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Seedling growth response of sesame (*Sesamum indicum* L.) to PEG-induced drought stress and different boron levels

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Abstract

Sesame (*Sesamum indicum* L.) is an important oilseed crop; however, its productivity is often adversely affected by drought stress, particularly during the seedling stage. Some micronutrients, such as boron (B), can significantly enhance plants' drought resistance; nevertheless, excessive levels may be toxic. The development of drought-resistant sesame varieties is essential for sustainable cultivation. The purpose of this study was to investigate the effects of drought stress, boron, and the combination of both on sesame seedling traits. Different doses of polyethylene glycol solution (PEG 6000) (PEG) as a drought stress (0; control, -2; P1, and -4; P2 MPa) and boric acid (H_3BO_3) (B) as a boron source (0; control, 5; B1, and 10; B2 mM) were used to apply to seeds. Drought stress adversely affected sesame seedling growth trait. The increase in PEG levels from 0 to -4 MPa significantly reduced root and shoot length, whereas they did not generate a significant difference in fresh root and fresh shoot weight. Furthermore, the findings indicated that increased B treatments reduced all seedling characteristics in sesame. The overall results indicate that the growth parameters of sesame seedlings were significantly reduced at -4 MPa of PEG and 10 mM concentrations of boron.

Keywords: Fresh root, Fresh shoot, Root lenght, Shoot lenght

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INTRODUCTION

Sesame (*Sesamum indicum* L.) is a prominent oilseed crop cultivated mostly in tropical and subtropical regions of Asia, Africa, and South America (Mehmood et al., 2021). Sesame seeds contain a significant quantity of oil, ranging from 50% to 60%, which might vary based on the specific cultivar and environmental factors (Wei et al., 2015). This oil has a high concentration of exclusive antioxidants called lignans, sesamin, and sesaminol, which contribute to its capacity for oxidative stability (Erbas et al., 2009). Sesame oil mostly comprises oleic and linoleic acids, which constitute around 80% of the total fatty acids (Yol et al., 2015). Sesame seeds are rich in minerals such as calcium, iron, zinc, and iodine, as well as vitamins including E, B6, thiamin, riboflavin, niacin, and folic acid (Pickersgill and Bedigian, 2011; Tripathy et al., 2019). These nutrients are particularly beneficial for a healthy human diet.

The rapid increase in the global population and the drastic changes in the climate are posing a serious threat, such as the occurrence of drought. This abiotic stress factor can affect plants, potentially hindering their optimal function and risking their survival (Fahad et al., 2017). Severe droughts result in significant reductions in agricultural yields due to adverse effects on plant growth, physiology, and reproduction (Barnabas et al., 2008). Sesame is mostly cultivated in arid and semi-arid regions, where its productivity is constrained by drought. Therefore, it is crucial to develop tolerances to these abiotic stress factors in order to ensure sustainable sesame productivity (Islam et al., 2016).

The significance of several micronutrients in plant metabolism has been well established. Boron (B) is a vital micronutrient necessary for the proper development of the majority of plants (Shireen et al., 2018). This micronutrient is involved in plant processes such as the movement of carbohydrates inside the plant, aiding in the transportation of sugar, and the production of DNA in meristems (Seervi et al., 2018). Boron is crucial for maintaining the integrity of plant cell walls and membranes (Bassil et al., 2004). It also promotes plant development and productivity by enhancing leaf expansion and yield components (Qamar et al., 2016). Shireen et al. (2018) reported that B improved growth and yield. Dey et al. (2023) found that B had a significant influence on the oil content, seed yield, and other components of the sesame yield. Khuong et al. (2022) found that foliar B application was beneficial in increasing the sesame growth in terms of plant height, number of leaves, chlorophyll content, and yield component. Similar results were obtained by Hamideldin and Hussein (2014), who reported that the application of boron B solutions enhances both the growth and yield of the sesame. However, the range of boron availability between insufficiency and toxicity is quite limited (Brdar-Jokanović, 2020). For example, Mertens et al. (2011) identified that increased boron concentrations adversely affect barley. Torun et al. (2006) documented same findings on wheat. In sunflowers, where a concentration of 0.5 ppm promotes healthy growth, an increase to 1 ppm results in toxicity (Eaton, 1940).

Abiotic stresses may have a negative impact on all stages of life, including the growth and development of plants (Khaeim et al., 2022). Seed germination and the establishment of seedlings are crucial phases in the life cycle of plants. However, drought stress during these stages is a significant limiting factor that restricts the effective establishment of crops (Pushpavalli et al., 2020). Sesame is also more susceptible during the germination and seedling stages, similar to other important crops (Orruno and Morgan, 2007). Dissanayake et al. (2020) and Ahmed et al. (2021) reported that high concentrations of PEG negatively affected seed germination and the seedlings. Micronutrient growth regulators, such as B, improve its capacity to tolerate abiotic stress conditions and improve parameters for growth (Abdel-Motagally and El-Zohri, 2018). Dehnavi et al. (2017) confirmed that boron has positive effects by leading to osmotic adjustment, reduction of oxidative damage, and maintenance of cell turgor on sesame in drought stress conditions. However, the optimal concentration range for boron is notably restricted (Hilal et al., 2011).

The impact of drought on the yield and quality of sesame seeds is significantly observed , particularly during the germination and seedling that are vital phases in the life cycle of plants (Bahrami et al., 2012; Dissanayake et al., 2020). Some micronutrients, such as boron, can help germination by combating the adverse effects of drought. However, it becomes toxic to plants when the amount of boron is slightly greater than required (Hilal et al., 2011). Therefore, this study aimed to understand the response of sesame seedling growth traits to different concentrations and different combinations of these concentrations of PEG, which causes drought stress, and boron, which is used as a micronutrient.

MATERIALS AND METHODS

The research used a sesame cultivar called Muganli-57, which had been previously released, as the genetic material. Seed sterilization was performed with 2% sodium hypochloride for 10–20 min, after which it was washed using double-distilled water. Each 10 cm diameter Petri dish contained a layer of Whatman No. 1 filter paper and ten healthy sesame seeds. We performed the experiment with nine treatments: two levels of boric acid (H3BO3) (5 and 10 mM; B1 and B2), two levels of PEG 6000 (Polyethylene glycol 6000) solution (-2 and -4 MPa; P1 and P2), four combinations of B and PEG (B1P1, B1P2, B2P1, and B2P2), and a control group (0) with tree replicates. The petri dishes were put in a growth chamber for a duration of 10 days at a temperature of 20 °C, following a photoperiodic condition of 14 hours of light and 10 hours of darkness each day for both treatments. The relative humidity was established at 70% throughout both the day and night. The Petri dishes were moistened, utilizing either deionized water for use as a control or 10 ml of treatment solution for each application. After a period of 10 days following seed germination, measurements were taken for root length, shoot length, root fresh weight, and shoot fresh weight.

These measurements were then analyzed using ANOVA and the least significant difference (LSD) test for comparisons. SAS version 9.3 (Anonymous, 2011) conducted the statistical analysis.

RESULTS AND DISCUSSION

One of the most significant agricultural and environmental challenges in cultivated regions is scarcity of water resources (Ceccarelli et al., 2010). According to climate forecasts, the availability of water resources is anticipated to decline. On the other hand, the growing global population and the rising demand for food require improvements in agricultural production to enhance food security. Identifying genotypes that exhibit drought resistance is critically important for crop breeding programs. Although sesame exhibits a greater tolerance to water scarcity than many other oilseed crops, its productivity and quality are adversely affected by severe drought conditions (Hassanzadeh et al., 2009; Bahrami et al., 2012). Some micronutrients such as boron can serve as beneficial elements for plant growth, particularly in conditions of drought stress. While a minimal quantity of boron is essential for the growth and development of plants, it can become toxic if present in slightly excessive amounts (Hilal et al., 2011). Therefore, in this study investigated the influence of boron on the characteristics of sesame seedlings subjected to drought stress.

Utilizing osmotic materials to generate drought potential is an important method for investigating the impact of drought stress for plants. Therefore, we used various dosages of PEG to investigate the effects of drought on sesame at the seedling stage. In this study, the statistical analysis revealed significant differences in root length and shoot length across the varied doses of PEG applications (Table 1). In comparison to the control condition, the root length showed a significant decrease as PEG levels increased; the control and -4 MPa had the highest and lowest values with 4.30 cm and 1.67 cm, respectively (Table 2). The reduction in root length may be attributed to diminished cellular reproduction during the germination phase (Frazer et al. 1990).The result aligned with the reports of Kızıl and Yol (2018), who reported that increasing concentrations of PEG from -2 to -6 MPa drastically reduced root length. The ability of advanced root systems to withstand drought conditions and are the first to be impacted under drought stress conditions make root traits important selection factors (Saxena et al., 1993). Reduced root lengths due to drought conditions have been documented in maize (Khodarahmpour, 2011), rapeseed (Bouchyoua et al., 2024), and oats (Mut and Akay, 2010). We identified the same negative effect on shoot lengths, recording 4.13 cm at 0 (control), 3.36 cm at -2, and 2.77 cm at -4 MPa. Previously, Ahmed et al. (2021) reported that shoot length decreased with the increase in drought stress in sesame. Although it was not statistically significant, fresh shoot and fresh root weight drastically reduced from -2 to -4 MPa, which was a result of restricted water conditions inhibiting plant development. These stress levels probably represent crucial values for sesame production (Kızıl and Yol, 2018).

Table 1. ANOVA on mean of squares of measured traits in Muganli-57 under control and different levels of PEG, Boron, and PEG x Boron

Source of Variation	df	Root Length	Shoot Length	Fresh Root Weight	Fresh Shoot Weight
Boron (B)	2	12.500**	10.509**	0.018**	0.059**
PEG (P)	1	12.339**	18.157**	0.005	0.133
B x P	2	8.204**	5.966**	0.014	0.053**

* and **; significant at 5% and 1% probability levels, respectively. df, represents degree of freedom

Boron has a limited range between deficiency and toxicity, and it is a vital plant micronutrient absorbed almost entirely in the form of boric acid via the roots (Brdar-Jokanović, 2020). Consequently, the soil boron that is insufficient for one crop may demonstrate toxic effects on another. In this study, different concentrations of boron had a statistically significant effect on all measured traits (Table 2). All traits were significantly reduced by increasing doses of boron. The control group exhibited the maximum values for all traits, while the lowest values were reached at 10 mM, measuring 0.23 cm for root length and 0.45 cm for shoot length. Excessive boron hinders cell division and impairs the thylakoid structure via influencing photosynthesis, therefore decreasing CO_2 uptake and leading to decreased root and shoot development (Reguera et al., 2009). Our findings supported this theory as we observed a significant reduction in the lenght of root and shoot at 10 mM. Culpan and Gürsoy (2023), and Eroğlu and Topal (2022) reported similar results, observing a decline in linseed and barley seedling characteristics as the boron dose increased, respectively. Moreover, the highest values were identified at control, while there was no statistical difference increase from B1 (5 mM) to B2 (10 mM) in fresh root and fresh shoot weight.

Table 2. Mean comparison of different doses of Bor (B), PEG (P), and Bor x PEG on sesame cultivar, Muganlı-57

Applications	Root Length (cm)	Shoot Length (cm)	Fresh Root Weight (g)	Fresh Shoot Weight (g)
Boron				
Control	4.30^{a}	4.13^{a}	0.16^{a}	0.47^{a}
B1	1.66^{b}	1.71^{b}	0.04^{b}	0.24^{b}
B2	0.23^{c}	0.45^{c}	0.01^{b}	0.22^{b}
PEG				
Control	4.30^{a}	4.13^{a}	0.16	0.47
P1	2.54^{b}	3.36^{b}	0.06	0.36
P2	1.67^{c}	2.77^{c}	0.03	0.25
Boron x PEG				
Control	4.30^{a}	4.13^{a}	0.16	0.47^{a}
B1P1	1.51^{b}	1.48^{b}	0.01	0.16^{b}
B1P2	0.32^{c}	0.65^{b}	0.35	0.27^{b}
B2P1	1.81^{b}	1.43^{b}	0.02	0.20^{b}
B2P2	0.32^{c}	0.64^{b}	0.05	0.21^{b}

*: Mean with different letter(s) in each trait is significantly different according to LSD multiple range test.

Generally, boron application is more effective when the absorption of nutrients in the roots is insufficient due to water scarcity (White et al., 2013). However, in this study, it was determined that increasing the PEG dose, especially with the addition of boron, had a more negative effect on the root length (Table 2). The highest and lowest values for root length were found in the control group and both at B1P2 and B2P2, respectively. These same effects were also observed in shoot lenght. There were no significant differences in fresh shoot weight for different combinations of boron and PEG and the control group had the highest value. This is thought to be due to two reasons. Firstly, although boron is important for plants, an excessive amount of it might result in certain adverse consequences in plant growth and development (Goldbach et al., 2001). Plants subjected to elevated levels of boron typically exhibit diminishing growth in both shoots and roots (Nable et al., 1990). Secondly, under conditions of drought stress, plants have a reduction in water absorption (Hussain et al., 2018). Consequently, there is a decrease in the rate of B influx into the root and its subsequent transportation from the root to the aerial organs (Liu et al., 2018).

CONCLUSION

Drought represents a reduction in water availability due to inadequate precipitation, which constrains plant growth, development, and productivity across various crops globally. A greater focus on developing drought-tolerant cultivars in breeding programs is gaining significance. This study examined the impact of drought on the seedling growth traits of sesame subjected to varying boron treatments. Drought stress negatively impacted the seedling growth traits of sesame (Muganlı 57). When combined with drought stress and boron, the reduction of seedling traits may be the result of drought stress as well as B toxicity. This cultivar should be evaluated under different ecological conditions in the field, focusing on its agro-morphological characteristics.

Compliance with Ethical Standards

Peer-review

Externally peer-reviewed.

Conflict of interest

The authors declare that they have no competing interests in this study.

Author contribution

The author contributed in the full study.

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