*Review Article*

"Impact of Zinc and Boron on the Growth, Yield, and Economic Performance of Linseed: A Review"

.

ABSTRACT

|  |
| --- |
| **Introduction:** Linseed (*Linum usitatissimum* L.) is an important oilseed crop grown in India, primarily on marginal lands with minimal inputs, leading to low productivity. Micronutrients like zinc and boron play a crucial role in enhancing growth, yield, and oil content.  **Objective:** This review evaluates the effect of zinc and boron supplementation on linseed growth, yield attributes, and oil quality, highlighting effective nutrient management strategies.  **Methodology:** The review compiles findings from various studies examining the soil and foliar application of zinc and boron, their impact on growth parameters, seed yield, oil content, and nutrient uptake in linseed cultivation.  **Key Findings:** Zinc is essential for enzyme activation, chlorophyll formation, and grain filling, while boron supports pollen viability, seed setting, and nutrient transport. Studies indicate that foliar application of ZnSO₄ (0.5%) and borax (0.3%) at 45 DAS significantly enhances seed yield, oil percentage, and stover yield. Integrating micronutrient management improves nutrient use efficiency and crop resilience.  **Conclusion:** Zinc and boron play a critical role in optimizing linseed production. Targeted foliar application at key growth stages can enhance yield and oil quality. Future research should focus on site-specific nutrient strategies for sustainable linseed cultivation. |

*Keywords: (Linseed, Zinc, Boron, Yield, Oil content )*

1. INTRODUCTION

Oilseeds hold significant importance in India's economy, ranking as the second-largest agricultural commodity after cereals. They occupy approximately 18.7% of the total cropped area and contribute 11.8% to overall food grain production (Agri. Statistics, 2022-23). The leading oilseed-producing states in India include Madhya Pradesh, Chhattisgarh, Uttar Pradesh, Maharashtra, Bihar, Odisha, Jharkhand, Nagaland, Karnataka, and Assam, accounting for over 95% of both cultivated area and production. Linseed (*Linum* *usitatissimum* L.) is a vital rabi oilseed crop cultivated in India. It thrives in cool-season conditions, requiring moderate to low temperatures during its growth period. The crop is generally grown in regions receiving an annual rainfall of around 500 mm. Among oilseeds, linseed is one of the oldest cultivated crops, valued for both its oil and fiber. It is grown in tropical and temperate regions worldwide, often on marginal and sub-marginal lands with minimal agricultural inputs. Globally, linseed is cultivated on approximately 32.23 lakh hectares, producing 30.68 lakh tonnes with an average yield of 952 kg/ha. In contrast, India cultivates linseed on around 1.7 lakh hectares, with a total production of nearly 1 lakh tonnes and an average productivity of 574 kg/ha. In terms of cultivated area, India ranks fifth, following Kazakhstan, the Russian Federation, Canada, and China. However, in production, it holds the sixth position, trailing behind Kazakhstan, Canada, the Russian Federation, China, and the USA (Annual Report, AICRP on Linseed, 2021-22). Each component of linseed holds economic significance. Linseed seeds contain 33–45% oil, which is extensively used in industries for paper manufacturing, paint production, and fiber processing (Rowland et al. 1995). In certain parts of India, both the seed and its oil are consumed directly in various culinary preparations. Linseed oil is also utilized in road construction in the USA. The seed contains an antibiotic, "Linative," which is known to treat diseases in humans and animals for which no medical remedy currently exists. Nutritionally, linseed is a rich source of protein, fats, and carbohydrates. It is especially valued for its high content of omega-3 and omega-6 fatty acids (Singh et al. 2013), essential for human health. Linseed is unique among vegetarian foods for having the highest concentration of omega-3 fatty acids and is classified as a functional food. Additionally, it contains linolenic acid, vitamins, minerals, and mucilage—a polysaccharide with food-binding and anti-coughing properties. Linolenic acid contributes to brain development as it gets converted into DPA and DHA. The plant's stem is used for scutching, while its fiber can be blended with wool, cotton, and silk to create high-quality threads for textiles (Sharma et al. 2015). Linseed is a valuable secondary oilseed crop extensively utilized in industrial applications and serves as a phytoremediation agent for heavy metal-contaminated soils. It can accumulate heavy metals such as iron, copper, and zinc, with iron being the most dominant. While these elements are essential micronutrients, their optimal levels are crucial for enhancing linseed productivity. Increasing linseed production requires cultivating high-yielding varieties (HYVs) with balanced fertilization, including micronutrient supplementation. Micronutrients, though required in small amounts, are vital for plant growth and include iron, manganese, zinc, boron, copper, molybdenum, and chlorine. In oilseed crops, micronutrients play a crucial role in photosynthesis, seed setting, sugar translocation, pollen germination, stigma receptivity, and protein synthesis, all of which contribute to higher productivity. Under intensive cropping systems, the depletion of these nutrients is evident, necessitating their external supplementation. Zinc and boron deficiencies are widespread, particularly in wetland rice soils, light-textured soils, and calcareous soils. Zinc is one of the 17 essential plant nutrients, acting as an enzyme activator and playing a key role in the biosynthesis of auxin, which regulates plant growth and cell division (Suresh et al. 2013). It facilitates protein synthesis, chlorophyll formation, carbohydrate metabolism, and starch-to-sugar conversion while enhancing plant cold resistance. Zinc deficiency adversely affects crop development, leading to poor growth, interveinal chlorosis, and leaf necrosis. It is particularly crucial for grain formation and maintaining plasma membrane integrity. Plants grown from zinc-deficient seeds are highly vulnerable to biotic and abiotic stresses. Enriching linseed seeds with zinc enhances germination, seedling vigor, plant growth, and yield. Addressing zinc deficiency in linseed is an emerging challenge for improving crop productivity. Boron is another vital micronutrient that supports various physiological functions, including cell wall development, membrane integrity, sugar transport, pollination, and seed set. Its deficiency can hinder root and shoot growth, vascular tissue formation, and reproductive processes, ultimately affecting seed quality and viability in subsequent crop generations (Bubarai et al. 2017). Inadequate boron supply also impairs nitrogen uptake and assimilation. Boron is particularly important during pod and seed formation, as it influences the absorption of nitrogen, phosphorus, and potassium, thereby maintaining nutrient balance in plants. Given its significance, the application of micronutrients alongside major nutrients has gained importance in modern agronomic practices. Linseed cultivation is largely limited to marginal and sub-marginal lands with minimal input management, leading to low productivity. To enhance linseed production, there is an urgent need to develop agronomic strategies that optimize crop yield. Adopting location-specific agricultural practices, particularly efficient micronutrient management, is essential in the context of changing climatic conditions. The role of micronutrients, alongside macronutrients, is crucial in improving growth, yield attributes, and overall productivity in linseed.

2. Effect of Zinc on growth and yield of linseed

Zinc supplementation has been shown to enhance flax growth and boost seed yield, as reported by Jiao et al. (2004). The application of phosphorus fertilizers, however, negatively impacted flax growth by inducing zinc deficiency compared to a no-phosphorus control. Zinc addition mitigated this deficiency, leading to improved growth and yield. Mousa et al. (2010) found that applying 45 kg N ha⁻¹ along with micronutrients like zinc and boron through foliar application resulted in the highest seed and straw yield while also enhancing fiber fineness in linseed. Babaeian et al. (2011) emphasized that zinc plays a crucial role in synthesizing tryptophan, which is essential for producing indole-3-acetic acid. Additionally, zinc positively affects photosynthetic activity and metabolism, contributing to higher metabolite accumulation in reproductive structures. Nofal et al. (2011) highlighted that foliar zinc application is key to maintaining nutrient balance in flax. Their study recommended applying zinc at 2 g L⁻¹ twice to maximize seed yield and fiber quality. Bakry et al. (2012) reported that a combined foliar application of Zn, Mn, and Fe improved seed, oil, and fiber yields in flax. They observed varietal differences in flax cultivars' responses to these micronutrients. Homayouni et al. (2013) found that the R24 linseed genotype responded significantly to 80 kg ha⁻¹ nitrogen combined with foliar zinc application, improving growth, yield attributes, and seed yield. Similarly, Habbasha et al. (2013) noted that nitrogen use efficiency increased in oilseed crops when N and Zn were applied together, particularly at flowering and seed-filling stages. The most efficient nitrogen use occurred when 30-40 kg N ha⁻¹ was applied alongside zinc. Suresh et al. (2013) determined that zinc levels in oilseed crops vary between 15-46 mg kg⁻¹, with soils containing less than 0.6 mg kg⁻¹ DTPA-Zn considered deficient. Zn deficiency rates range from 21-86%, with an average of 49%. Zinc stress tolerance varies among oilseed cultivars, and residual Zn from previous crops can benefit subsequent oilseed plantings. Foliar ZnSO₄ sprays (0.2-0.5%) are recommended when Zn deficiency symptoms appear. Integrated nutrient management, incorporating balanced Zn application, enhances oilseed productivity. Tahir et al. (2014) found that foliar zinc application at 3.0% during bud initiation and after capsule filling significantly improved plant height, stem length, fruiting branches, 1000-seed weight, straw yield, and seed yield in linseed. Bakry et al. (2015) reported that linseed growth and yield responded well to foliar zinc application in sandy soils. Applying potassium sulfate at 100 kg ha⁻¹ alongside 0.5% zinc foliar spray resulted in the highest yield across different flax varieties.

Eldaiem et al. (2016) observed significant increases in plant height, technical length, stem diameter, fruiting branches, straw yield, seed yield, long fiber yield, and nutrient uptake (N, P, K, Zn) in flax due to foliar zinc application at 500 ppm. They concluded that zinc plays a critical role in enzyme function, photosynthesis, saccharide metabolism, nucleic acid synthesis, and protein metabolism. Gonzalez et al. (2016) emphasized the importance of balanced micronutrient supply for optimal crop yield and quality. Their study found that Zn-EDDHSA and Zn-HEDTA were effective in weakly acidic soils, while Zn-EDTA and Zn-EDDHSA were most efficient in calcareous soils. These fertilizers improved fiber properties and reduced zinc leaching. Khan et al. (2017) reported that soil application of 10 kg ha⁻¹ ZnSO₄, 10 kg ha⁻¹ Borax, and 5 kg ha⁻¹ MnSO₄, along with recommended macronutrients, significantly increased sesame seed yield. Kumar (2018) found that foliar application of micronutrients (Zn, B, Fe, Mn, Cu) improved oilseed crop yield, and integrated micronutrient management enhanced nutrient use efficiency. Maharnor et al. (2018) noted that Zn application improved seed quality, oil percentage, protein content, and overall yield. The best results were obtained using ZnSO₄ at 30 kg ha⁻¹ combined with a recommended fertilizer dose. Diwan et al. (2019) suggested that applying 0.5% S ha⁻¹ with 7.5 kg Zn ha⁻¹, along with recommended N, P, and K doses, maximized rainfed linseed production. Aboyeji et al. (2019) found that while zinc had minimal impact on vegetative growth, applying 8 kg Zn ha⁻¹ significantly increased seed quantity and quality. They also noted that 600 ml Boron ha⁻¹ improved seed quality without increasing heavy metal content beyond safe limits. Jahan et al. (2019) highlighted zinc's significant role in sesame crop growth, yield, and oil content, noting that inadequate Zn application leads to yield losses. Nandi et al. (2020) found that omitting Zn and B reduced plant growth, nutrient uptake, and yield. Foliar spraying of zinc and boron increased plant biomass, leaf area, and chlorophyll content, with higher concentrations intensifying these benefits. Zinc application had a more pronounced impact on plant physiology than boron alone, while the combined application of Zn and B enhanced plant growth and nutrient accumulation, ultimately improving seed yield. Singh et al. (2020) conducted an experiment during the rabi season of 2018-19 at the Oilseed Research Farm, Kalyanpur, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, to investigate the effect of zinc and boron on the growth, yield attributes, seed yield, and economics of linseed. The results indicated that among the various treatments, foliar application of ZnSO4 at 0.5% and borax at 0.3% at 45 days after sowing (DAS) was the most effective, leading to the highest plant growth includes plant height and dry matter accumulation. Alam et al. (2021) carried out an experiment during the Rabi seasons of 2018-19 and 2019-20 at the Research Farm of Birsa Agricultural University, Kanke, Ranchi, Jharkhand, to investigate the impact of Zinc and Boron on the growth, yield, and economics of Linseed *(Linum usitatissimum* L.) in the region’s medium land. The results showed that foliar application of Zinc Sulfate (ZnSO4) at 0.5% and Borax at 0.3% at 45 days after sowing (DAS) produced the best results in growth parameters like higher plant height, better plant stand, increased dry matter accumulation in both the years. Awasthi et al. (2024) conducted an experiment on the "Effect of Boron and Zinc on Yield, Water Use Efficiency, and Economics of Linseed (*Linum usitatissimum* L.) under Limited Water Supply during rabi 2023-24 at the Oilseed Farm, Rama University, Mandhana, Kanpur. The results showed significantly higher yield attributes, oil content, oil yield, seed yield, stover yield. These factors led to higher seed yield compared to other

3. EFFECT of boron on growth and yield of linseed

Brown et al. (1993) highlighted boron's essential role in plant development, particularly in cell wall synthesis, lignification, carbohydrate and RNA metabolism, respiration, indole acetic acid metabolism, phenol metabolism, and membrane transport in field crops. Sarker et al. (2002) studied soybean grown in silt loam soil and found that boron application significantly influenced yield components. The highest plant height and branch count per plant were observed with 4.0 kg B ha⁻¹, while 1.0 kg B ha⁻¹ increased the number of effective pods per plant, and 2.0 kg B ha⁻¹ significantly improved the 100-seed weight. Karthikeyan et al. (2008) found that boron and sulfur applications significantly affected the protein content in sunflower and mustard seeds. In sunflower, protein content increased by 13.8%–16.3% with sulfur application and 14.4%–15.9% with boron. Similarly, mustard seed protein content rose from 19.2% to 21.6% with sulfur and 19.3% to 21.3% with boron. Nadian et al. (2010) reported that while sulfur alone had no significant impact on yield, the combination of sulfur and boron positively influenced canola yield and its components. The highest grain yield was achieved with 2.5 kg B ha⁻¹ and 80 kg S ha⁻¹. However, excessive boron application (>2.5 kg ha⁻¹) led to reduced grain, protein, and oil yields, likely due to boron toxicity, particularly in the presence of sulfur. Amery et al. (2011) noted that foliar boron application at the flowering stage significantly improved seed set and yield in sunflower. Hossain et al. (2011) found that soil-applied boron increased mustard seed yield by 30%–35%, with an optimal application rate of 1.0 kg B ha⁻¹. A higher dose (2.0 kg B ha⁻¹) did not negatively impact the crop. Kabir et al. (2013) determined that phosphorus (50 kg ha⁻¹) and calcium (11 kg ha⁻¹) combined with boron (2.5 kg ha⁻¹) resulted in optimal growth and yield of oilseed crops. They suggested further research on various nutrient combinations, crop varieties, growing seasons, and soil types.

Hamideldin et al. (2014) concluded that boron is crucial for sesame growth, as foliar boron application enhanced growth, productivity, and oil quality. Kumararaja et al. (2015) observed a 30%–35% increase in oilseed crop yield due to boron application. In calcareous soils, 16 kg borax ha⁻¹ was optimal for mustard seed yield, while higher doses (20 kg borax ha⁻¹) did not significantly affect crop performance. Yadav et al. (2016) emphasized boron's vital role in oilseed production, reporting significant improvements in yield, oil content, and boron uptake with 1.5 kg B ha⁻¹, leading to 36% and 52% increases in seed and oil yield, respectively. Dandoti et al. (2017) found that seed polymer coating (2 ml kg⁻¹ of seed) with micronutrients (ZnSO₄, borax, FeSO₄, ammonium molybdate, and calcium sulfate) improved linseed yield and seed quality. Akashatha et al. (2017) recommended applying 3 kg borax ha⁻¹ with a 0.2% foliar spray of boron at the flowering stage of sesame for optimal growth, yield, and economic returns in kharif season in medium to deep black soils. Mamatha et al. (2017) reported that 5.0 kg B ha⁻¹ was the ideal soil application rate for sesame to maximize nutrient uptake, seed yield, and stover yield, with 7.5 kg B ha⁻¹ yielding similar results. Shoja et al. (2018) found that the combined application of Zn, B, and S with NPK fertilizers increased rapeseed yield, oil content, and oil quality by enhancing fatty acid composition. Masum et al. (2019) observed that applying boron twice—at the vegetative and pod development stages—improved the yield of Brassica genotypes. Shamsuzzoha et al. (2019) suggested that a combined application of nitrogen (60 kg ha⁻¹) and boron (3.0 kg ha⁻¹) in sesame crops resulted in better yields and economic returns. Singh et al. (2020) conducted an experiment during the rabi season of 2018-19 at the Oilseed Research Farm, Kalyanpur, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, to investigate the effect of zinc and boron on the growth, yield attributes, seed yield, and economics of linseed. The results indicated that among the various treatments, foliar application of ZnSO4 at 0.5% and borax at 0.3% at 45 days after sowing (DAS) was the most effective, leading to the highest yield attributes and seed yield. Alam et al. (2021) carried out an experiment during the rabi seasons of 2018-19 and 2019-20 at the Research Farm of Birsa Agricultural University, Kanke, Ranchi, Jharkhand, to investigate the impact of Zinc and Boron on the growth, yield, and economics of Linseed (*Linum usitatissimum* L.) in the region’s medium land. The results showed that foliar application of Zinc Sulfate (ZnSO4) at 0.5% and Borax at 0.3% at 45 days after sowing (DAS) produced the best results. This treatment led to improved yield components such as the number of capsules per plant, number of seeds per capsule, and 1000-seed weight. Awasthi et al. (2024) conducted an experiment on the "Effect of Boron and Zinc on Yield, Water Use Efficiency, and Economics of Linseed (*Linum usitatissimum* L.) under Limited Water Supply during rabi 2023-24 at the Oilseed Farm, Rama University, Mandhana, Kanpur. The results showed significantly higher plant height and dry matter accumulation. These factors led to higher growth parameters compared to other treatments.

**4. EFFECT OF ZINC ON ECONOMICS OF LINSEED**

Aruna et al. (2001) observed that foliar spraying of 2% DAP combined with 5% ZnSO₄ and 0.5% boric acid significantly enhanced the yield and yield components of groundnut. This treatment also resulted in higher net returns of ₹36,347 per hectare and a benefit-cost (B:C) ratio of 2.44. Shanmugasundaram and Savithri (2005) reported that the highest combined economic yield of maize and sunflower, reaching 25 tonnes per hectare, was achieved by applying zinc sulphate at a rate of 37.5 kg/ha to the first crop, followed by 12.5 kg/ha for all subsequent crops. Rashid and Akhtar (2006) found that the application of boron and zinc fertilizers was highly profitable, with a benefit-cost ratio of 2.2 for soil application and 3.1 for foliar spray. Additionally, foliar application of 0.2% boron in green gram increased the B:C ratio to 1.54. Husain et al. (2009) conducted a three-year field study (2002–03 to 2004–05) at Kanpur on a rice (*Oryza sativa* L.)-linseed (*Linum usitatissimum* L.) cropping system in silty loam soil with a zinc content of 0.85 ppm. The experiment included eight treatments, and results showed that applying zinc through zinc sulphate at 25 kg/ha along with farmyard manure (FYM) at 5 t/ha to rice in the sequence yielded the highest net monetary return of ₹17,419 per hectare. This was statistically similar to treatments where zinc was applied to both crops with FYM in rice and where zinc was applied to linseed with FYM in rice. Vijayakumari et al. (2009) estimated that the cost of cultivating groundnut was ₹8,881 per hectare, with an average gross return of ₹11,676, resulting in a net profit of ₹1,995 per hectare. The study found that the average groundnut yield in the research areas was 10.09 q/ha. Patil et al. (2012) reported that applying a micronutrient mixture at 20 kg/ha, containing Fe (29%), Mn (0.5%), Zn (5%), Cu (0.2%), and B (0.5%), resulted in a higher benefit-cost (B:C) ratio of 1.79 compared to the control treatment (NPK + water spray), which recorded a B:C ratio of 1.33 in sesame. Madhu Bala and Kedar Nath (2015) found that the highest groundnut pod yield (2,169 kg/ha) and B:C ratio (5.45) were achieved with the application of the recommended dose of fertilizers (RDF) at the basal stage along with FYM at 7.5 t/ha. This was followed by the treatment where 100% RDF was applied at the basal stage, with an additional 50% RDF at 30 days after sowing (DAS) along with FYM at 7.5 t/ha, yielding 2,006 kg/ha. The lowest yield was recorded when 75% RDF was applied at both the basal stage and 30 DAS. Singh et al. (2020) carried out an experiment during the rabi season of 2018-19 at the Oilseed Research Farm, Kalyanpur, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, to investigate the effect of zinc and boron on the growth, yield attributes, seed yield, and economics of linseed. The results indicated that among the various treatments, foliar application of ZnSO4 at 0.5% and borax at 0.3% at 45 days after sowing (DAS) was the most effective, leading to the highest economic return includes gross monetary return, and net monetary return followed by the soil application of ZnSO4 at 25 kg/ha + borax at 1.5 kg/ha. Alam et al. (2021) carried out an experiment during the rabi seasons of 2018-19 and 2019-20 at the Research Farm of Birsa Agricultural University, Kanke, Ranchi, Jharkhand, to investigate the impact of Zinc and Boron on the growth, yield, and economics of Linseed (*Linum usitatissimum* L.) in the region’s medium land. The results showed that foliar application of Zinc Sulfate (ZnSO4) at 0.5% and Borax at 0.3% at 45 days after sowing (DAS) produced the best results. This treatment led to higher net return and an improved benefit-cost ratio in both years. Awasthi et al. (2024) conducted an experiment on the "Effect of Boron and Zinc on Yield, Water Use Efficiency, and Economics of Linseed (*Linum usitatissimum* L.) under Limited Water Supply during rabi 2023-24 at the Oilseed Farm, Rama University, Mandhana, Kanpur.The application of ZnSO4 at 25 kg/ha and Borax at 1.5 kg/ha, incorporated into the soil, resulted in the highest net return and B:C ratio.

**5. EFFECT OF BORON ON ECONOMICS OF LINSEED**

Paramasivam et al. (2003) reported that supplementing the recommended NPK dose for sesame with seed treatment and foliar application of 0.5% DAP, 0.2% ammonium molybdate, 0.1% boric acid, 40 ppm NAA, 100 ppm salicylic acid, and phytohormones resulted in a 30.5% increase in seed yield. This treatment also achieved a benefit-cost (B:C) ratio of 1.61, surpassing the use of the recommended fertilizers alone. Rashid and Akhtar (2006) observed that applying boron and zinc fertilizers was highly profitable, with a B:C ratio of 2.2 for soil application and 3.1 for foliar spray. Similarly, Dixit and Elamathi (2007) found that foliar spraying of 0.2% boron in green gram improved the B:C ratio to 1.54. Patil et al. (2012) noted that incorporating a micronutrient mixture at 20 kg/ha—comprising Fe (2%), Mn (0.5%), Zn (5%), Cu (0.2%), and B (0.5%)—resulted in a higher B:C ratio of 1.79 compared to the control (NPK + water spray) in sesame. Ansari et al. (2016) found that groundnut productivity, net returns, and B:C ratio, along with energy use efficiency and energy productivity, were maximized with solubor (soil application), followed by borosol (soil application), compared to no boron application.. Prathima (2013) reported that spraying 0.4% borax at the capitulum stage when ray florets opened, along with RDF, significantly enhanced seed and oil yield (2,176 kg/ha and 858.5 kg/ha, respectively). This treatment also resulted in higher net returns (₹44,527/ha) and a B:C ratio of 3.37. Bhattacharya et al. (2015) conducted an economic analysis of sunflower cultivation at different boron fertilization levels. They confirmed that applying boron at 2 kg/ha in soil or 0.2% as a foliar spray led to the highest gross returns (₹63,560/ha), net returns (₹46,250/ha), and a B:C ratio of 2.67, outperforming the recommended dose of fertilizers (RDF), which yielded ₹47,040/ha in gross returns, ₹30,330/ha in net returns, and a B:C ratio of 1.82. Raghav et al. (2016) studied the impact of sulphur and boron application on linseed yield and nutrient uptake in rainfed conditions in the North Chota Nagpur region of Jharkhand. Their three-year experiment (2005–2008) at the Zonal Research Station, Dumka (Birsa Agricultural University, Ranchi), was conducted in sandy loam soil with an initial pH of 5.55, organic carbon content of 0.34%, available sulphur at 10.2 mg/ha, and boron at 0.48 mg/ha. The factorial randomized block design included three sulphur levels (0, 15, and 30 kg/ha) and four boron levels (0, 1.0, 1.5, and 2.0 kg/ha). The highest B:C ratio was achieved with 30 kg sulphur and 1.5 kg boron per hectare. Kavita (2017) found that seed priming with 0.2% nano-boron significantly increased seed yield (2,788 kg/ha) and oil yield (1,022 kg/ha). This improvement was attributed to a higher SPAD (chlorophyll content) reading of 44.50, reduced days to 50% flowering (61.33 days), enhanced growth parameters, net returns of ₹66,950/ha, and a B:C ratio of 2.72. Singh et al. (2020) conducted a rabi 2018–19 study at the Oilseed Research Farm, Kalyanpur, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, to examine the effects of zinc and boron on the growth, yield attributes, and economics of linseed. The randomized block design experiment revealed that the highest gross monetary return (₹92,115/ha) was recorded with foliar application of 0.5% ZnSO₄ + 0.3% borax at 45 DAS, followed by soil application of 25 kg ZnSO₄/ha + 1.5 kg borax/ha. The maximum net monetary return (₹65,508/ha) and B:C ratio (3.46) were also achieved with foliar application of 0.5% ZnSO₄ + 0.3% borax at 45 DAS, followed by soil application of 25 kg ZnSO₄/ha + 1.5 kg borax/ha.

6. Conclusion

Linseed is a vital oilseed crop with significant economic and nutritional value, but its productivity in India remains low due to marginal land use and poor input management. Zinc and boron play crucial roles in enhancing plant growth, seed yield, and oil content. Optimizing micronutrient management can boost linseed production, ensuring better economic returns and sustainable cultivation. In conclusion, effective zinc and boron supplementation can substantially enhance linseed productivity and quality. Future research should focus on refining nutrient management practices, exploring site-specific recommendations, and integrating sustainable agronomic strategies to maximize linseed production in India.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

References

1. Aboyeji, C., Dunsin, O., Adekiya, A. O., Chinendum, C., Suleiman, K. O., Okunlola, F. O., Aremu, C. O., Qwolabi, I. O. & Iofintoye, T.A.J. (2019). Zinc Sulphate and Boron based foliar fertilizer effect on growth, yield, minerals, and heavy metals composition of groundnut grown on Alfisol. International Journal of Agronomy, Volume 2019, 1-7.
2. Akshatha, S. & Rajkumar, S. (2017). Response of sesame to different levels and methods of Boron application. J. Farm Sci., 31(1),(46- 49).
3. Alam, Md., P., Menka, K. & Sulochana (2021). Effect of zinc and boron on growth, yield and economics of linseed (*Linum usitatissimum* L.) under medium land of Jharkhand. The Pharma Innovation Journal,10(4),462-465.
4. Amery, M.M. Al., Hamza, J. H. & Fuller, M. P. (2011). Effect of Boron foliar application on reproductive growth of sunflower. International Journal of Agronomy,Volume 2011, 1-5.
5. Anonymous (2022). Annual report linseed, 2021-22, Project co-ordinate unit (Linseed), ICAR-Indian Institute of Pulse Research, Kanpur- Pp. 194.
6. Ansari, M. A., Prakash, N., Singh, I. M. & Sharma, P. K. (2016). Efficacy of boron sources on groundnut production under North East Hill Regions. Indian Research Journal of Extension Education,14(2),123-126.
7. Aruna, E., Rao, P. G. & Krishnamurthy, V. R. (2001). Effect of post flowering nutrition on dry matter production and nutrient uptake in bold kernel type of groundnut (*Arachis hypogaea*). Research on Crops,2(2),134-136.
8. Awasthi, A.K., Singh, R., Maurya, D.K., Pal, R.K. and Sonkar, S. (2024). Effect of boron and zinc on yield, water use efficiency and economic of linseed crop under limited water supply. International Journal of Research in Agronomy,7(6),642-645.
9. Babaeian, M., Piri , I., Tavaassoli , A. & Esmaeilian, Y. (2011). Effect of water stress and micronutrients (Fe, Zn and Mn) on chlorophyll fluorescence, leaf chlorophyll content and sunflower nutrient uptake. African Journal of Agricultural Research,6(15),3526- 3531.
10. Bakry , B. A., Tawfik , M.M.,Mekki, B.B. & Zeidan, M.S. (2012).Yield and yield components of three flax cultivars (Linum usitatissimum L.) in response to foliar application with Zn, Mn and Fe under newly reclaimed sandy soil condition. American-Eurasian J. Agric. & Environ. Science,12 (8),1075-1080.
11. Bakry, B.A.,Nofal, O.A.,Zeidan, M. S.& Hozayn, M. (2015).Potassium and Zinc in relation to improve flax varieties yield and yield components as grown under sandy soil conditions. Agricultural Sciences,6,152-158.
12. Bhattacharyyaa, K., Mandalb, H., Banerjee, H., Alipatrad, A., Krishnendu, R. & Phonglosaa, A. (2015). Boron fertilization in sunflower in an Inceptisol of West Bengal, India. Comm. Soil Sci. Plant Annal,46(4),528-544.
13. Brown, P.H. and Shelp, B. J. (1993). Boron mobility in plants. Plants and Soil,193,85-101.
14. Bubarai, M.L., Tahir, A.L. & Solomon, R.I. (2017).The micronutrients Boron its influence on growth and development of plant and factors effecting availability.IOSR Journal of Agriculture and Veterinary Science,10(12),10-13.
15. Dandoti, K., Shakuntala, N.M., Macha, S. & Vasudevan, SN (2017) . Effect of seed polymer coating with micronutrients on growth, seed yield and quality of linseed (*Linum usitatissimum* L.). International Journal of Chemical Studies,5(5),1879-1883.
16. Diwan, D., Sirothia, P. & Kumar, A.K. (2019). The interaction effect of sulphur and zinc on yield of linseed crop. Journal of Pharmacognosy and Phytochemistry,8(3),2047-2050.
17. Eldaien, A. M.A.M & Sherif, M.A.B. El (2016). Effect of organic, phosphorous and zinc fertilization on yield and quality of flax.International Journal of Advance Research in Biological Sciences,3(1),161-173.
18. Gonzalez, D., Almendros, P. & Alvarez, J.M. (2016). Effects of synthetic zinc chelates on flax response and soil Zn status. Spanish Journal of Agricultural Research,14(3),1-14.
19. Habbasha, S. F. El, Taha, M. H. & Jafar, N.A. (2013). Effect of nitrogen fertilizer levels and zinc foliar application on yield, yield attributes and some chemical traits of groundnut. Research Journal of Agriculture and Biological Sciences,9(1),1-7.
20. Hamideldin, N. & Hussein, O. S. (2014). Response of sesame plants to foliar spray with different concentration of boron. J Am Oil Chem Soc.,91,1949-1953.
21. Homayouni, G. Souri, M. & Zarein, M.(2013). Effects of zinc and nitrogen on yield components of five flax genotypes. Global Journal of Science Frontier Research,13(5),1-4.
22. Hossain, M.A., Jahiruddin, M. & Khatun, F. (2011). Effect of boron on yield and mineral nutrition of mustard. Bangladesh J. Agril. Res.,36(1),63-73.
23. Husain, K., Chandra, R., Srivastav, R. IL., Dubey, S. D., Singh, K. & Saxena, M. C. (2009). Effect of zinc and farmyard manure on productivity and profitability of rice (*Oryza sativa*) - linseed (*Linum usitatissimum*) crop sequence. Indian Journal of Agronomy,54(4),395-400.
24. Jahan, N. S., Alam, A.B.M., Mitu, A. S., Habib, Md. A. & Ali, Md. K.J. (2019). Effect of zinc on growth and yield of sesame. International Journal of Natural and Social Sciences,6(3), 11-16.
25. Jiao, Y., Grant, A.C. & Bailey, L.D. (2004).Growth and nutrients response of flax and durum wheat to phosphorous and zinc fertilizers. Can. J. Plant Sci., 87,461-470.
26. Kabir, R.,Yeasmin, S., Islam, A K M M. & Sarkar, Md. A.R. (2013). Effect of phosphorous, calcium and boron on the growth and yield of groundnut. International Journal of Bio- Science and Bio- technology,5(3),51-54.
27. Karthikayan, K. & Shukla, L.M. (2008). Effect of Boron- Sulphur interaction on their uptake and quality parameters of mustard and sunflower. Journal of Indian Society of Soil Science, 56(2),225-230.
28. Khan, M.N., Manaf, A., Hassan, F.U. & Ahmed, M.S. (2017). Micronutrients (Zn,B and Mn) effects on sesame. International Journal of Agronomy and Agricultural Research,10(5),92-101.
29. Kumar, S.N. (2018). Effect of micronutrients on oilseed crops. International Journal of Current Advance Research,Volume 7,Issue 8(I),15178-15192.
30. Kumararaja, P., Premi, O.P. & Kandpal, B.K. (2015). Application of boron enhances Indian mustard productivity and quality under boron deficient calcareous soil in semi-arid environment. Eco.Env. And Con. pp.(S249-S254).
31. Madhu Bala & Kedar Nath. (2015). Maximization of groundnut (*Arachis hypogaea* L) yield by nutrient management practices. J. Expet. Bio. Agril. Sci.,3(3),241-245.
32. Maharnor, R.Y., Indulkar, B.S.,Lokhande, P.B., Jadhav, L.S.,Padghan, A.D. & Sonune, P.N. (2018). Effect of different levels of Zn on yield and quality of groundnut. International Journal of Current Microbiology and Applied Sciences,6,2843-2848.
33. Mamatha , K., Vidyasagar , G.E.Ch., Laxminarayana, P. & Padmaja, G. (2017).Effect of boron levels and farmyard manure on physiological growth and quality of sesame. International Journal of Current Microbiology and Applied Sciences,6(8),2568- 2574.
34. Masum, M.A., Miah, M.N.H., Islam, M.N., Hossain, M.S., Mandal, P. and Chowdhury, A.P. (2019). Effect of boron fertilization on yield and yield attributes of mustard. Journal of Bioscience and Agriculture Research,20(2),1717-1723.
35. Mousa, M.A., Eman, A.E. EL-Kady & Zedan, Z.S. (2010). Effect of nitrogen fertilizers and some micronutrients on flax yield and chemical composition characters. J. Plant Production, Mansoura Univ.,1(5),713-720.
36. Nandi, R.,Reja, H., Chatterjee, N., Bag, A.G. & Hazra, G. C.(2020). Effect on Zn and Boron on the Growth and Nutrient uptake in Groundnut. Current Journal of Applied Science and Technology,39(1),1-10.
37. Nadian, H., Najarzadegan, R., Saeid, K.A., Gharineh, M.H. & Siadat, A. (2010). Effects of boron and sulphur application on yield and yield components of mustard. World Applied Science Journal,11(1),89-95.
38. Nofal, O., Zedian, M.S. & Bakry, A.M. (2011). Flax yield and quality traits as affected by zinc foliar application under newly reclaimed sandy soils. Journal of Applied Sciences Research. 7(9),1361-1367.
39. Patil, D. B., Jadhav, S. H. & Bhaburdekar, S. B. (2012). Interactive effect of boron and sodium chloride on germination performance in soybean. International Journal of Applied biology and Pharmaceutical Tech.,3(4),366-368.
40. Paramasivam, V., Ravichandran, V. K., Venkatesan, P. K. & Manoharan, V. (2003). Nutrient management for seed yield maximisation in sesame (*Sesamun indicum* L.). Sesame and Safflower Newsletter,(18),61-63.
41. Prathima, A. S. (2015). Boron nutrition in sunflower (*Helianthus annus* L.). Agric. Sci., Bengaluru.
42. Raghav, D. K., Singh, R. K. & Saha, P. B. (2016). Effect of sulphur and boron application on uptake and yield of linseed under rainfed conditions. The Ecosan, Special issue. Vol. IX, 737-741.
43. Rashid, A. & Akhtar, M. E. (2006). Soil fertility and nutrient management in Pakistan. In: Proceedings of Symposium on Balanced Fertilizer use: Impact on crop production, Ocober 30-31, Islamabad, Pakistan, Pp 90-113.
44. Rowland, G.G., Mchughen, A., Gusta, L.V., Bhatty, R.S., Mackenzie, S.L. & Taylor, D.C. (1995). The application of chemical mutagenesis and biotechnology to the modification of linseed. Euphytica,85,317-321.
45. Sarkar, S.K., Chowdhury, M.A.H. & Zakir, H.M. (2002). Sulphur and Boron fertilization on yield quality and nutrient uptake by soybean. Journal of Biological Sciences,2(11),729-733.
46. Singh, A., Singh, D., Verma, V. K., Pyare, R. & Hussain, M., F. (2020).Studies on the effect of zinc and boron on growth and yield of linseed (*Linum usitatissimum* L.) under limited irrigation. International Journal of Chemical Studies,8(5),1964-1966.
47. Shamsuzzoha, Md., Kundu, P. K., Rouf, Md. A., Afrose, & Mostofa, M. (2019). Effect of combined Application of Nitrogen and Boron on yield contributing characters and yield of sesame. Annual Research & Review in Biology,31(5),1-12.
48. Shanmugasundaram, R. & Savithri, P. (2005). Effect of levels and frequency of zinc sulphate application on yield and DTPA-Zn availability in maize-sunflower cropping system. Madras Agric. J.,92(4-6),252-257.
49. Sharma, D.J., Parihar, R. & Pandey, D. (2015). Screening of linseed entries under rainfed condition at Bilaspur Chhattisgarh, India. National Seminar on Strategic Interventions to enhance Oilseeds production in India. Feb 19-21, pp. 116-117.
50. Shoja, T.,Majidian, M. & Rabiee M. (2018). Effects of zinc, boron and sulphur on grain yield , activity of some antioxidant enzymes and fatty acid composition of rapeseed. Acta Agriculture Slovenica,111(1),73-84.
51. Suresh, G., Murthy, IYLN., Babu, SNS. & Varaprasad, K. S. (2013). An overview of Zn use and its management in oilseed crops. Journal of SAT Agricultural Research,11,1-11.
52. Tahir, M., Irfan, M.& Rahman, A.U. (2014). Effect of foliar application of Zn on yield and oil contents of flax . Pakistan J. Agric. Res.,27(4),287-295.
53. Viyayakumari, R. Narender & Sastry, T.V.N. (2009). Economics analysis of groundnut cultivation in grantlapalle watershed project of chittoor district in Andhra Pradesh. Journal of Oilseed Research. 16(1),101-107.
54. Yadav, S.N., Singh, S.K. & Kumar, O. (2016). Effect of boron on yield attributes, seed yield and oil content of mustard. Journal of Indian Society of Soil Science. 64(3), Pp 291-296.