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# Improving the Growth Characteristics and Grain Production of Camelina (*Camelina sativa* L.) under Salinity Stress by Silicon Foliar Application

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**ABSTRACT**

In agriculture, there has always been an attempt to increase the tolerance of crops to environmental stresses. Therefore, pot research was done to investigate the impacts of silicon foliar application on the mitigation of salinity stress in camelina. The study was done as a factorial based on a randomized complete block design with three replications at Razi University, Kermanshah, Iran, during 2020-21. The experimental factors were two camelina genotypes (Soheil cultivar and Line-84), salinity (at three levels 6, 60 and 120 mM) and foliar spraying of sodium silicate (at four levels control, 2, 4, 6 and 8 mM). The results illustrated that salinity stress reduced plant growth, grain production and its components. By increasing the salinity intensity, silicon foliar application led to reducing the impacts of salinity on total dry matter, grain weight and the number of siliques per plant. Under non-saline conditions, a silicon concentration of 6 mM increased the total dry matter, the grain weight and the number of siliques per plant by about 7.7 and 6%, respectively. Under mild and severe salinity conditions, 6 mM silicon increased the total dry matter 9 and 10%, the grain weight by 11 and 8%, and the siliques per plant by 9 and 9%, respectively. The maximum grain weight per plant was related to the silicon foliar spraying of 6 mM. Silicon foliar spraying 2, 4, 6 and 8 mM increased the grain weight per plant by 3, 7, 10 and 9%, respectively compared to the control. In general, it seems that the foliar application of silicon reduces the salinity of camelina plant growth, grain weight per plant and its components.

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## 1. Introduction

Camelina (*Camelina sativa* L.) is an annual oil crop in the family Brassicaceae (Shahidi, 2005). The origin of this plant is native to Europe and South Asia. Camelina was not considered a commercial plant before 2005, but with the recognition of omega-3 fatty acids in this plant, its cultivation increased (Mieriņa *et al.*, 2017). The oil content of camellia seeds is 30-40% (Pavlista *et al.*, 2016). The greater part of seed oil consists of α-linolenic acid (30-40%), linoleic acid (15-25%), oleic acid (10-20%) and other fatty acids (Waraich *et al.*, 2013). Studies have shown that camelina has a high adaptability to adverse environmental conditions such as salinity (Morales *et al.*, 2017).

Soil and water salinity is a limitations for proper agriculture production (Setayesh Mehr and Esmaeizadeh Bahabadi, 2013). Salinity causes changes in the cell surface, tissue and plant organs (Munns, 2002). Its primary effects include water deficiency and ion toxicity because of the accumulation of sodium and chlorine, which leads to many secondary effects such as oxidative stress. Disturbing the balance of production and decomposition of active oxygen species leads to aggravating the harmful effects of salinity stress. Reactive oxygen species can react with many cell compounds and cause the destruction of membranes and other essential macromolecules such as photosynthetic pigments, proteins, nucleic acids and also lipid oxidation (Blokhina *et al.*, 2003).

Plants have antioxidant defense enzymatic and non-enzymatic systems which are used in stress conditions to inhibit excessive radical accumulation (Shi *et al.*, 2007). The salinity tolerance mechanisms cause

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changes in morphologic, anatomic and physiologic traits (Hashemi *et al.*, 2010).

Silicon (Si) is the second most abundant element on earth after oxygen. silicon is often fixed as silicates and is not available for plants (Sakihama *et al.*, 2002). Since silicon is not mentioned as an essential element for plants, not many studies have been conducted on its biological roles (Guo *et al.*, 2013). Silicon can affect plant growth and health, increase yield quantity and quality, and stimulate the production of some antioxidant enzymes (Chérif and Bélanger, 1992). The effect of silicon on plant products may be due to its deposition in the leaf, increasing the leaf strength (Adatia and Besford, 1986), increasing the chlorophyll content (Maghsoudi *et al.*, 2016) and rising the efficiency of photosystem II (Yordanov *et al.*, 2000), which increases the plant's ability to use radiation more effectively. Also, the use of silicon increases the RubisCO enzyme content in the leaves (Gao *et al.*, 2006; Sonobe *et al.*, 2010).

If silicon is available to the plant, it plays roles in growth, mineral nutrition and resistance to different stresses (Farooq *et al.*, 2009). Silicon improves water use efficiency and regulates the enzymatic and non-enzymatic antioxidant defense systems (Cooke and Leishman, 2011). Silicon has been effective in reducing salinity in plant species like barley (*Hordeum vulgare*) (Liang *et al.*, 2005), and wheat (*Triticum aestivum*) (Tuna *et al*., 2008). Al-aghabary et al. (2005) investigated the effects of silicon on salinity tolerance in tomato. The results illustrated that silicon significantly reduced the negative effects of salt and created resistance. Some mechanisms by which silicon increases salinity resistance include: improving photosynthetic activity, increasing absorption and transfer of K+ and decreasing absorption and transfer of Na+ from the root to the shoot, increasing the activity of enzymes, and increasing soluble substances in the vessels.

Salinity stress is one of the common difficulties of agriculture in Iran, so management strategies to achieve proper yield and increase plant tolerance are very important. There is not enough information about the effect of silicon on reducing salinity stress damage in camelina. Therefore, this study was done to figure out the effects of silicon foliar spraying levels on growth, grain production and its components in camelina plants under salinity stress conditions.

## 2. Materials and methods

This research was carried out during 2020-21 at the Campus of Agriculture and Natural Resources, Razi University, Kermanshah, Iran. The experiment was done in pots under natural environmental conditions. the research was done as a factorial based on a randomized complete block design with three replications. The factors were two camelina genotypes (Soheil cultivar and line-84), salinity stress levels (6, 60 and 120 mM) and silicon foliar spraying (0, 2, 4, 6 and 8 mM sodium silicate). Plastic pots with a diameter and height of 30 cm were considered. In order to pot drainage, four similar holes were made in the bottom of each pot and also 800g coarse sand was placed on the bottom of each pot. The pots were filled with 10 kg soil, a mixture of agricultural soil, perlite, and fine sand with a volume ratio of 6:3:1. The texture of the soil used in the pots was sandy-loam. Twenty camellia seeds were planted in each pot on October 29, 2020. Seedlings were thinned at the 2-3 leaf stage and eight seedlings were kept in each pot. Based on the soil test results (Table 1), 100 kg/ha of triple superphosphate and 150 kg/ha of urea fertilizer were used. Pre-sowing phosphorus and half of the nitrogen fertilizer were mixed with the soil before planting. The rest of the nitrogen fertilizer was consumed at the beginning of the stem elongation.

**Table 1. Physicochemical analysis of the soil**

| Objective | Value | Objective | Value |
|---|---|---|---|
| Soil depth (cm) | 0 – 30 | Total N (%) | 0.09 |
| EC (ds.m$^{-1}$) | 1.82 | Avail. P (mg.kg$^{-1}$) | 18 |
| pH | 7.8 | Avail. K (mg.kg$^{-1}$) | 360 |
| $CaCO_3$ (%) | 28 | Mn (mg.kg$^{-1}$) | 14 |
| O.M. (%) | 0.99 | Fe (mg.kg$^{-1}$) | 4.5 |
| Sand (%) | 41.5 | Zn (mg.kg$^{-1}$) | 0.48 |
| Silt (%) | 42.8 | Cu (mg.kg$^{-1}$) | 1.8 |
| Clay (%) | 15.7 | Texture | Silty Clay |

Foliar spraying of silicon was done at three times of early, mid and late stem growth stages (codes 29, 39 and 60 BBCH) (Martinelli and Galasso, 2011). In foliar spraying, Tween-20 (as a surfactant) was used with a concentration of 0.1% (v/v) for greater solubility and better effectiveness. At the time of foliar application, the greenhouse temperature was 25±2 ºC and the relative humidity was 70±10%. Foliar spraying was done uniformly throughout the plant.

The pots were irrigated with non-saline water from the planting until the beginning of the stem elongation.

The salinity treatments were started from the beginning of the stem elongation by irrigation with salty water. Sodium chloride was used to prepare salinity. All pots were watered simultaneously and equally based on the treatments. In order to prevent the accumulation of salt, irrigation was carried out alternately with saline and non-saline water. The well water which was used to irrigate the control treatment has a salinity of 6 mM.

Harvesting was done in June when the grain moisture percentage was about 12% (code 89 BBCH) (Martinelli and Galasso, 2011). In this experiment, traits related to growth, grain weight per plant and its components were measured as follows:

Total dry matter (TDM): The plants in each pot were cut from the soil surface and after drying, they were weighed and reported as g/plant.

Grain weight per plant: At the grain ripening stage, the grains belonging to the plants of each pot were harvested and weighed, then divided by the number of plants to obtain the grain weight per plant (g/plant).

Harvest index: It was calculated by dividing the grain weight by the TDM multiplied by 100 (Zarei *et al.*, 2021).

Plant height: The main stems of five plants in each pot were randomly selected and the length of the stem was recorded from the collar to the end of the plant by a ruler (Hasani Balyani *et al.*, 2020).

The number of siliques per plant: The number of siliques per plant in five plants was counted and their average was determined (Hasani Balyani *et al.*, 2020).

The number of grains per silique: The siliques of five plants per pot were harvested, then the grains were separated, counted and divided by the number of siliques (Amiri-Darban *et al.*, 2020).

The number of sub-branches and leaves per plant: In five plants of each pot, the sub-branches and leaves were counted (Amiri-Darban *et al.*, 2020).

Oil weight per plant: After measuring the oil percentage of the grains (A.O.A.C., 1990), the oil weight was calculated by multiplying the grain weight per plant by the oil percentage.

Data analysis was done with MSTATC and SAS statistical softwares. Means were compared using Duncan's multiple range test (P≤0.05). Excel software was used to draw figures.

## 3. Results and discussion

### *3.1. Total dry matter (TDM), grain yield per plant, harvest index (HI)*

Analysis of variance demonstrated that the simple effects of genotype, salinity, and silicon, as well as the interaction effect of genotype × salinity on TDM, were significant (Table 2). This means comparison showed that the silicon foliar application increased TDM compared to the control. So, foliar silicon spraying 2, 4, 6 and 8 mM increased the TDM by 3, 6, 8 and 7%, respectively, compared to the control. The highest TDM was related to the foliar application of 6 mM silicon, although it did not have a significant difference with 4 and 8 mM (Fig. 1A). The interaction effect of salinity × genotype showed that line-84 had more TDM than Soheil cultivar in non-saline treatment. But under salinity conditions, the two camelina genotypes did not have a statistically significant differences. Mild and severe salinity decreased TDM by about 31 and 39% compared to the control (Fig. 2A).

Analysis of variance demonstrated the simple impacts of saline, genotype, silicon and salinity × genotype on grain weight per plant (Table 2). The lowest grain weight per plant belonged to the control. Silicon foliar application increased the grain weight per plant. So, foliar spraying 2, 4, 6 and 8 mM silicon caused to increase of 3, 7, 10 and 9% grain weight per plant in comparison to the control. The maximum grain weight per plant was obtained at 6 mM silicon as much as 0.464 grams per plant (Fig. 1B). Mild and severe salinities decreased grain weight per plant by about 41 and 49% respectively, compared to the control. In non-saline conditions, the Soheil cultivar had 15% less grain weight per plant than line 84, but under mild and severe salinities, no significant difference was observed between these genotypes (Fig. 2B). The mean comparison of salinity × silicon interaction illustrated that the highest amount of grain weight per plant was related to 6 mM silicon × non-saline treatment, which had no significant difference with 2, 4 and 8 mM silicon under non-saline conditions. But, it had significant differences from other treatments. By increasing salinity stress, silicon foliar application reduced the effects of salt stress on grain weight per plant. Under non-saline, mild and severe salinity conditions, 6 mM silicon foliar application increased 7, 11 and 8% respectively, grain weight per plant (Fig. 3A). This shows the positive effect of silicon foliar application in salinity stress conditions.

The effects of salinity and salinity × genotype on harvest index were significant (P≤0.05) (Table 1). The harvest index decreased by salinity intensity. Under mild and severe salinities, the harvest index decreased by 13 and 15% respectively, compared to the control. Under non-saline conditions, Line-84 had a higher harvest index than Soheil cultivar (Fig. 2C).

### *3.2. 1000-grain weight, the number of sub-branches, siliques per branch, siliques per main stem, siliques per plant, grains per silique*

Analysis of variances illustrated that the simple impacts of salinity, genotype, silicon, and salinity × genotype interaction on the 1000-grain weight, the number of siliques per branch, siliques per plant and grains per silique were considerable. Also, the impression of salinity, silicon, and salinity × genotype on the number of sub-branches were significant. The effects of salinity, genotype, silicon, salinity × genotype, salinity × silicon, and genotype × silicon on the siliques per main stem were significant (Table 2).

The salinity × genotype interaction effect showed that in the non-saline treatment, line-84 had more 1000-grain weight than Soheil cultivar. The 1000-grain weight was decreased by 18 and 22% under mild and severe salinity compared to non-saline, respectively (Fig. 2D).

The mean comparison showed that the number of sub-branches was increased by about 2, 4, 5 and 4% by 2, 4, 6 and 8 mM silicon foliar spraying compared to the control, respectively. The maximum number of sub-branches (4.88 sub-branch) was related to the silicon foliar spraying 6 mM (Fig. 1A). The means comparison of salinity × genotype interaction showed that the increase in salinity intensity decreased the sub-branches per plant in both camelina genotypes. The sub-branches decreased 24 and 29% in mild and severe salinity compared to the control, respectively (Fig. 2E).

Increasing the concentration of silicon foliar spraying raised the siliques per branch so that the highest siliques per branch were observed at 8 mM. There was no statistically significant difference among 4, 6 and 8 mM silicon treatments (Fig. 1D). The silicon spraying at 2, 4, 6, and 8 mM increased the number of siliques per branch by about 1, 3, 4, and 5%, respectively. The results showed that in non-saline conditions, line-84 had more siliques per sub-branch than the Soheil cultivar. However, this superiority was not observed in mild and severe stress conditions. Mild and severe salinity stress decreased the number of siliques per branch by about 10 and 12% in comparison to the control, respectively (Fig. 2F). The salinity × silicon foliar spraying interaction showed that the maximum number of siliques per main stem (12.68 siliques) related to 6 mM silicon in non-saline conditions, which had no significant difference with 4 mM silicon in non-saline treatment. The lowest number of siliques per main stem (10.9 siliques) was obtained under severe salinity × no-silicon application (Fig. 3B). On average, silicon foliar spraying 2, 4, 6, and 8 mM increased the number of siliques per main stem by 2, 3, 5, and 3% compared to the control, respectively. The siliques per the main stem declined by salinity intensity. The number of siliques per main stem was decline about 4 and 7% in mild and severe salinities compared to the control (Fig. 3B). Silicon foliar application 6 mM in non-saline, mild and severe salinity treatments increased the number of siliques per main stem about 6, 5 and 6% compared to the control, in the same order. The mean comparison of salinity × genotype interaction showed that the Soheil cultivar had more siliques per main stem under non-salinity, while under mild and severe salinity, the statistical difference between the Soheil cultivar and line-84 was negligible. The lowest number of siliques per main stem (11.3 siliques) was observed in the severe salinity for line-84 (Fig. 2G). By increasing the salinity intensity, the siliques per the main stem decreased. On average, mild and severe salinity treatments decreased the number of siliques per main stem by about 8 and 11% compared to the control, respectively. The mean comparison of the simple effect showed that the silicon foliar application raised the siliques per plant. The most number of siliques per plant (37.5 siliques) was related to the silicon foliar spraying 6 mM which had no significant difference with silicon 4 and 8 mM (Fig. 1E).

The mean comparison of salinity ×genotype interaction showed that line-84 had further siliques per plant than Soheil cultivar. The lowest siliques per plant (30.8 siliques) belonged to Soheil cultivar at severe salinity. The non-saline conditions (control) had 24.5 and 29.3% greater siliques per plant than the mild and severe salinity treatments (Fig. 2H). Silicon foliar application 6 mM under non-saline, mild and severe salinity increased the siliques per plant by about 6, 9 and 9% respectively, compared to the absence of silicon in the same treatments (Fig. 3C).

The mean comparison of salinity × camelina genotype interaction showed that in non-saline conditions, the Soheil cultivar had more the number of grains per silique than line-84. Line-84 was less affected in mild and severe salinity conditions compared to the Soheil cultivar. So that under mild and severe salinity, the number of grains per silique decreased by about 1 and 3% in line-84, but by 5 and 9% in the Soheil cultivar, respectively (Fig. 2I). On average, under salinity stress conditions, the two camelina genotypes had the same number of grains per silique. Mild and severe salinity stresses decreased about 3 and 6% of the grains per silique in comparison to the control.

**Table 2. Analysis variance (mean squares) of the effects of genotype (G), salinity (S), silicon foliar application (Si) and their interactions on some traits in camelina.**

| SOV | df | Total dry matter | Grain weight | Harvest index | 1000 grain weigh | sub-branches per plant | Siliques per branch | Siliques per main- stem | Siliques per plant |
|---|---|---|---|---|---|---|---|---|---|
| Replication | 2 | 0.006$^{ns}$ | 0.005$^{**}$ | 15.5$^{**}$ | 0.003$^{*}$ | 0.123$^{ns}$ | 1.688$^{**}$ | 2.242$^{**}$ | 39.4$^{**}$ |
| G | 1 | 0.132$^{**}$ | 0.017$^{**}$ | 0.444$^{ns}$ | 0.021$^{**}$ | 0.105$^{ns}$ | 2.547$^{**}$ | 0.389$^{*}$ | 44.8$^{**}$ |
| S | 2 | 4.1$^{**}$ | 0.826$^{**}$ | 281.8$^{**}$ | 0.480$^{**}$ | 24.872$^{**}$ | 4.097$^{**}$ | 5.347$^{**}$ | 1472.7$^{**}$ |
| G×S | 2 | 0.084$^{**}$ | 0.019$^{**}$ | 3.85$^{**}$ | 0.012$^{**}$ | 0.426$^{**}$ | 1.447$^{**}$ | 0.339$^{*}$ | 73.6$^{**}$ |
| Si | 4 | 0.037$^{**}$ | 0.005$^{**}$ | 0.344$^{ns}$ | 0.001$^{ns}$ | 0.171$^{**}$ | 0.148$^{**}$ | 0.998$^{**}$ | 22.0$^{**}$ |
| G×Si | 4 | 0.0005$^{ns}$ | 0.00025$^{ns}$ | 0.140$^{ns}$ | 0.00002$^{ns}$ | 0.011$^{ns}$ | 0.022$^{ns}$ | 0.205$^{*}$ | 0.735$^{ns}$ |
| S×Si | 8 | 0.00037$^{ns}$ | 0.00012$^{ns}$ | 0.011$^{ns}$ | 0.0001$^{ns}$ | 0.005$^{ns}$ | 0.018$^{ns}$ | 0.205$^{*}$ | 0.123$^{ns}$ |
| G×S×Si | 8 | 0.00025$^{ns}$ | 0.00006$^{ns}$ | 0.007$^{ns}$ | 0.00006$^{ns}$ | 0.003$^{ns}$ | 0.014$^{ns}$ | 0.130$^{ns}$ | 0.575$^{ns}$ |
| Error | 58 | 0.004 | 0.00048 | 0.301 | 0.001 | 0.046 | 0.033 | 0.083 | 1.963 |
| CV (%) | | 4.54 | 4.92 | 1.69 | 3.03 | 4.47 | 3.53 | 2.45 | 3.84 |

*, ** and ns: are significant at 5 and 1% probability levels and non-significant, respectively.

**Continuation of Table 2. Analysis variance (mean squares) of the effects of genotype (G), salinity (S), silicon foliar application (Si) and their interactions on some traits in camelina.**

| SOV | df | Grains per silique | Plant height | Stem dry weight | Leaves per plant | Leaf dry weight | Oil weight |
|---|---|---|---|---|---|---|---|
| Replication | 2 | 0.451$^{**}$ | 7.408$^{ns}$ | 0.002$^{ns}$ | 2.878$^{ns}$ | 0.001$^{**}$ | 0.001$^{**}$ |
| G | 1 | 1.542$^{**}$ | 624.1$^{**}$ | 0.001$^{ns}$ | 15.2$^{*}$ | 0.001$^{*}$ | 0.001$^{**}$ |
| S | 2 | 5.607$^{**}$ | 2895.9$^{**}$ | 0.124$^{**}$ | 451.9$^{**}$ | 0.023$^{**}$ | 0.138$^{**}$ |
| G×S | 2 | 0.728$^{**}$ | 208.2$^{**}$ | 0.001$^{ns}$ | 0.278$^{ns}$ | 0.0005$^{ns}$ | 0.002$^{**}$ |
| Si | 4 | 0.011$^{ns}$ | 318.6$^{**}$ | 0.017$^{**}$ | 186.4$^{**}$ | 0.011$^{**}$ | 0.003$^{**}$ |
| G×Si | 4 | 0.004$^{ns}$ | 9.746$^{ns}$ | 0.0005$^{ns}$ | 3.73$^{ns}$ | 0.0005$^{ns}$ | 0.00006$^{ns}$ |
| S×Si | 8 | 0.008$^{ns}$ | 9.24$^{*}$ | 0.0002$^{ns}$ | 4.68$^{ns}$ | 0.0004$^{ns}$ | 0.00012$^{ns}$ |
| G×S×Si | 8 | 0.009$^{ns}$ | 5.20$^{ns}$ | 0.0002$^{ns}$ | 2.014$^{ns}$ | 0.0002$^{ns}$ | 0.000068$^{ns}$ |
| Error | 58 | 0.047 | 4.03 | 0.001 | 2.315 | 0.0003 | 0.00006 |
| CV (%) | | 1.66 | 3.17 | 4.48 | 9.17 | 15.92 | 5.38 |

*, ** and ns: are significant at 5 and 1% probability levels and non-significant, respectively.

### *3.3. Plant height, stem dry weight, the number of leaves per plant, leaf dry weight, oil production*

The result of analyzing variance demonstrated that the simple efficacies of salinity, genotype, silicon and the impact of the interaction of salinity × genotype on plant height were significant. Also, the simple effects of salinity and silicon on the stem dry weight were significant. The simple effects of genotype, salinity and silicon on the number of leaves and leaf dry weight were significant, too (Table 2).

The mean comparison of salinity × camelina genotype interaction showed that Soheil cultivar had a longer stem than line-84 under non-stress and mild salinity stress conditions. Salinity stress decreased plant height, so mild and severe stress reduced plant height by 16 and 26%, respectively, compared to the control (Fig. 2J). The mean comparison of salinity × silicon interaction showed that the maximum plant height was related to the silicon spraying 6 mM in non-stress conditions. Foliar silicon spraying 2, 4, 6, and 8 mM increased the plant height by about 6, 13, 18, and 15% compared to the control, respectively (Fig. 3D).

The maximum stem dry weight was obtained in the non-saline treatment (0.635 g). Mild and severe salinity treatments decreased the Stem dry weight by about 6 and 19%, respectively (Fig. 4A). The means comparison showed that the highest stem dry weight was obtained in the silicon foliar spraying at 6 mM, which did not have a significant difference with 4 and 8 mM. Silicon foliar application at 2, 4, 6 and 8 mM increased the stem dry weight by about 6, 10, 14, and 12% compared to the control, respectively (Fig. 1F).

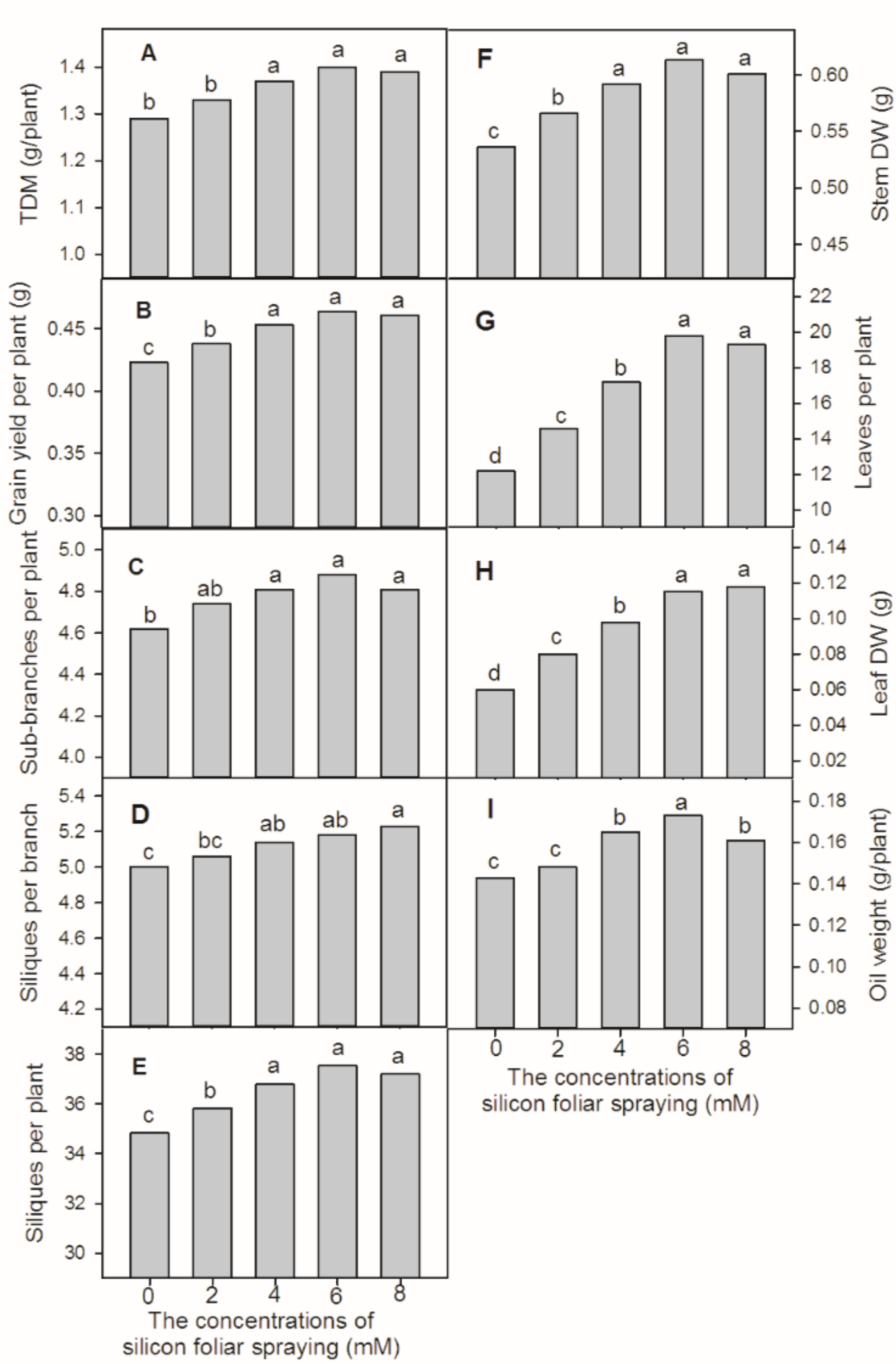



**Figure 1. Mean comparison of silicon foliar application concentrations for some traits of camelina (Duncan test, P≤0.05).**

Mild and severe salinities decreased the number of leaves per plant by about 29 and 34%, respectively, compared to the control (Fig. 4B). The highest number of leaves per plant (19.7 leaves) was obtained in silicon 6 mM, which was not significantly different from 8 mM. The effect of silicon foliar application increased the number of leaves per plant, so that concentrations of 2, 4, 6, and 8 mM raised the number of leaves per plant by 19, 41, 62, and 58%, in the same order, to compare the control treatment (Fig. 1G).

The mean comparison illustrated that the mild and severe salinities caused to 20 and 46% decrease in leaf dry weight compared to the control, respectively (Fig. 4C). Silicon foliar application, at all concentrations, increased leaf dry weight. The leaf dry weight increased with increasing silicon concentration (Fig. 1H).

The average comparison of salinity × camelina genotype showed that the oil weight per plant in non-saline treatment for line-84 was higher than Soheil cultivar. But, in the mild and severe salinity treatments, Soheil cultivar and Line-84 had no significant difference. Salinity decreased the oil weight per plant. So, the oil weight per plant decreased by about 44 and 46% in mild and severe salinities compared to the control, respectively (Fig. 2K). Spraying silicone increased the oil weight per plant. Foliar spraying of silicon in concentrations of 2, 4, 6 and 8 mM increased the oil weight per plant by about 3, 15, 21 and 12%, respectively, compared to the control. The highest oil weight per plant was related to silicon foliar spraying 6 mM (Fig. 1I).

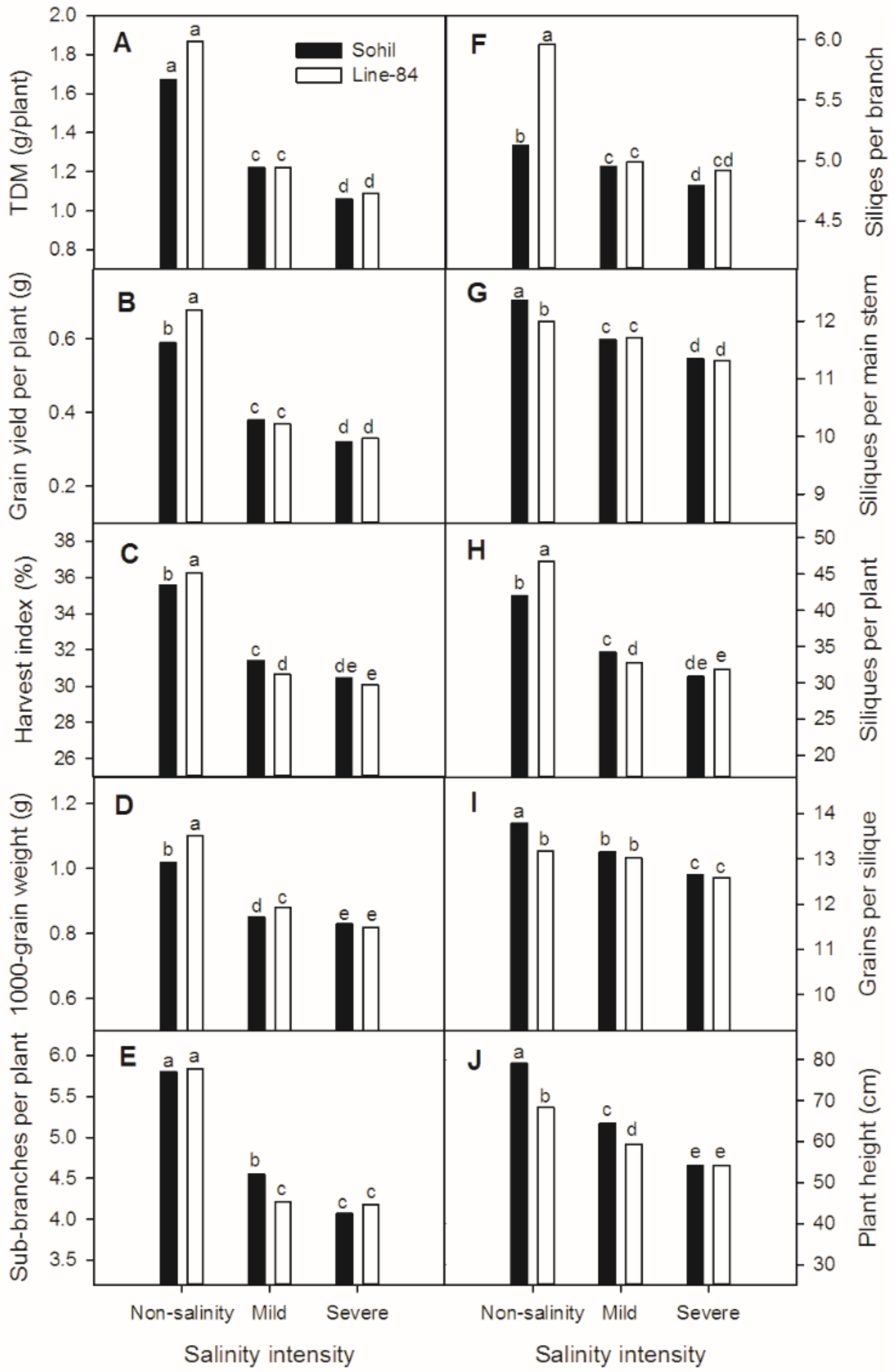
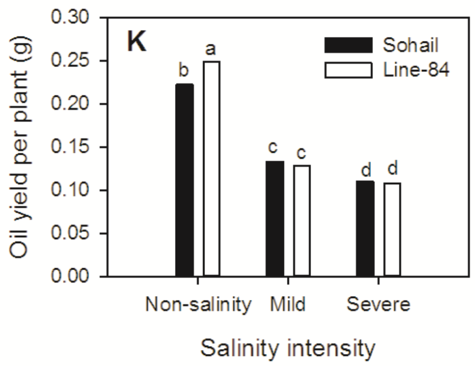



**Figure 2. Means comparison of salinity × camelina genotypes interaction for some traits of camelina (Duncan test, P≤0.05).**




**Continuation of Figure 2. Means comparison of salinity × camelina genotypes interaction for oil weight per plant in camelina (Duncan test, P≤0.05).**

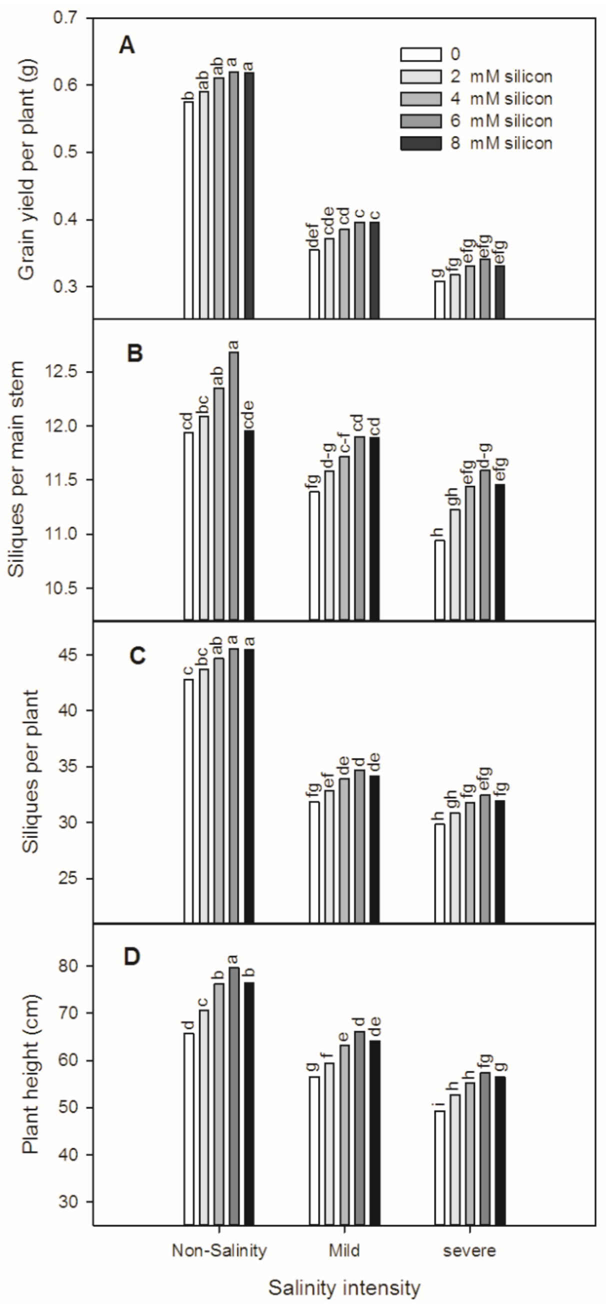



**Figure 3. Means comparison of salinity × silicon foliar application interaction for some traits of camelina (Duncan test, P≤0.05).**

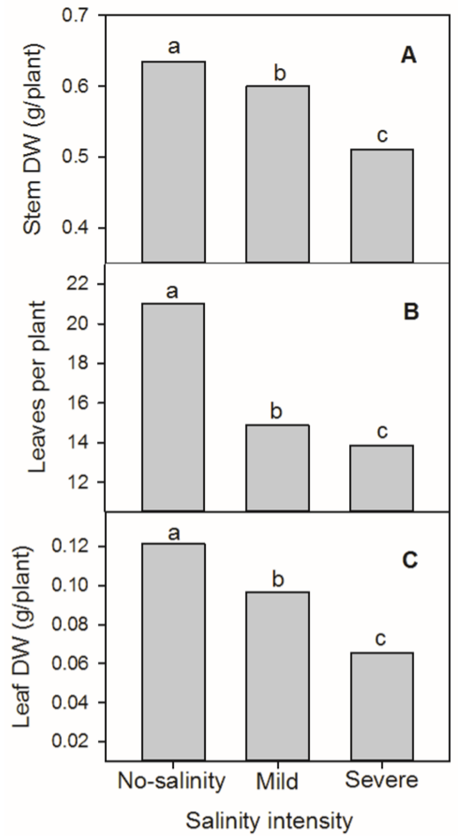



**Figure 4. Means comparison of salinity intensities in terms of stem dry weight, the number of leaves per plant, and leaf dry weight (Duncan test, P≤0.05).**

### *3.4. Total dry matter (TDM), grain yield per plant, harvest index (HI)*

The silicon foliar application increased TDM compared to the control. The application of silicon caused to increase in photosynthesis and TDM by affecting the plant height and the number of leaves. Gong et al. (2003) found that the use of 7.14 mM sodium silicate per 8 kg soil leads to rising wheat leaf area (by 8.3 $cm^2$/plant) and TDM (45.3 mg). TDM in both camelina genotypes was affected by salinity stress and TDM decreased compared to the control condition. It seems that salinity stress has reduced the water absorption and root development, followed by the reduction of leaf water, stomata closure, and also a decrease in the grain weight per plant as TDM components. On the other hand, the drawbacks of salinity on the leaves and stems growth led to a decrease in TDM. It has been reported that the reduction of chlorophyll content, stomatal conductance and net photosynthesis under stress conditions can lead to biomass reduction (Liu *et al.*, 2004). Decreasing photosynthesis and excessive energy use to control the salinity stress to establish ionic and osmotic balance and prevent ions toxicity are the main reasons for TDM reduction (Chartzoulakis and Klapaki, 2000). Reduction of TDM due to salinity stress has been reported in wheat, too (Kerepesi and Galiba, 2000).

Salinity stress decreased the grain weight per plant in both camelina genotypes. Under salinity stress, the limitation of water and nutrient absorption leads to a decrease in the availability of photosynthetic substances for vegetative and reproductive organs. Researchers reported that compatible soluble substances such as proline and glycine betaine are produced due to salinity. These materials are made to increase salinity tolerance, which has high carbon content and therefore indirectly reduces growth. On the other hand, plant growth reduces under salinity conditions due to spending a lot of energy on ion transportation (Taiz and Zeiger, 2002). Kaya et al. (2006) said that salinity affected the vegetative and reproductive growth of spinach and decreased TDM and yield. The adverse effects of salinity on plant growth occur through the reduction of the soil osmotic potential, the nutritional disturbance, the effects of specific ions or their combinations (Ashraf and Harris, 2004). salinity stress has disturbed the growth, flowering and flower fertility, which caused to decrease in the grain weight per plant and finally the harvest index. The application of silicon caused to increase in camellia yield components, including the number of siliques per plant, the number of grains per silique, the 1000-grain weight, and finally the seed weight per plant. Silicon causes anatomical changes in plants through deposition in the cell wall (Ma and Takahashi, 2002). The deposition of silicate crystals in the epidermal cells makes the leaves strong and reduces water loss through the cuticle. As a result, silicon can be useful in stressful conditions where plant growth is affected by the reduction of cell water (Liang *et al.*, 2007). It has been reported that the use of silicon causes increased photosynthesis and grain yield (Chen *et al.*, 2011; Gottardi *et al.*, 2012). Previous studies have shown that silicon has positive efficacy on plant growth and yield (Miao *et al.*, 2010). Lee et al. (2010) said that adding 2.5 mM silicon to hydroponic soybean plants improved significantly growth characteristics under salinity stress and reduced the adverse effects of NaCl.

*3.5. 1000-grain weight, the number of sub-branches, siliques per branch, siliques per main stem, siliques per plant, grains per silique*

The 1000-grain weight decreased in both genotypes under salinity conditions. The 1000-grain weight is the last yield component that is formed during the post-anthesis stages. The 1000-grain weight depends on the rate and the length of grain filling period and is provided by two sources: current photosynthesis and remobilization of storage assimilate (Diepenbrock, 2000). It seems that changes in the synthesis and stability of photosynthetic pigments due to salinity stress lead to the reduction of the fertile flowers and the 1000-grain weight. Shabani et al. (2012) investigated the effect of salinity stress on rapeseed for two years. In the first year, the salinity was 0.6, 4, 7, and 10 dS/m, and in the second year, 0.6, 4, 8, and 12 dS/m were applied. The results showed that the increase in salinity intensity caused to decrease in the dry weight, the plant height, the grain production, the 1000-grain weight, the grain oil and the amount of protein.

The silicon foliar application at all concentrations increased the number of sub-branches compared to the control. the number of sub-branches per plant is influenced by genetics and environment. Sub-branches formed from the main stem have a great effect on grain yield. The increase in sub-branches by silicon foliar application can be caused by increasing the plant height and vegetative growth. Salinity stress in both genotypes caused a decrease in the sub-branches and the siliques per branch. Salinity stress affects plant growth by reducing osmotic potential and disrupting water and nutrient absorption due to the effects of sodium and chlorine. In saline conditions, the restriction of water and nutrient absorption leads to a decrease in the assimilated content and its partitioning to the reproductive organs, and finally it leads to the falling of flowers and fruits. Gan et al. (2004) reported that the grain yield was affected by salt stress because of a decrease in the number of siliques per plant and the grain weight. Environmental factors have a greater impact on the number of siliques per plant than genetic factors (Diepenbrock, 2000). The number of siliques in camelina is determined at the flowering. Salinity accelerates flowering and shortens the grain-filling duration, so it causes less vegetative growth and photosynthetic assimilates production, which finally leads to a decrease in the number of siliques per plant.

Application of silicon under salinity stress increased the number of siliques per plant than the non-stress conditions. The stages of reproductive development such as pollination and grain filling are the most sensitive stages of plant growth to salinity stress, so any reduction in water supply will reduce the absorption of nutrients, the photosynthetic substances production and transfer them to the grains. The positive effect of silicon can be due to increasing photosynthesis and reducing the effects of salinity stress. Ma (2004) stated that silicon is deposited under the leaf cuticle and reduces transpiration. Silicon reduced the transpiration rate by up to 30% in rice. Application of silicon improved plant growth under salt stress conditions in sweet potato (Haghighi and Pessarakli, 2013). The decrease in the number of siliques per plant under salt stress is due to the decrease in the leaf area and photosynthesis. This declines the grains per plant. Romero-Aranda et al. (2006) showed that the application of silicon led to an increase in the leaf area and photosynthesis in tomato under salt stress. Ma (2004) reported that the use of silicon led to a reduction in the effects of stress, which led to an increase in the stem and leave growth and the of grains per silique.

*3.6. Plant height, stem dry weight, the number of leaves per plant, leaf dry weight, and oil production*

It seems that the salinity stress by disrupting photosynthesis, prevents the plant from full potential. Also, the salinity stress increases the competition for the partitioning of photosynthetic assimilates among the plant aerial and terrestrial parts, plant allocates a smaller amount of assimilates to the aerial part, which reduces the stem height. Reduction of stem length and leaf area due to salinity has been reported in sorghum, too (de Lacerda *et al.*, 2003). Past studies show that due to salinity stress, plant height and leaf area decrease faster than other morphological parameters (Munns, 2002). Silicon foliar spraying in all concentrations increased the plant height compared to the control. A decrease in the stem and root dry weight in barley has been reported, too (El-Tayeb, 2005). Salinity stress decreased the stem dry weight, the number of leaves per plant and the leaf dry weight, on the other hand, the Silicon foliar application increased the stem dry weight, the number of leaves per plant and leaf dry weight compared to the control. Hernández et al. (2001) reported that salinity stress leads to a decrease in the fresh and dry weight of leaves, stem and root in pea plants. Liang et al. (2003) reported that the plant fresh and dry weights of barley (*Hordeum vulgare* L.) decreased when the plant was under saline conditions, but this negative effect of salinity stress was reduced by adding silicon. Hashemi et al. (2010) have reported increasing the growth of rapeseed (*Brassica napus*) under salinity stress with silicon foliar spraying. Silicon has a beneficial effect on the growth, height and yield, as well as on the physiology and metabolism of crops (Gong *et al.*, 2003).

The oil weight per plant decreased under salinity conditions. The grain oil content is a genetic characteristic. The origin of grain oil production is the photosynthesis process. Any factor (such as salinity) that reduces photosynthesis, causes a decrease in grain oil content and finally oil weight per plant. The grain weight and the grain oil content are two components of the oil weight per plant. Silicon foliar spraying with positive effects on these two components causes an increase in the oil weight per plant.

## 4. Conclusion

In most regions of the world, soil and water salinity are often observed. The results of this experiment illustrated that the salinity stress affected the vegetative and reproductive growth of camelina and caused a decrease in grain production and its components. To find the maximum grain yield and yield components under salt stress conditions, the silicon foliar spraying at 6 mM concentration had the greatest effect. Silicon foliar application reduced the adverse effects of salinity stress by affecting the growth, the siliques per plant and the grains per silique. Silicon foliar application under salinity stress conditions increased grain yield compared to non-salinity stress conditions. So, the silicon foliar spraying of 2, 4, 6 and 8 mM compared to the control increased grain yield 2.78, 6.26, 7.82 and 7.47% under non-salinity, 4.5, 8.73, 11.54 and 11.26% under mild-salinity, and 3.24, 7.46, 10.71 and 8.11% under severe salinity stress, respectively. In general, silicon foliar application leads to improvements in the growth and grain yield of camelina under salt stress conditions.

## Conflict of interests

All authors declare no conflict of interest.

## Ethics approval and consent to participate

No human or animals were used in the present research.

## Consent for publications

All authors read and approved the final manuscript for publication.

## Availability of data and material

All the data are embedded in the manuscript.

## Authors' contributions

All authors had an equal role in study design, work, statistical analysis and manuscript writing.

## Informed consent

The authors declare not to use any patients in this research.

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