Research Article

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Foliar selenium application for improving drought tolerance of sesame (*Sesamum indicum* L.)

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Abstract: Drought is the main constraint for crop growth worldwide. Selenium reportedly plays an important role in improving plant tolerance to drought stress. In this study, two experiments were conducted to investigate the effects of foliar selenium application on the drought tolerance of sesame. Five selenium concentrations (0, 5, 10, 20, and 40 mg/L) were used in the first experiment. Water deficit was triggered 25 days after sowing. The application of 5 or 10 mg/L of selenium maintained the number of leaves and increased the number of capsules. However, higher concentrations induced necrosis. The second experiment aimed to study the effect of selenium concentrations (5 and 10 mg/L) and the number of applications (one to three times). Drought stress was triggered 50 days after sowing, and selenium was sprayed 50, 55, and 60 days after sowing. The results indicated that a one-time foliar selenium application of 5 mg/L was able to maintain the number of leaves and to increase proline accumulation, plant biomass, and grain weight per plant. This finding confirms that selenium can be applied to enhance sesame's tolerance to drought stress.

Keywords: crop, grain yield, proline, selenium, sesame

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1 Introduction

Drought is a big problem in global agricultural production (Hu et al. 2014; Leng and Hall 2019), which affects the physical and chemical, as well as the microbiological, parameters of soil fertility, which are important factors for plant biomass and grain production (Chodak et al. 2015). Drought has gradually become more severe. In the Mekong Delta, Vietnam, drought and saline intrusion have become serious issues, causing considerable loss of paddy fields. Therefore, alternative species or cropping methods should be explored to cope with this situation. Several cash crops can be grown in rotation with rice during the dry season. Sesame is an important crop because of its high oil, antioxidant, and protein content (Koca et al. 2007). In addition, sesame is generally tolerant of drought stress and has thus become one of the obvious choices for farmers (Golestani and Pakniyat 2015). However, certain stages of sesame, such as seed germination and flowering, remain particularly sensitive to drought (Boureima et al. 2011).

Drought stress has been reported to hinder germination, plant growth, flowering, number of capsules per plant, and seed yield (Hassanzadeh et al. 2009; Bahrami et al. 2012; Kassab et al. 2012). Many approaches have been used to alleviate the effects of drought on crops. Several studies have indicated that micronutrients, such as boron (Naeem et al. 2018), molybdenum (Rana et al. 2020), and silica (Ahmed et al. 2011), help plants to tolerate drought. Although selenium is not an essential element for plant growth, it has been reported to stimulate crop tolerance to drought conditions (Andradea et al. 2018). At low dosages, selenium imparts diverse beneficial effects and stimulates growth (Kaur and Nayyar 2015). Many researchers have reported that selenium induces plant drought coping mechanisms by reducing water evaporation (Djanaguiraman et al. 2005), increasing the activities of oxide enzymes such as superoxide dismutase and peroxidase (Nawaz et al. 2016), promoting the synthesis of chlorophyll and carotenoid (Malik et al. 2012;

Nawaz et al. 2016), and enhancing the accumulation of proline (Ahmad et al. 2016). Proline accumulation is a common response in plants exposed to drought stress (Yao et al. 2009). In pea and wheat, proline was the only measured stress marker that was increased primarily by drought stress (Alexieva et al. 2001). Proline, a proteinogenic amino acid, helps osmotic adjustment during stress and protects the native structure of macromolecules and membranes during extreme dehydration (Gehlot et al. 2005). According to Verbruggen and Hermans (2008), proline helps plants in the adaptation to drought conditions. Soil or foliar application of selenium can improve the growth and yield of plants; however, selenium spray is more effective than soil application (Karimi et al. 2020). Currently, there have been limited efforts to understand the role of selenium in sesame under drought conditions. Therefore, this study was carried out to determine the optimal concentration and number of foliar selenium applications for the sesame DH-1 variety for drought tolerance.

2 Materials and methods

2.1 Materials

A pot experiment was carried out at the College of Agriculture's Farm, Can Tho University, Vietnam, from November 2018 to October 2019. The sesame variety DH-1 is 100–120 cm in height and has a short growth duration of 75–80 days, with a yield of 1.2–2.0 tons/ha. This sesame variety was screened from 14 varieties in the Mekong Delta, Vietnam (our unpublished data). Each black plastic pot (33 cm in width × 27 cm in height) was filled with 11 kg of dried paddy soil. The physicochemical analysis of the paddy soil showed the following concentrations: 0.83% organic matter, total nitrogen (N) 0.33 mg/kg dry soil, phosphorous (P) 4.9 mg/kg dry soil, potassium (K) 128 mg/kg dry soil, and calcium (Ca) 101 mg/kg dry soil. It also showed a pH of 6.5. The soil was identified as a Gleysol according to the World Reference Base classification, with soil textures of sand, silt, and clay of 1.40, 39.8, and 58.8, respectively. Ten sesame seeds were sown in each pot, and 7 days after germination, the plants were thinned to one plant per pot. N, P, and K (90, 60, and 90 kg/ha of N, P_2O_5, and K_2O, respectively) were used for fertilization based on the soil analysis results. The actual chemicals used were urea for N (46% N), superphosphate fertilizer for P (16% P_2O_5), and potassium chloride for K (60% K_2O). In Experiment 1, 25 days after sowing, drought stress was induced by completely stopping irrigation until harvest. In Experiment 2, drought stress started 50 days after sowing. These periods were selected based on the scarcity of fresh water in the Mekong Delta. To avoid interference from rainfall, all pots were wrapped with plastic covers to prevent any water droplets entering the soil. To prepare different Se concentrations (5, 10, 20, and 40 mg/L) for foliar application, selenium crystals were broken down by HNO_3 (Vogel 1974).

2.2 Methods

2.2.1 Experiment 1

In this experiment, which aimed to identify the optimal foliar selenium application for sesame growth under drought conditions, five treatments (different concentrations of Se: 0, 5, 10, 20, and 40 mg/L) were used 25 days after sowing. On the same day, the drought stress began. A randomized block design was used with five replications. Each replication contained five pots.

2.2.2 Experiment 2

This experiment aimed to determine the suitable selenium concentrations (0, 5, and 10 mg/L) and number of foliar applications (one to three times) for the growth of sesame under water-deficit conditions. The drought stress was created 50 days after sowing. This pot experiment was carried out in a randomized block design with five replications. Each replication contained five pots.

2.2.3 Brief description of the observed responses and measured parameters

Plant height (cm) was measured from the soil surface to the highest point of the plant. The number of leaves was counted at harvest. For the measurement of leaf proline content (µmol/g fresh weight) 5 days after selenium application, leaves were randomly selected (starting from the fifth leaf from the top). The samples were composited for each plot and thoroughly mixed and analyzed using the methods of Bates et al. (1973). The soil plant analysis development (SPAD) index was detected directly after 5 days of spraying with selenium on the twelfth leaf from the soil surface using SPAD-502 Plus (Konica Minolta), according to the manufacturer's instructions. The number of mature and immature capsules per plant was assessed at harvest. The sesame plants were oven-dried at 80°C for 48 h, or until they reached a constant weight, to measure their dry weight. The weight of seeds (g) was recorded at 8% moisture.

2.3 Data analysis

The data given in this study were the mean values of five replications, unless otherwise stated. The data were analyzed using one-way analysis of variance (ANOVA) for Experiment 1 and two-way ANOVA for Experiment 2 with the SPSS software package version 13.0. All the mean values were analyzed using ANOVA, and a comparison among the means for determining significant differences was performed using Duncan's multiple range test at $p < 0.05$.

Ethical approval: The research conducted is not related to either human or animal use.

3 Results and discussion

3.1 Plant height and number of leaves

Selenium did not improve the height of the sesame plants under drought conditions (Figure 1). This result was similar to the results observed in wheat with foliar applications of 18 and 36 mg/L selenium (Teimouri et al. 2014). However, the number of leaves growing under drought stress was significantly affected by selenium levels (Figure 1), with 5 and 10 mg/L having the highest number of leaves. The number of leaves on the plants was reduced when they were sprayed with a selenium concentration of 20 or 40 mg/L (Figure 1). Grape plants produced the highest number of leaves when 5 mg/L of selenium was sprayed (Karimi et al. 2020). Meanwhile, according to Li et al. (2015), high concentrations of selenium (40 mg/kg) induce toxicity in *Brassica* plants.

Without selenium application, the sesame plants could not maintain their leaves under prolonged water deficit (Figure 2). Spraying with selenium concentrations of 5–20 mg/L maintained the number of leaves on the plants, and the leaves were fresher than the leaves without spraying with selenium (Figure 2). Meanwhile, the number of leaves was reduced at 40 mg/L. According to Shahzadi et al. (2017), selenium helps plant to delay pigment degradation. These results were similar to the responses of the okra plant to drought conditions when 3 mg/L of selenium was applied (Ali et al. 2020). High foliar selenium concentrations (40 mg/L) induced leaf necrosis and deformity (Figure 2).

One day after spraying with 20 and 40 mg/L selenium, phytotoxicity symptoms, such as necrosis and young leaf curls, appeared (Figure 3d and e). However, these leaves did not turn yellowish or drop in the following days. These observations are similar to those made by Mora et al. (2008) on white clover when 60 mg/ha of selenium was applied to the soil. High selenium concentrations (13 mg/kg soil) have been reported to reduce leaf chlorophyll in maize (Sali et al. 2018). According to Feng et al. (2013), selenium, especially in low concentrations, plays an important role in plant growth under abiotic stresses.

3.2 Number of capsules

Under drought conditions, selenium application improved the number of sesame capsules per plant (Figure 4). When

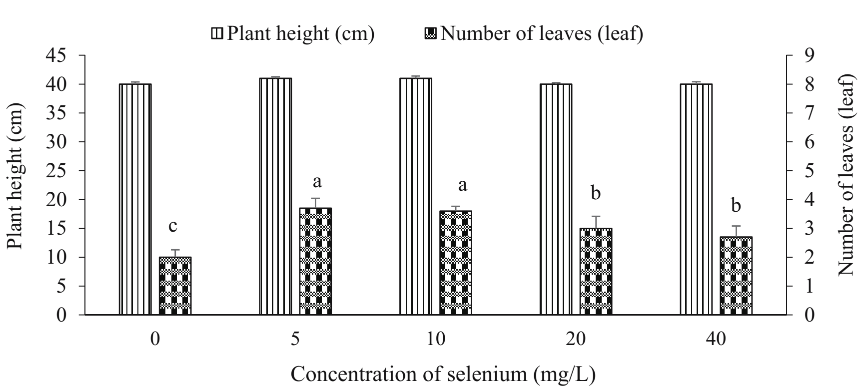

Figure 1: Effect of selenium on plant height and number of leaves under drought conditions. Means (±SD, $n = 5$) with different letters above the bars are significantly different ($p < 0.05$) according to Duncan's multiple range test. Means without letters are not significantly different.

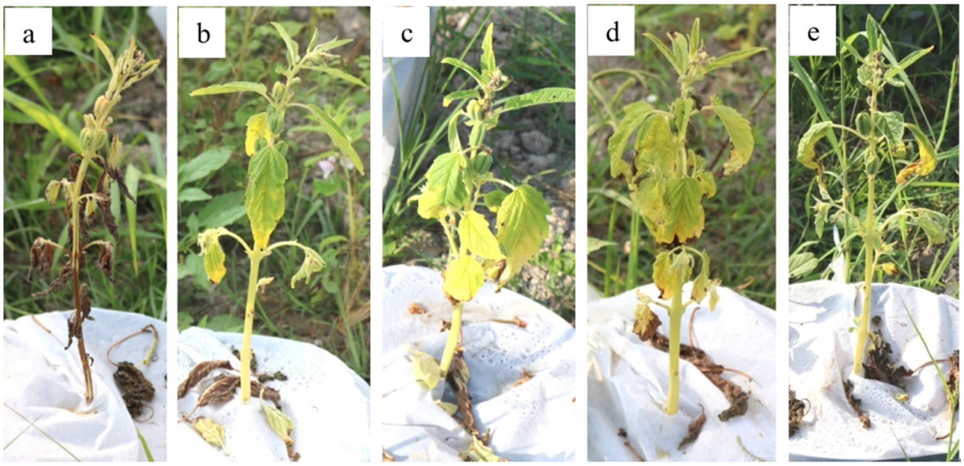

Figure 2: Sesame plants after 20 days of non-irrigation and after treatments with different selenium concentrations: (a) 0 mg/L, (b) 5 mg/L, (c) 10 mg/L, (d) 20 mg/L, and (e) 40 mg/L.

5 and 10 mg/L of selenium were applied, the number of capsules increased significantly. Meanwhile, higher concentrations resulted in marked reductions in capsule yields. These results are similar to those of studies on mung bean (Kaur and Nayyar 2015) and black peanut (Irmak 2017) when they were treated with selenium. According to Myint et al. (2020), the number of capsules per plant is one of the most important yield-related traits in sesame.

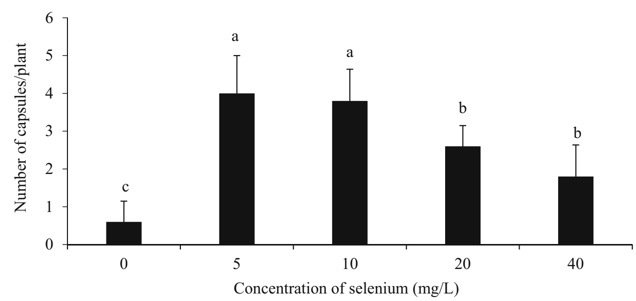

Figure 4: Number of capsules per plant for different treatments at harvest time. The letters above the columns represent a significant ($p < 0.05$) difference.

3.3 Effect of dose and number of applications of selenium on number of leaves

After 10 days without irrigation, the number of leaves was not different among the treatments (Figure 5). However, after 15 days, selenium application improved the number of intact leaves compared with sesame plants without selenium application. Meanwhile, the frequency of selenium application did not affect the number of leaves (Figure 5). Selenium delays senescence, prevents chlorophyll degradation, and maintains leaf area for a longer period (Xue et al. 2001; Djanaguiraman et al. 2004).

Under drought conditions, the SPAD index in the selenium treatment groups was higher than that in the control group. However, increasing the number of applications did not affect the SPAD index. Sesame plants that were sprayed once with 5 and 10 mg/L of selenium had, respectively, 17.7 and 11.2% higher SPAD readings compared with plants without selenium application (Figure 6). Several reports have shown the beneficial effects of foliar selenium on chlorophyll content in different crops, such as rice (Andradea et al. 2018), wheat

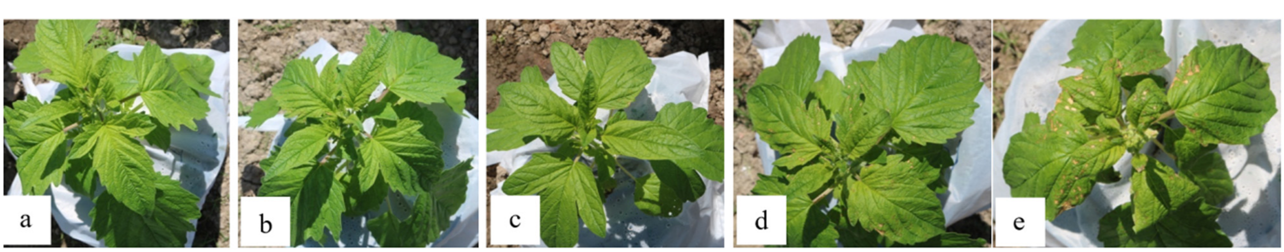

Figure 3: Sesame leaves after 1 day of spraying with selenium: (a) 0 mg/L, (b) 5 mg/L, (c) 10 mg/L, (d) 20 mg/L, and (e) 40 mg/L.

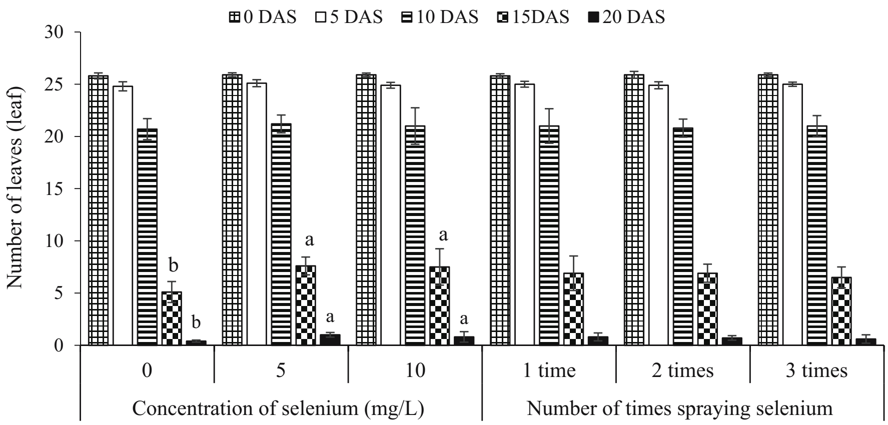

Figure 5: Effect of Se concentration and number of applications on number of leaves. Means (±SD, $n = 5$) with different letters above the bars are significantly different ($p < 0.05$) according to Duncan's multiple range test. Means without letters are not significantly different. DAS = days after sowing.

(Shahzadi et al. 2017), and spinach (Saffaryazdi et al. 2012), under water-deficit conditions. Canola has also been reported to accumulate high concentrations of chlorophyll when sprayed with 10 µg of selenium per plant (Hajiboland and Keivanfar 2012). The high SPAD readings in sesame plants with selenium application could be due to the positive influence of exogenous selenium on chlorophyll synthesis, preventing chlorophyll degradation under water-deficit conditions (Shahzadi et al. 2017).

3.4 Proline accumulation

Under drought conditions, spraying with selenium induced proline accumulation in the sesame leaves. The results showed that with one single treatment of 5 and 10 mg/L selenium, fresh leaf proline content reached 1,092 and 1,051 µmol/g of fresh leaf, respectively, increasing by 33.8 and 28.7% as compared with fresh leaf proline content without application of selenium (Figure 7). A single foliar selenium application was seen to be more effective than multiple applications. In wheat, plants produced a high amount of proline (0.869 µmol/g of fresh leaf) when 2 mg/kg of selenium was applied to the soil (Yao et al. 2009). Eggplant produced high amounts of proline when they were sprayed with 30 µM of selenium (Abul-Soud and Abd-Elrahman 2016). These results indicate that selenium plays a role in plant drought tolerance by promoting proline accumulation. In the present study, only proline was measured as a biochemical parameter because of its effects on drought stress.

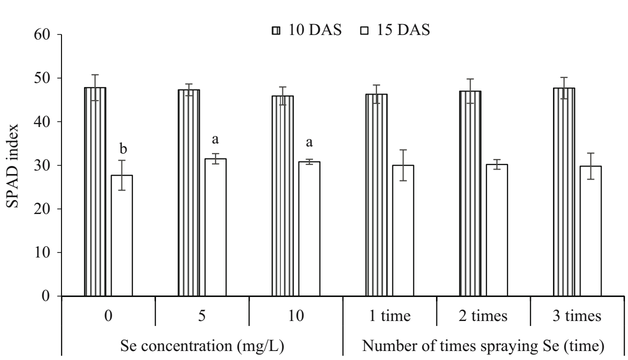

Figure 6: SPAD index of leaves after 15 days of spraying with selenium. Means (±SD, $n = 5$) with different letters above the bars are significantly different ($p < 0.05$) according to Duncan's multiple range test. Means without letters are not significantly different. DAS = days after sowing.

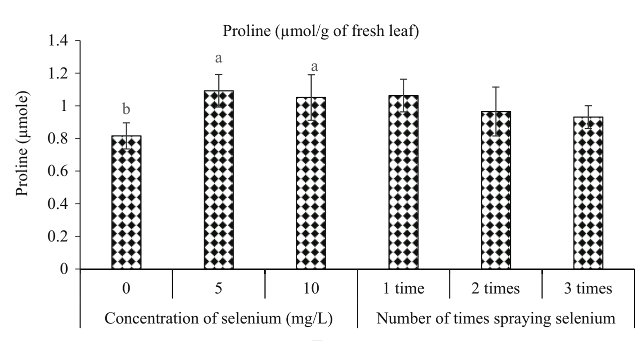

Figure 7: Proline content in fresh leaves after 15 days without irrigation. Means (±SD, $n = 5$) with different letters above the bars are significantly different ($p < 0.05$) according to Duncan's multiple range test. Means without letters are not significantly different.

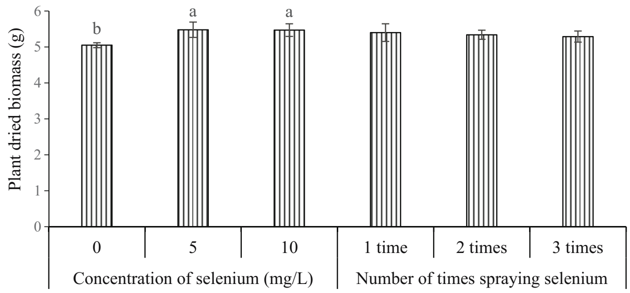

Figure 8: Dry weight of plants at harvest. Means (±SD, $n = 5$) with different letters above the bars are significantly different ($p < 0.05$) according to Duncan's multiple range test. Means without letters are not significantly different.

3.5 Dry biomass of plants

Under drought stress, a single selenium treatment improved sesame's dry biomass (Figure 8). The dry biomass of plants receiving 5 mg/L selenium was 8.3% higher than that of plants without selenium application. The dry biomass of sesame plants receiving selenium treatments was high because these plants maintained a high number of leaves. However, increasing the number of times selenium was applied did not affect the dry biomass of sesame plants (Figure 8). *Brassica* plants produced the highest shoot biomass when 5 mg/kg of selenium was applied to the soil, whereas the shoot biomass was significantly reduced when the concentration of selenium was increased from 10 to 40 mg/kg (Li et al. 2015).

3.6 Number of capsules, ratio of immature capsules, and grain weight

Spraying sesame with selenium (5 and 10 mg/L) increased important yield attributes, such as the total number of mature capsules per plant and the grain weight per plant. The grain weight per plant of plants receiving 5 and 10 mg/L selenium was, respectively, 18.1 and 17.0% higher than that of plants without selenium treatment. This result is consistent with the results obtained in tomato plants (Radya et al. 2020), soybean plants (Djanaguiraman et al. 2005), and broccoli plants (Hajiboland and Keivanfar 2012). However, increasing the number of applications of selenium did not benefit the yield attributes of sesame plants growing under prolonged water deficit (Figure 9).

The number of immature capsules per plant was higher in the sesame plants without selenium treatment owing to early leaf senescence. The sesame plants with selenium application maintained fresher leaves and generated more leaves than the control plants (Figure 10). According to Kuznetsov et al. (2003), under conditions of water deficiency, selenium does not decrease the rate of water loss from plants.

4 Conclusion

Spraying 5 mg/L of selenium on sesame plants 50 days after sowing helped the plants to tolerate drought conditions. A single foliar selenium application at a concentration of 5 mg/L at the grain-setting stage was able to maintain the number of intact leaves, to increase plant biomass, to enhance proline accumulation in the leaves, and to improve grain yield. The grain weight per plant of plants receiving 5 mg/L of selenium was 18.1% higher than that of plants without selenium treatment. We therefore recommend that field experiments be conducted to confirm the selenium effects on growth and yield of sesame under drought stress conditions.

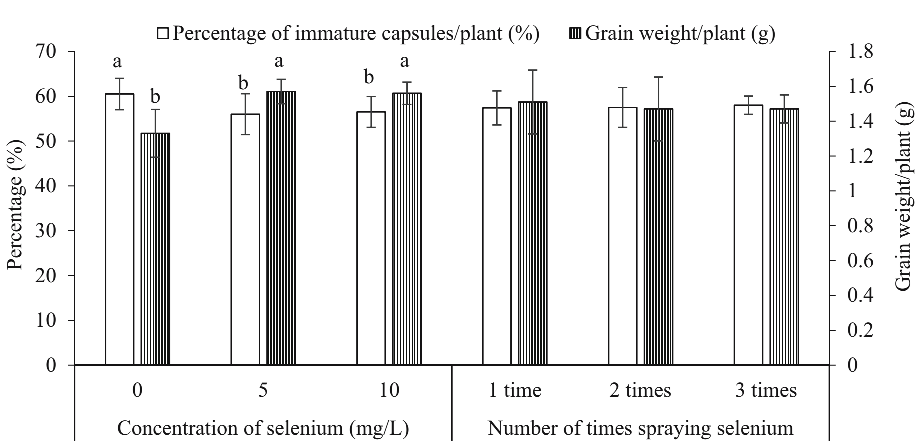

Figure 9: Percentage of immature capsules per plant and seed weight per plant. Means (±SD, $n = 5$) with different letters above the bars are significantly different ($p < 0.05$) according to Duncan's multiple range test. Means without letters are not significantly different.

Figure 10: Sesame plants after 20 days without irrigation and after treatments with different selenium concentrations and numbers of applications: (a) 0 mg/L, (b) once with 5 mg/L, (c) twice with 5 mg/L, (d) thrice with 5 mg/L, (e) once with 10 mg/L, (f) twice with 10 mg/L, and (g) thrice with 10 mg/L.

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

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

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