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Response of mustard (*Brassica juncea*) to sulphur and boron application under irrigated conditions

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Abstract

Nearly 40% of oilseed mustard fields across tropical and subtropical regions show sulphur deficiency symptoms that go undiagnosed until yield losses become apparent. This research evaluated the response of mustard (*Brassica juncea* cv. Pusa Bold) to graded levels of sulphur (0, 20, 40, 60 kg ha⁻¹) and boron (0, 0.5, 1.0, 1.5 kg ha⁻¹) under irrigated conditions at the University of São Paulo, Piracicaba, during the 2022-2023 growing season. The experiment followed a factorial randomized block design with three replications. Application of sulphur at 40 kg ha⁻¹ combined with boron at 1.0 kg ha⁻¹ produced the highest seed yield (1,847 kg ha⁻¹), representing a 43.2% increase over the unfertilized control. Oil content peaked at 41.3% under the same combination. Sulphur uptake and use efficiency responded positively up to 40 kg ha⁻¹, beyond which marginal returns diminished. These results indicate that balanced sulphur-boron nutrition can substantially improve mustard productivity and oil quality under irrigated tropical conditions.

Keywords: Mustard, *Brassica juncea*, sulphur fertilization, boron application, seed yield, oil content, nutrient interaction, irrigated agriculture, oilseed crops

Introduction

About 28.6 million hectares of mustard are cultivated worldwide, making it the third largest oilseed crop after soybean and palm ^[1]. Indian mustard (*Brassica juncea* L. Czern. & Coss.) accounts for over 80% of rapeseed-mustard production across South Asia and parts of South America ^[2]. Despite its economic importance, average yields remain well below the potential, often because of imbalanced nutrient management particularly regarding secondary and micronutrient elements.

Sulphur is the fourth major plant nutrient after nitrogen, phosphorus, and potassium, and it plays a direct role in the synthesis of amino acids (cysteine, methionine), glucosinolates, and oil in Brassica crops ^[3]. Deficiency of sulphur has become widespread in intensive cropping systems where high-analysis NPK fertilizers have replaced traditional single superphosphate, which once supplied incidental sulphur ^[4]. Reported yield gains from sulphur application in mustard range from 15-45% depending on native soil sulphur status ^[5].

Boron, though needed in small quantities, is critical for pollen germination, cell wall synthesis, and sugar transport in reproductive tissues ^[6]. Boron deficiency causes poor pod setting and hollow stems in Brassica species. The interaction between sulphur and boron has received limited attention in mustard, despite evidence that boron improves sulphur uptake efficiency in oilseed crops ^[7]. This research investigated the individual and combined effects of graded sulphur and boron doses on growth, yield attributes, oil content, and nutrient uptake in irrigated mustard at Piracicaba, Brazil ^[8].

Research area description

The field trial was established at the Experimental Farm of the Department of Agronomy, University of São Paulo, Piracicaba, Brazil (22.7°S, 47.6°W, 546 m elevation). The soil was classified as Rhodic Ferralsol (Latossolo Vermelho) with sandy clay loam texture. Initial soil properties (0-20 cm) were: pH 5.8, organic matter 2.31%, available S 8.7 mg kg⁻¹ (below the critical level of 10 mg kg⁻¹), hot water-extractable B 0.34 mg kg⁻¹, available P 14.2 mg kg⁻¹, and exchangeable K 2.8 mmolc dm⁻³ ^[9].

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Climatic conditions during the research period

The trial was conducted from May to September 2023, covering the dry-season mustard crop window. Mean temperatures ranged from 17.3 °C (July) to 24.1 °C (September). Total rainfall during the crop period was 187 mm, supplemented by four irrigations of 40 mm each at critical growth stages. Relative humidity averaged 61.4%. These conditions were typical for the Piracicaba region and suitable for mustard cultivation ^[10].

Materials and Methods

Materials

Mustard cultivar Pusa Bold, a widely adapted variety of *B. juncea*, was used. The experiment was laid out in a 4 × 4 factorial randomized block design with three replications, giving 48 plots. Each plot measured 4.0 m × 3.0 m with row spacing of 30 cm. Four sulphur levels (0, 20, 40, 60 kg ha⁻¹ as elemental sulphur) and four boron levels (0, 0.5, 1.0, 1.5 kg ha⁻¹ as borax) constituted the 16 treatment combinations. Sowing was done on May 12, 2023, at 5 kg ha⁻¹ seed rate. A uniform basal dose of

80-40-40 kg ha⁻¹ N-P₂O₅-K₂O was applied through urea, triple superphosphate, and potassium chloride ^[11].

Methods

Plant height, branches per plant, and siliquae per plant were recorded at maturity from ten randomly tagged plants per plot. Seeds per silique and 1000-seed weight were determined from a subsample of 20 siliquae per plot. Seed yield was recorded from the net plot area after sun-drying to 8% moisture. Oil content was determined by Soxhlet extraction using petroleum ether (60-80 °C boiling range). Protein content was estimated by the micro-Kjeldahl method (N × 6.25). Sulphur in plant tissue was analyzed by the turbidimetric method, and boron by the azomethine-H colorimetric method ^[12]. Nutrient uptake was calculated as concentration × dry matter yield. Data were subjected to two-way ANOVA and means separated by Duncan's multiple range test at p = 0.05 using R software version 4.2.1 ^[13].

Results

Table 1: Effect of sulphur levels on growth and yield attributes of mustard

Sulphur (kg ha ⁻¹)	Height (cm)	Branches plant ⁻¹	Siliquae plant ⁻¹	Seeds silique ⁻¹	1000-seed wt (g)	Yield (kg ha ⁻¹)
0	142.3	7.2	186.4	11.3	4.12	1,289
20	156.8	8.7	218.7	12.1	4.38	1,547
40	168.4	10.3	261.3	13.4	4.67	1,742
60	171.2	10.8	268.9	13.7	4.71	1,769
SE(m)±	3.41	0.43	8.72	0.38	0.09	41.3
CD (5%)	10.17	1.28	26.01	1.14	0.27	123.1

All growth and yield attributes increased significantly with sulphur application up to 40 kg ha⁻¹ (Table 1). Beyond this level, increments were not statistically significant. Seed yield at S₄₀

was 35.1% higher than the control. Siliquae per plant showed the strongest response among yield components, rising by 40.2% at 40 kg S ha⁻¹.

Table 2: Effect of boron levels on yield attributes and quality parameters of mustard

Boron (kg ha ⁻¹)	Siliquae plant ⁻¹	Seeds silique ⁻¹	Yield (kg ha ⁻¹)	Oil (%)	Protein (%)	S uptake (kg ha ⁻¹)
0	214.7	11.8	1,478	37.6	21.3	8.42
0.5	231.6	12.4	1,612	38.8	21.9	9.87
1.0	248.3	13.2	1,724	40.1	22.7	11.34
1.5	244.1	12.9	1,697	39.7	22.4	10.91
SE(m)±	7.13	0.31	38.7	0.42	0.28	0.47
CD (5%)	21.27	0.93	115.4	1.26	0.84	1.41

Boron at 1.0 kg ha⁻¹ produced the highest values for most parameters (Table 2). Seed yield improved by 16.6% over the no-boron control. Oil content peaked at 40.1% with B_{1.0}, and sulphur uptake was 34.7% higher, confirming the synergistic

effect of boron on sulphur utilization. At 1.5 kg B ha⁻¹, a slight but non-significant decline occurred, suggesting marginal toxicity.

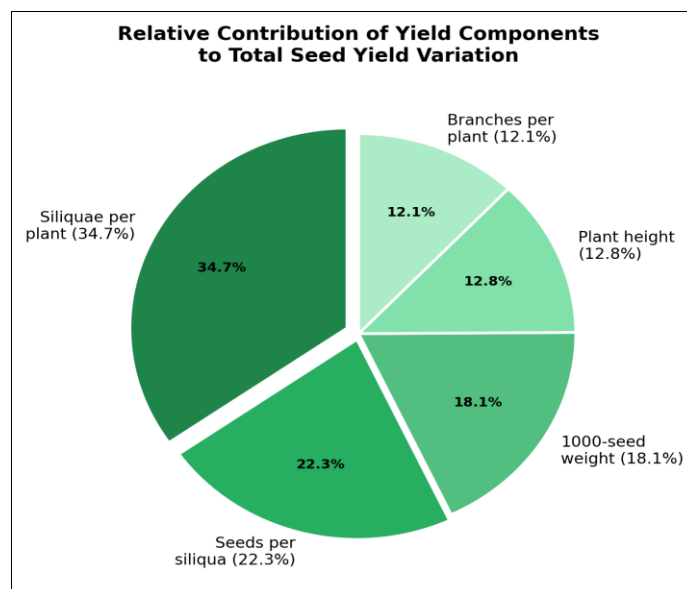


Fig 1: Relative contribution of yield components to total seed yield variation in mustard as determined by path coefficient analysis

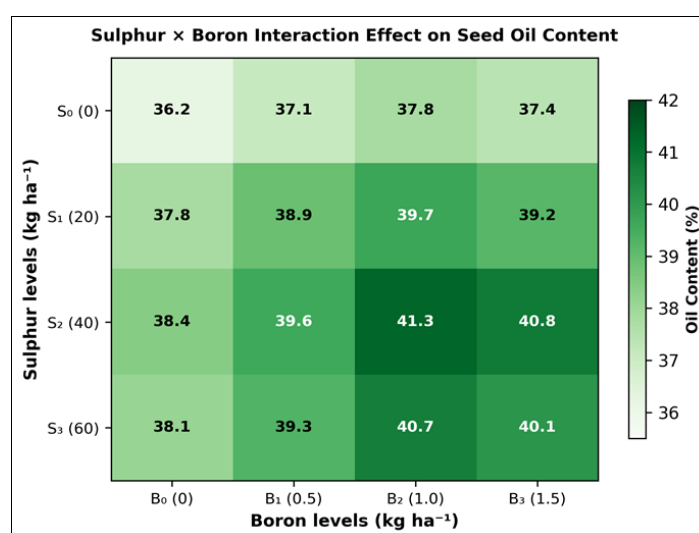


Fig 2: Interaction effect of sulphur and boron levels on seed oil content (%) of mustard. Values in cells represent treatment means

Comprehensive interpretation

The interaction between sulphur and boron was significant for seed yield and oil content (Figure 2). The S₄₀B_{1.0} combination gave the absolute highest seed yield of 1,847 kg ha⁻¹ and oil content of 41.3%. Path analysis revealed that siliquae per plant exerted the largest direct effect (34.7%) on yield variation, followed by seeds per siliqua (22.3%) (Figure 1). Sulphur uptake efficiency peaked at 40 kg ha⁻¹ and declined at 60 kg ha⁻¹, indicating diminishing returns beyond the optimum.

Discussion

The positive yield response to sulphur up to 40 kg ha⁻¹ confirms earlier findings by Aulakh and Pasricha [3] who identified this range as optimal for Brassica crops on sulphur-deficient soils. The lack of significant response beyond 40 kg ha⁻¹ likely reflects luxury consumption, where additional sulphur accumulates in vegetative tissues without translating into higher reproductive output [5]. The initial soil available S (8.7 mg kg⁻¹) was below the established critical limit of 10 mg kg⁻¹ for mustard, explaining the strong response to applied sulphur [4]. Boron improved pollen viability and siliqua setting, consistent with its role in reproductive tissue development [6]. The synergy

between S and B on oil content may be explained by sulphur's direct incorporation into glucosinolates and methionine, while boron enhances membrane integrity and sugar transport to developing seeds [7]. The slight yield decline at 1.5 kg B ha⁻¹ aligns with the narrow range between boron sufficiency and toxicity reported for Brassica species [14].

The path analysis showing siliquae per plant as the dominant yield determinant agrees with results from Shekhawat *et al.* [15], suggesting that management practices targeting siliqua number such as balanced S-B nutrition during the branching and flowering stages offer the greatest leverage for yield improvement. One limitation was that only one cultivar was tested; genotypic variation in S and B response merits further investigation [16].

Conclusion

Sulphur at 40 kg ha⁻¹ combined with boron at 1.0 kg ha⁻¹ was the most effective nutrient combination for maximizing seed yield and oil content of mustard (*B. juncea*) under irrigated conditions on sulphur-deficient Ferralsol soils. This combination produced 1,847 kg ha⁻¹ seed yield and 41.3% oil content gains of 43.2% and 14.1% over the unfertilized control, respectively.

Higher sulphur doses (60 kg ha^{-1}) and boron doses (1.5 kg ha^{-1}) did not improve returns and may cause incipient toxicity in the case of boron.

Farmers growing irrigated mustard on soils with available S below 10 mg kg^{-1} and hot water-extractable B below 0.5 mg kg^{-1} should consider adopting this balanced fertilization strategy. Split application of sulphur half at sowing, half at first irrigation could further improve efficiency and warrants testing across multiple locations and seasons.

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