and leads to the accumulation of carbohydrates within plant tissues.

Apart from nutrient management, optimum plant spacing is another vital agronomic factor influencing crop performance. Appropriate spacing ensures efficient utilization of available resources such as sunlight, water, nutrients, and growing space (Prajapati *et al.*, 2024). Since plant growth and development vary among varieties and agro-climatic conditions, determining an optimum spacing is essential for maximizing yield per unit area. Therefore, proper spacing combined with balanced nutrient management, particularly sulphur nutrition, plays a significant role in improving the productivity and profitability of linseed cultivation (Pardeshi *et al.*, 2024). Among the different factors influencing crop production, spacing and sulphur levels play a vital role and require careful consideration to achieve the maximum yield potential of linseed. With this understanding, the present field experiment was carried out.

Materials and Methods

The field experiment was carried out at the Agronomy Research Farm, School of Agricultural Sciences, Jaipur National University, Jaipur, Rajasthan during kharif season of 2025. The experimental site is situated in semi-arid eastern plains of Rajasthan and lies between 26°92' North latitude, 75°78' East longitude and at an altitude of 430 meters from the mean sea level. The soil of the experimental field was sandy in texture and slightly alkaline in reaction with PH 7.58, organic carbon (OC) (0.43 %), available nutrient (nitrogen 217.30 kg ha^{-1}; phosphorus 20.28 kg ha^{-1} and potassium 219.20 kg ha^{-1}). The experiment was laid out in split plot design with three replications. The four spacing treatments as main plot *viz.*, (i) 30 cm x 10 cm, (ii) 30 cm x 15 cm, (iii) 45 cm x 10 cm and (iv) 45 cm x 15 cm and the three sulphur levels as sub plot treatments *viz.*, (i) control, (ii) 20 kg S ha^{-1} and (iii) 30 kg S ha^{-1}. The linseed variety "Kota Barani Alsi 5" was sown. All agricultural practices were kept uniform in all the plots.

Results and Discussion

Growth Parameters

Effect of Spacing

Data presented in Table 1 revealed that plant height of linseed was significantly influenced by spacing at 45, 60, 75 DAS and at harvest. Among the spacing treatments, 30 cm × 10 cm recorded the tallest plants (22.50 cm at 45 DAS; 27.55 cm at 60 DAS; 31.10 cm at 75 DAS and 31.75 cm at harvest) and it was statistically at par with the spacing 30 cm x 15 cm. The taller plants at closer spacing could be attributed to intense intra-plant competition for light, causing etiolation and upward growth. These findings are in agreement with Kumar *et al.* (2020) who reported significantly taller linseed plants under narrow row spacing due to apical dominance triggered by reduced light interception plant^{-1}. Similarly, Sharma and Verma (2019) observed that reduced spacing in linseed resulted in taller plants owing to competitive effects for solar radiation.

The data in Table 1 indicated that number of branches plant^{-1} was significantly affected by spacing from 45 DAS onwards. Wider spacing of 45 cm × 15 cm produced the maximum branches (5.95 at 45 DAS; 6.99 at 60 DAS; 7.95 at 75 DAS and 8.15 at harvest) and it was statistically at par with the spacing 45 cm x 10 cm. Plants under wider spacing had greater access to sunlight, moisture, and nutrients, which promoted lateral branching. These results are consistent with Yadav *et al.* (2020) who reported that wider spacing in linseed promoted branching due to reduced inter-plant competition. Tripathi *et al.* (2019) similarly noted that decreased plant population density resulted in enhanced branching plant^{-1} in linseed, as individual plants had better access to growth resources.

Dry matter accumulation (g plant^{-1}) was significantly influenced by spacing at 45 DAS and beyond (Table 1). The maximum dry matter (3.65 g at 45 DAS; 6.70 g at 60 DAS; 7.96 g at 75 DAS and 9.15 g at harvest) was recorded with 45 cm × 15 cm spacing and it was statistically at par with the spacing 45 cm x 10 cm. At wider spacing, each plant had greater access to light, water, and nutrients which enhanced photosynthesis and ultimately dry matter production per plant. These findings are supported by Rajput *et al.* (2022) who observed higher dry matter accumulation plant^{-1} in linseed at wider spacings due to greater resource availability per individual plant.

Effect of sulphur levels

Sulphur application significantly affected plant height at 45, 60, 75 DAS and at harvest (Table 1). Application of 30 kg S ha^{-1} recorded the maximum plant height (21.11 cm at 45 DAS; 25.98 cm at 60 DAS; 29.33 cm at 75 DAS and 29.95 cm at harvest), which was significantly superior to 20 kg S ha^{-1} and control. Sulphur is an essential constituent of amino acids (cysteine and methionine) and plays a vital role in protein synthesis, which promotes cell division and elongation, thereby enhancing plant height. These results corroborate the findings of Meena *et al.* (2021) who reported progressive increase in plant height of linseed with increasing sulphur fertilization, attributing it to improved nitrogen metabolism. Patel and Singh (2022) also observed that sulphur application up to 30 kg ha^{-1} significantly enhanced plant height in oilseed crops through better photosynthetic efficiency.

Sulphur application significantly enhanced branching at 45, 60, 75 DAS and at harvest (Table 1). The maximum number of branches (5.61 at 45 DAS; 6.59 at 60 DAS; 7.50 at 75 DAS and 7.69 at harvest) was recorded with 30 kg S ha^{-1}, followed by 20 kg S ha^{-1} and control. Sulphur improves the synthesis of chlorophyll and growth hormones, thereby stimulating axillary bud development and branching. Singh *et al.* (2021) reported that sulphur application at 30 kg ha^{-1} significantly improved the number of branches in linseed by enhancing the availability of sulphur-containing amino acids essential for meristematic activity. Joshi *et al.* (2023) also found that adequate sulphur nutrition promoted axillary branching in oilseed crops through enhanced cytokinin activity.

Sulphur application significantly increased dry matter accumulation at 45 DAS onwards (Table 1). Application of 30 kg S ha^{-1} recorded the maximum dry matter (3.44 g at 45 DAS; 6.32 g at 60 DAS; 7.51 g at 75 DAS and 8.63 g at harvest), followed by 20 kg S ha^{-1} (7.92 g $plant^{-1}$) and control (7.35 g $plant^{-1}$). Sulphur enhances photosynthetic efficiency through chlorophyll synthesis and enzyme activation, thereby increasing dry matter production. Meena *et al.* (2021) reported similar findings that sulphur fertilization significantly improved dry matter accumulation in linseed through enhanced metabolic activities. Kumar and Yadav (2020) also observed that sulphur application improved the dry matter production in oilseed crops by promoting photosynthesis and assimilate translocation.

Yield attributes and yield

Effect of spacing

The data in Table 2 revealed that the number of capsules $plant^{-1}$ was significantly influenced by spacing. The maximum capsules were produced at 45 cm × 15 cm spacing (52.00), and it was statistically at par with the spacing 45 cm x 10 cm. Plants under wider spacing produced more capsules due to better light penetration and reduced competition. These results align with Yadav *et al*. (2020) who reported more capsules $plant^{-1}$ at wider spacing in linseed.

The number of seeds $capsule^{-1}$ was significantly affected by spacing (Table 2). Wider spacing (45 cm × 15 cm: 8.30 seeds) produced more seeds $capsule^{-1}$. Test weight, however, did not differ significantly by spacing, suggesting that seed size is largely a genotypic characteristic. Patel and Singh (2022) similarly found that spacing had a significant effect on seeds $capsule^{-1}$ but not on test weight in linseed.

Seed yield, straw yield, and biological yield were significantly affected by spacing (Table 2). The highest seed yield (1145 kg ha^{-1}), straw yield (2240 kg ha^{-1}) and biological yield (3385 kg ha^{-1}) were recorded with 30 cm × 10 cm spacing. Although individual plant performance was better at wider spacing, the higher plant population density at 30 cm × 10 cm compensated to give higher yield $hectare^{-1}$. The harvest index did not differ significantly among spacing treatments (33.83–34.04%), indicating that the proportion of economic yield to total biomass was unaffected by spacing. Kumar *et al*. (2020) reported that closer spacing in linseed resulted in higher seed yield $hectare^{-1}$ through increased plant population. Tripathi *et al.* (2019) also observed maximum seed yield at 30 cm × 10 cm spacing due to optimal canopy utilization.

Effect of sulphur levels

The data in Table 2 revealed that the number of capsules $plant^{-1}$ was significantly influenced by sulphur levels. The maximum capsules were produced with application of 30 kg S ha^{-1} gave the maximum capsules (51.05), followed by 20 kg S ha^{-1} (47.00) and control (43.79). These results align with Singh *et al.* (2021) who noted higher capsule number with sulphur application.

The number of seeds $capsule^{-1}$ was significantly affected by both sulphur levels (Table 2). The maximum number of seeds $capsule^{-1}$ (8.43) was recorded with the application of 30 kg S ha^{-1}. Test weight, however, did not differ significantly with sulphur treatments, suggesting that seed size is largely a genotypic characteristic. Joshi *et al.* (2023) observed that sulphur application improved the number of seeds $capsule^{-1}$ by enhancing reproductive efficiency during grain filling.

Among sulphur levels, 30 kg S ha^{-1} recorded the highest seed yield (1054 kg ha^{-1}), straw yield (2055 kg ha^{-1}) and biological yield (3109 kg ha^{-1}), significantly superior to 20 kg S ha^{-1} and control. Sulphur plays a critical role in chlorophyll biosynthesis, protein metabolism, and enzyme activation, ultimately improving yield. The harvest index was not significantly affected by sulphur levels. Meena *et al.* (2021) reported that sulphur application at 30 kg ha^{-1} significantly increased seed yield in linseed through better capsule formation and seed filling. Rajput *et al.* (2022) also observed a progressive increase in linseed yield with increasing sulphur doses up to 30 kg ha^{-1}.

Conclusion

The results of the present investigation clearly indicated that spacing and sulphur application significantly influenced the growth and yield of linseed. Wider spacing (45 cm × 15 cm) improved individual plant performance, yield attributes, oil content and nutrient concentration, whereas closer spacing (30 cm × 10 cm) produced higher seed, straw and biological yields due to greater plant population. Application of sulphur up to 30 kg S ha^{-1} significantly enhanced growth, yield attributes, yield, oil yield, nutrient uptake and economic returns. The interaction of 30 cm × 10 cm spacing and 30 kg S ha^{-1} proved most effective in maximizing productivity of linseed.

Table 1: Effect of spacing and sulphur levels on growth parameters of linseed at successive stage

Treatment	Plant height (cm)					Number of branches plant^{-1}					Dry matter accumulation (g plant^{-1})				
	30 DAS	45 DAS	60 DAS	75 DAS	At harvest	30 DAS	45 DAS	60 DAS	75 DAS	At harvest	30 DAS	45 DAS	60 DAS	75 DAS	At harvest
Spacing															
30 cm x 10 cm	15.10	22.50	27.55	31.10	31.75	3.15	4.32	5.07	5.78	5.92	0.34	2.65	4.87	5.79	6.64
30 cm x 15 cm	14.28	21.46	26.37	29.77	30.40	2.98	4.76	5.59	6.36	6.51	0.33	2.92	5.36	6.37	7.32
45 cm x 10 cm	12.26	17.61	22.02	24.86	25.38	2.56	5.70	6.69	7.61	7.80	0.28	3.49	6.42	7.62	8.76
45 cm x 15 cm	12.19	15.82	20.00	22.58	23.05	2.54	5.95	6.99	7.95	8.15	0.28	3.65	6.70	7.96	9.15
SEm±	1.93	0.48	0.54	0.61	0.62	0.40	0.12	0.14	0.16	0.16	0.04	0.07	0.13	0.16	0.18
CD (*p*=0.05)	NS	1.66	1.88	2.12	2.16	NS	0.41	0.48	0.54	0.55	NS	0.25	0.46	0.54	0.62
Sulphur levels															
Control	12.72	17.71	22.13	24.99	25.51	2.65	4.78	5.62	6.39	6.55	0.29	2.93	5.38	6.40	7.35
20 kg S ha^{-1}	13.40	19.22	23.84	26.91	27.48	2.79	5.15	6.05	6.88	7.05	0.31	3.16	5.80	6.89	7.92
30 kg S ha^{-1}	14.25	21.11	25.98	29.33	29.95	2.97	5.61	6.59	7.50	7.69	0.33	3.44	6.32	7.51	8.63
SEm±	0.52	0.18	0.21	0.23	0.24	0.11	0.04	0.05	0.06	0.06	0.01	0.03	0.05	0.06	0.07
CD (*p*=0.05)	NS	0.55	0.62	0.70	0.72	NS	0.13	0.16	0.18	0.18	NS	0.08	0.15	0.18	0.21

Table 2: Effect of spacing and sulphur levels on yield attributes and yield of linseed

Treatment	Number of capsules plant^{-1}	Number of seeds capsules^{-1}	Test weight (g)	Seed yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Harvest index (%)
Spacing							
30 cm x 10 cm	41.76	7.30	7.91	1145	2240	3385	33.83
30 cm x 15 cm	45.57	7.84	8.25	1032	2013	3045	33.89
45 cm x 10 cm	49.78	8.14	8.52	873	1697	2570	33.99
45 cm x 15 cm	52.00	8.30	8.70	774	1493	2267	34.04
SEm±	1.02	0.14	0.36	27	18	34	0.80
CD (*p*=0.05)	3.54	0.50	NS	92	63	119	NS
Sulphur levels							
Control	43.79	7.41	7.76	865	1680	2545	33.97
20 kg S ha^{-1}	47.00	7.86	8.30	949	1847	2796	33.93
30 kg S ha^{-1}	51.05	8.43	8.98	1054	2055	3109	33.92
SEm±	0.39	0.05	0.44	10	19	23	0.32
CD (*p*=0.05)	1.17	0.16	NS	31	58	68	NS

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