Research Article

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Foliar application of boron positively affects the growth, yield, and oil content of sesame (*Sesamum indicum* L.)

<https://doi.org/10.1515/opag-2022-0067>

received October 18, 2021; accepted January 29, 2022

Abstract: The objective of this study was to determine the optimal concentration of boron (B) to obtain the highest growth, yield, and oil content of black sesame. A field experiment was conducted in a completely randomized block design with five treatments and five replications. Treatments included foliar application of B at five rates: control, 50, 100, 150, and 200 mg L⁻¹ at 25 and 35 days after sowing. Results showed that spraying B on leaves increased sesame growth in terms of plant height, number of leaves, and chlorophyll content. Moreover, spraying B increased yield components including the number of pods; the highest pods per plant was 46.2 in the B application treatment with 150 mg L⁻¹ compared to the control with 27.2 pods per plant. The grain yield of the B spray treatment produced 1.10–1.32 t ha⁻¹, with the highest yield at the dose of 150 mg L⁻¹ and the lowest yield at no B spray treatment. Spraying B on leaves at optimal concentration also increased the oil content in seeds up to 5.3% compared to the control treatment. The findings of the study suggest that foliar B application with 150 mg L⁻¹ increases the growth, fruit set, seed yield, and oil content in sesame.

Keywords: boron spray, sesame grain yield, oil concentration

1 Introduction

Sesame is one of the oldest oilseed crops and it is grown widely in subtropical and tropical areas for its edible oil, proteins, vitamins, and amino acids [1]. It is traditionally categorized as a health food in Asian countries [2]. Sesame oil has a remarkable stability because it contains natural antioxidants, i.e., sesamin, sesamol, and sesamol [3]. In the world, sesame consumption is nowadays steadily increasing [2]. In the Mekong Delta, Vietnam, sesame is an attractive crop to grow in rotation with rice due to its relatively low nutrient requirements, resilience to low soil moisture (as it is not dependent on post-germination irrigation), and heat tolerance. In recent years, the growth and yield of sesame has been reduced due to a decline in fruit drop. Boron is an essential micronutrient required for normal growth of most plants [4], which is involved in plant processes such as leaf photosynthesis, cell elongation and division, and nitrate metabolism [5]. Stomatal conductance was significantly reduced in turmeric in boron (B) deficiency treatment [6]. Boron has been seen to have a significant influence on fruit set [7], which is associated with the pollen-producing capacity of the anther, the viability of pollen, pollen tube germination, and growth of pollen tubes [8]. Boron plays an important role in plant cell wall and membrane constancy [9] and helps plants increase their yield and growth by increasing the leaf expansion area and yield components [10]. Shireen et al. [4] proved that B enhanced the growth and yield of crops. Mary et al. [11] found that foliar B application was beneficial in increasing the number of pods per branch, the number of seeds per pod, and seed yield of plants. According to Dordas et al. [12] and Dehnavi et al. [13], there is a much higher demand for B during flowering and seed set, even in crops where B levels in leaves are in the adequate range. Many results show an increase in fruit, seed set, and yield with foliar B applications [14–16]. Therefore, this study was carried out to determine the optimal concentration of foliar B

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application on the growth, seed yield, and oil content of sesame.

2 Materials and methods

2.1 Materials

The field experiment was carried out in Thoi Thuan area, Phuoc Thoi ward, Omon district, Can Tho city from February to May 2019. Soil characteristics for the field site are listed in Table 1. A local black sesame variety was used with traits including short duration growth (approximately 75–81 days), drought tolerance, high yield ($0.9\text{--}1.4\text{ t ha}^{-1}$), and oil content (47.5%).

2.2 Methods

2.2.1 Experimental design

The field experiment was carried out in a randomized complete block design including five treatments, each with five replications. Plot size was 25 m^2 . Treatments were applied as a foliar spray as follows: spray water without B (control), and with 50, 100, 150, and 200 mg L^{-1} of B. The different concentrations of B solution were applied directly to the total leaf surface area at the growth stage of flower bud formation, i.e. 25 days after sowing (DAS) and flowering - 35 DAS.

Table 1: Initial physical and chemical characteristics of the soil (0–20 cm depth)

Characteristics	Unit	Value
pH _{H2O} (1:2.5 soil–water)	—	4.81 ± 0.01
CEC	meq/100 g	17.8 ± 0.19
Carbon	%	2.44 ± 0.04
N _{total}	%	0.18 ± 0.01
NH ₄ ⁺	mg kg ⁻¹	29.5
P _{total}	%	0.028 ± 0.001
P _{available}	mg kg ⁻¹	51.2
K _{total}	%	1.47 ± 0.03
K ⁺	meq/100 g	0.10
Mg ²⁺	meq/100 g	3.07
Ca ²⁺	meq/100 g	1.32

CEC: cation exchange capacity.

2.2.2 Seed population

Four kilogram of sesame seeds were broadcasted for one hectare, mixed with sand at a ratio of 2:1 (sand:sesame) to ensure uniform seed distribution [17].

2.2.3 Fertilizers application

Mineral fertilizers were applied in this research at the recommended rate of 90 kg N, 60 kg P₂O₅, and 60 kg K₂O per hectare. Single super phosphate (16% P₂O₅) was applied as a basal application. Urea (46% N) was applied as split application, with 30, 40, and 30% applied at 15, 30, and 40 DAS, respectively. Potassium oxide (60% K₂O) was applied as split application, with 50% applied at 15 and 30 DAS [17].

2.2.4 Growth parameters and yield of sesame

Plant height (cm) of 20 plants per plot was measured from the soil surface to the highest growth peak at harvest time. Percentage stained pollen (%): detached pollen grains stained with aceto-carmine 5% were assessed according to Saini et al. [18]. Using a M-40X microscope objective, stained and unstained pollens in five frames on each flower were counted and recorded. Leaf chlorophyll index (SPAD index) was measured using a hand-held dual-wavelength chlorophyll meter (SPAD 502; Minolta) at 40 DAS. Stomatal conductance was determined using a SC-1 Leaf Porometer (Decagon Devices, Pullman, WA, USA) on the 5th leaf from the top of each plant at 35 and 60 DAS. The number of pods per plant was assessed at harvest time. The number of seeds per pod was assessed in 20 randomly selected pods per replicate. Seed moisture was assessed by oven drying the seeds at 45°C for 72 h. The weight (g) of 1,000 seeds was recorded at 9% moisture. Yield (kg ha⁻¹) was calculated using the weight of seeds of the 25 m^2 plot at harvest based on 9% moisture [17].

2.2.5 Seed oil and leaf nutrient uptake analysis

The full leaves at 50 DAS were collected to analyze N, P, and K content following the method reported by Jones and Case [19] and B content following the method reported by Dehnavi et al. [13]. The lipid content of the sesame seeds was assessed using the Soxhlet method [20]. All methods

were described as follows: an oxidative mixture of 100 mL of saturated H_2SO_4 , 18 mL of water, and 6 g salicylic acid was used to break the structure of the leaves samples. These samples were heated and added with H_2O_2 until they were completely oxidized. Then, the inorganic solution was used to measure the amount of N, P, and K. N was determined by Kjeldahl method and P was determined by color method of phosphomolybdate blue complex made from ammonium molybdate, reduced by ascorbic acid, and measured at a wavelength of 880 nm. K and B concentrations were measured by atomic absorption spectrophotometry at a wavelength of 766.5 and 249.8 nm, respectively.

2.3 Statistical data analysis

The data presented in this research are the mean values of five replications. All data were analyzed using one-way analysis of variance (ANOVA) using SPSS software package version 13.0, and were compared for significant differences for treatment effects using Duncan's test at $P < 0.05$ or $P < 0.01$.

3 Results and discussion

3.1 Effect of boron on plant height and number of leaves

Plant height and number of leaves were recorded at harvest time, and foliar application of B significantly ($P < 0.05$)

increased plant height (Figure 1). The greatest plant height (mean value 144.1 cm) was recorded at 150 mg L^{-1} of B and this was significantly ($P < 0.01$) higher than the control, 50, and 100 mg L^{-1} of B (119.3, 131.0, and 131.5 cm, respectively). There was no significant difference in plant height between B applications of 150 and 200 mg L^{-1} (144.1 and 135.7 cm, respectively). Significantly, the lowest sesame plant height of 119.3 cm was recorded with no boron application at harvest. There were significantly ($P < 0.05$) more leaves on plants with boron application at 150 mg L^{-1} compared with the control, 50, and 100 mg L^{-1} , and no significant difference was observed between the leaves count at higher rates of treatment (Figure 1). Our results support the growing evidence that the application of B promotes overall plant growth, as indicated here by plant height and number of leaves per plant [10]. This result was similar to the previous research by Hamideldin and Hussein [21]; the height of sesame plants with foliar B application of 20 mg L^{-1} was higher (177.0 cm) than plants without B application (146.2 cm). Bellaloui et al. [22] showed that foliar B application increased the number of leaves in soybean plants.

3.2 Effect of boron on chlorophyll content in leaves

Foliar B applications were observed to have significant ($P < 0.01$) effects on the SPAD index (Figure 2). A comparison of mean values showed that the foliar applications,

Figure 1: Plant height and number of sesame leaves at harvest for different concentrations of boron. Letters within the columns represent a significant difference ($P < 0.05$).

Figure 2: Effect of boron on the chlorophyll content in leaves. Letters within the columns represent a significant difference ($P < 0.05$).

compared with the water-only application, led to significant increase in the SPAD index. The SPAD index was observed to increase in all the foliar B treatments. Similar results were found when studying sesame sprayed with an additional B of 2 g L^{-1} . B is reported to lead to significant enhancements in plant chlorophyll content and leaf photosynthesis rates [23].

3.3 Effect of boron on stomatal conductance

The stomatal conductance of sesame leaves at 34 and 64 DAS was significantly ($P < 0.01$) different (Table 2). Boron sprayed at 150 and 200 mg L^{-1} were $2,001.5$ and $1,966.1 \text{ mmol m}^{-2} \text{ s}^{-1}$ at 34 DAS, respectively, and significantly higher in comparison to the others. At 64 DAS, B applied at 50 mg L^{-1} and above had significantly ($P < 0.05$) higher stomatal conductance compared to

the control and different with the application of B treatment. According to Ahmed et al. [5], boron's role in stomatal conductance has not been clearly understood. It means that there were several reports that indicated boron deficiency was a reduction in stomatal conductance in turmeric [6], mustard (*Brassica* spp.) [24], and kiwifruit (*Actinidia* spp.) [25]. Addition of boron increased stomatal conductance has been reported for other plant species [26].

3.4 Effect of boron on leaf content of N, P_2O_5 , K_2O , and B

There was a significant difference ($P < 0.05$) in leaf N concentration between plants applied with B and the control treatment without B application (Figure 3a). Among B application treatments, leaf N concentrations were not significantly different. At a B concentration of 100 mg L^{-1} , there was a significantly higher ($P < 0.05$) P and K concentrations in leaves compared to the treatments with lower B concentrations (Figure 3b and c). The concentrations of N and P in the leaves of plants treated with boron were higher than in the plants not treated with B (Figure 3a and b). According to Kumar et al. [27], plants require B for a number of growth processes like translocation of N and P, synthesis of amino acids and proteins, etc. Kumar et al. [28] and Shamsuzzoha et al. [29] found that the concentrations of N, P, and K in sesame seeds were significantly higher in plants treated with B in comparison to those without B treatment. Figure 3d shows that in plants treated with B, the B content in leaves ranged from $16\text{--}20.5 \mu\text{g g}^{-1}$. These were significantly different from the control treatment ($7.4 \mu\text{g g}^{-1}$). In the research by Dehnavi et al. [13], the

Table 2: Opening and closing of the stomata of sesame at 34 and 64 days after sowing

Boron (mg L^{-1})	Stomata conductance ($\text{mmol m}^{-2} \text{ s}^{-1}$)	
	34 DAS	64 DAS
0	1717.7 ^b	1.602 ^b
50	1792.1 ^b	1.768 ^a
100	1781.4 ^b	1.724 ^{ab}
150	2001.5 ^a	1.705 ^{ab}
200	1966.1 ^a	1.634 ^{ab}
CV (%)	10.5	6.2

Letters within the column represent a significant ($P < 0.05$) difference. CV: coefficient of variation; DAS: Days after sowing.

results showed that in sesame plants treated with 2 g L^{-1} of boric acid, the boron content was $25.9 \mu\text{g g}^{-1}$, which was more than double compared to plants without B application.

3.5 Effect of boron on the number of stained pollens

The percentage of successfully dyeing pollen grains ranged from 82.9 to 97.6%. The successful dyeing ratio of pollen grains increased when sprayed with B at a concentration of 150 mg L^{-1} . However, there was no statistically significant difference between the treatments with B content lower or

higher than 150 mg L^{-1} and those without B application (Figure 4). According to Padilla *et al.* [30], sesame plants treated with 150 mg L^{-1} B might have better pollen viability compared to the other treatments. B is necessary for pollen viability in crops [27].

3.6 Effect of boron on the number of pods per plant, number of seeds per pod, and weight of 1,000 seeds

The results in Figure 5 show that the number of pods per plant in the treatments was statistically significant difference at 5%. The number of pods per plant was highest in

Figure 3: Effect of boron on the percentage of N (a), P_2O_5 (b), K_2O (c) and boron (d) in leaves. Letters within the columns represent a significant difference ($P < 0.05$).

Figure 4: Effect of boron on dyeing pollen. Letters within the columns represent a significant difference ($P < 0.05$).

the plants treated with 150 mg L⁻¹ B (46.2 pods per plant). Among the treatments with B concentrations of 50, 100, and 200 mg L⁻¹, the number of pods were 32.3, 35.2, and 35.5, respectively, which is not significantly different from the control treatment. The increased number of pods per plant is due to the higher number of nodes, internode elongation, and more branches produced on the stems (Figure 6). Hamideldin and Hussein [21] found that application of 20 and 30 mg L⁻¹ B helped sesame produce a significant number of pods per plant compared to plants without B application. Increased pod production after B application is mainly due to production of auxins, which helped in retention of the pods and

reduced the pod drop (Figure 6). When the concentration was increased to 200 mg L⁻¹ B, the number of pods on plants was reduced. The sesame treated with 150 mg L⁻¹ B showed a significant difference in the number of pods on plants compared to the control treatments. However, the number of seeds per pod was not significantly different. These results were similar to the study by Shamsuzzoha et al. [29], in which sesame plants were treated with B of 2 kg ha⁻¹. In this study, the number of seeds per pod and the weight of 1,000 seeds were not affected by B application (Figure 5). Padasalagi et al. [8] recorded that the number of seeds per pod was significantly increased when borax of 5 kg ha⁻¹ was applied.

Figure 5: Effect of boron on number of pods per plant, number of seeds per pod, and weight of 1,000 seeds. Letters within the columns represent a significant difference ($P < 0.05$).

Figure 6: Number of fruits on sesame plants at different concentrations of boron.

3.7 Effects of boron on sesame seed yield and oil content

The results presented in Figure 7 show that the application of B with a concentration of 150 mg L⁻¹ has the highest yield, with 1.32 t ha⁻¹, and there was a statistically significant difference at 5% compared to the control treatment

(1.02 t ha⁻¹), 50 mg L⁻¹ B (1.10 t ha⁻¹), and 100 mg L⁻¹ B (1.12 t ha⁻¹). Significantly, the lowest seed yield was recorded with no B application treatment. There were no significant differences in sesame yield between plants sprayed with B concentrations from 150 to 200 mg L⁻¹. Figure 7 shows that the application of B increased the oil content in sesame seeds compared to the control treatment. Among the sesame

Figure 7: Effect of boron on yield and oil content. Letters within the columns represent a significant difference ($P < 0.05$).

plants treated with various B concentrations, there were no significant differences in oil content. Similar to the study results obtained when spraying 100 mg L⁻¹ B on the Prachi sesame variety, the seed yield and oilseed content were significantly different from the control plant that was not sprayed with B [31]. Hamideldin and Hussein [21] found that in sesame plants treated with B up to 40 mg L⁻¹, there were no significant differences in oil content. Kumar et al. [27] found that in sesame plants treated with 0.15% B, the oilseed content increased significantly. Akshatha and Rajkumara [32] indicated that B helps sesame produce higher seed oil content. B contributes to cell wall and membrane constancy for plant growth by enhancing the leaf expansion area [9]. B also increases flower production, retention, pollen tube elongation, and fruit development. Thus, spraying B on sesame leaves resulted in higher growth and yield [33].

4 Conclusion

Application of B at a concentration of 150 mg L⁻¹ at 25 and 35 DAS helps to increase the growth indicators of plant height and number of leaves of sesame plants. Content of chlorophyll, nitrogen, phosphorus, and potassium in leaves when spraying B at a concentration of 150 mg L⁻¹ was compared to leaves with no B application. B helps increase the number of pods per plant. At the same time, B also increases the number of seeds per pod and the seed weight per plant. Sesame yield increased by 1.29 times when B was sprayed at a concentration of 150 mg L⁻¹ compared to plants not sprayed with B. Applying B at a concentration of 150 mg L⁻¹ by spraying through the leaves also helps to increase significantly the oil content in sesame seeds.

Acknowledgments: The authors would like to thank Assistant Professor Akagi Isao, Faculty of Agriculture, Kagoshima University, Japan, for the consultant to collect field soil samples in this research.

Funding information: This study was funded by the author's affiliated institution.

Author contributions: LVT: supervision, conceptualization, writing – review and editing, and funding acquisition; J-IS: conceptualization and writing – review and editing; NTBT: project administration; TNH: visualization and data curation; NQK: formal analysis and writing – original draft.

Conflict of interest: The authors state no conflict of interest.

Data availability statement: The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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