

Foliar Application of Silicon Alleviates Adverse Effect of Drought Stress by improving Growth, Physiological attributes, and Antioxidant Defense of Camelina (Camelina sativa L.) and Canola (Brassica napus L.)

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Abstract

Purpose: Drought stress is a global phenomenon that poses harmful impacts on crop growth and development leading to yield losses in oilseed crops. Canola and camelina are highly sensitive to drought stress. The present study investigated the role of foliar-applied silicon to alleviate the harmful effect of drought stress in camelina and canola genotypes.

Methods: Different concentrations of silicon (Si) foliar applications (NS= no spray, WS= water spray, Si-2= 2 mM Si, Si-4= 4 mM Si, Si-6= 6 mM Si) were used along with different levels of drought stress i.e., control (100% field-capacity) and drought stress (50% field-capacity), for two genotypes of camelina (611 and 618) and two canola genotypes (Super and Rachna).

Results: Drought stress caused marked reductions in the growth of canola and camelina genotypes as compared with control-100% field capacity. Compared to control, drought stress decreased shoot length of canola and camelina by 25% and 28%, respectively. Physiological attributes were also decreased under drought stress as photosynthetic rate, relative water content (RWC), and chlorophyll content were decreased by 39, 38 and 42% in canola and 35, 45, and 39% in camelina, respectively, as compared to control. Drought stress was found to increase the oxidative damage in both crops. Foliar applications of Si improved the morpho-physiological and biochemical attributes in canola and camelina genotypes as compared to NS. Silicon applications at 4 mM upregulated the activities of catalase, superoxide dismutase, and peroxidase were increased by 16, 18, and 12% in canola and 17, 14, and 15% in camelina respectively, reducing the electrolyte leakage as compared to NS. Under drought stress, maximum improvements in plants performances were observed when Si was foliarly applied at 4 mM followed by 6 mM and 2 mM. Among the genotypes, canola genotype Rachna showed better performance as compared to Super, while camelina genotype 618 showed better performance as compared with 611.

Conclusion: In crux, Si foliar application particularly at 4 mM improved the morpho-physiological and biochemical attributes in canola and camelina genotypes under drought-stressed conditions. The better growth and greater stress tolerance of Si-applied plants was attributed to maintenance of plant water status and photosynthetic pigments, lower oxidative damage, and higher activities of antioxidant enzymes under drought.

1. Introduction

Drought is considered as one of the major contributors to significant yield losses that affect both agricultural production and crop quality, making drought stress one of the biggest threats to global food security [1, 2, 3]. Drought stress reduces growth in a variety of commercially important crops, by negatively affecting plant morphological and physicochemical attributes [4, 5]. The photosynthetic ability was negatively impacted by drought-stressed conditions, specifically because of a reduction in the surface area of the leaf and stomatal conductance, which limited fruit growth and reduced the seed yield [6].

Oilseeds are a significant class of crop plants that are essential to both industry and human sustenance. Canola (*Brassica napus* L.) contains approximately 35% of seed oil and 42–45% of protein. When compared to other oilseed crops like soybean, corn, sunflower, and canola oils have a higher nutritional value as it contains high content of polyunsaturated fatty acids (linoleic acid and linolenic acid) [7]. Abiotic stresses may have different kinds of impacts on canola genotypes [8, 9, 10]. Ling et al. [11] revealed that canola yield was significantly affected by 30% under drought stress that could negatively affect the oil quality. In canola, drought stress greatly damages the photosynthetic machinery, plant physiological characteristics, plant growth, leaf expansion, stomatal conductance, stem elongation, and chlorophyll concentration [12].

Camelina (*Camelina sativa* L.) is a cool-seasoned, highly nutritious oilseed with low input requirements and oil potential of 35–45%. Camelina oil has unique characteristics including the presence of 90% of unsaturated fatty acids with a higher percentage of polyunsaturated fatty acids (60%) [13, 14, 15]. Even though it is still a new crop, camelina is far more resilient in terms of input needs, load, and resilience to stressed conditions than its “sister crop,” oilseed [16, 17, 18]. The camelina cultivation area is further expanded due to winter and spring biotypes, which are distinguished on the basis of morpho-physiological parameters at plant and seed levels. According to the literature, camelina may be grown virtually everywhere in the world [19]. George et al. [20] and Ahmad et al. [9] revealed that camelina showed more resistance as compared to oilseed rap under stressful environments, including heat and drought stress.

Due to their limited ability to move, plants are not able to escape from abiotic stress. As a result, they must employ multiple tactics to combat various stressors concurrently, which are typically linked to oxidative stress tolerance [21]. A comprehensive and better understanding of the underlying mechanism of oxidative stress tolerance is important to reduce the damage to morphophysiological and yield attributes of crops [22]. In light of the fact that the resistance of crop plants against drought stress has resulted in the perception of signaling mechanism and subsequent signal transduction that activates a plant defense system based on plant physiological and biochemical attributes. Several defense mechanisms against drought stress have been demonstrated based on antioxidant activities or metabolite accumulation [23, 24]. Furthermore, results have demonstrated that drought stress may lead to a decline in dry matter production and a decrease in leaf area, both of which are essential for photosynthesis [25]. Therefore, a proper mechanism to improve morphophysiological and biochemical attributes, and yield parameters under drought stress is required.

Silicon (Si) is the 2nd most predominant element in the earth crust (Epstein 1994) [26]. Its build-up has been related to better growth in plants, especially those under stress, even though it is not thought of as a necessary element in plants [27]. Silicon applications can ameliorate the negative impacts of abiotic stresses in plants by acting as a biochemical arbitrator activating hypersensitive reactions in the plant [28]. Its applications may lead to the polymerization of the cell wall and reparation of the cell membrane to minimize electrolyte leakage [29, 30], and uphold the photosynthetic efficiency by improving the quantum productivity of functional leaf area and photosystem II [31, 32]. According to reports, some cultivars of the *Gramineae* family that are drought-tolerant can deposit Si in endodermal tissues under drought stress [33, 34]. The depositions of Si on a cuticular layer may lead to reducing

transpiration due to the hydrophilic behavior [35] of Si which may lead to reducing the loss of water by controlling stomatal conductance may be the mechanism to maintain the production of plant dry matter accumulation under drought stress [36, 37]. Furthermore, polar and polymerized silicic acid creates H-bonds between hydrated silica and water in epidermal cell walls to reduce water molecule evaporation from leaf structure and maintain the plant's water status [38, 39, 40]. Saja-Garbarz et al. [30] have reported the role of Si application to improve root water uptake by upregulating the expression to encode the genes related to aquaporin. Silicon promotes the quality of crop yield by regulating the reproductive and vegetative growth in plants. The presence of silicon content can alter the concentration of lignin and cellulose in different plant parts [42, 43]. Silicon reduces the loss of water through transpiration under stressed conditions by thickening the cuticle layer of the leaf, making it harder to survive in a stressed environment by improving the gas exchange attributes in plants [44, 45]. Results of several studies have shown that Si applications can ameliorate the deleterious impacts of stressed conditions by upregulating plant defense [46, 47]. Henceforth, Si treatment may regulate the ability of plants to survive drought to maintain crop growth and yield. The Si treatment can therefore be a useful strategy for reducing water requirements and improving the ability of plants to withstand drought. Furthermore, because of its noncorrosive and nonpolluting nature, Si could be a high-quality fertilizer for sustainable agriculture. The numerous advantages of using Si under drought stress that was just described have increased its significance in agriculture [48, 49]. The supplementation of Si resulted in to prevention of harmful effects of drought stress, mainly due to the upregulation of antioxidant defence. Additionally, Si supplementation can enhance the effectiveness of water consumption during drought stress, for instance, by increasing stomatal conductance, which in turn enhances the rate of photosynthetic activity [50, 51]. As water use efficiency can be improved due to its relation to the total water transpired through the plant's leaves, which reduces the water loss from the cuticle [29, 52].

In order to enhance plant drought tolerance, Si applications are projected to become more popular in agricultural farming. However, the effect of Si on morpho-physiological attributes in oilseed crops especially canola and camelina need to be studied. It was hypothesized that the applications of Si may improve the drought stress tolerance in oilseed canola and camelina. The objective of this study was to evaluate if silicon applications could improve growth by maintaining the plant's physiological attributes and chlorophyll contents in canola and camelina under drought stress. The influence of silicon on the plant gas exchange characteristics, water relations, and photosynthetic pigments was investigated.

2. Materials and Methods

2.1. Plant Materials, Experimental Treatments and Design, and Plant Husbandry

In this study, the canola genotypes (Super and Rachna) and camelina genotypes (611 and 618) were sown in pots (35 × 20 cm) having a capacity of 5 kg filled with soil (Table 1). Canola seeds were obtained from the Ayub Agriculture Research Institute, Faisalabad, Pakistan, and camelina seeds were obtained from the Department of Agronomy, University of Agriculture, Faisalabad. In each pot, 10 seeds were sown in the soil under well-watered conditions and maintained only 5 plants per pot after emergence, and then the pots were divided into two groups, including well-watered pots and drought-stressed pots. The well-watered plants were grown at 100% FC and drought stress was imposed by withholding water at 50% FC at vegetative stage of the crops.. For the drought treatment, the 100% field capacity and 50% field capacity were maintained on weight basis. The Si concentrations were NS = no spray, WS = distilled water spray, Si-2 = 2 mM, Si-4 = 4 mM, Si-6 = 6 mM. The foliage spray of Si was performed by using a sprayer manually and 1.6 mL of Si solution was applied in each treatment per pot in the phenological stage in canola at BBCH scale code-40, Principal growth stage 4: development of harvestable vegetative parts [53, 54] and in camelina at BBCH scale code-40, Principal growth stage 4: development of harvestable vegetative parts [55]. Distilled water spray was used as the control treatment and the pH of distilled water and Si solution was maintained at 5.5 ± 0.2 by using of HCL/NaOH (1.0 mol L^{-1}) solutions. However, plant nutritional requirements were fulfilled by applying Hoagland's solutions. Hoagland's solution with full-strength along with the water was applied at sowing, while, half-strength was applied throughout crop growth to remove the odds of nutrient toxicity every fortnight [56].

2.2. Parameters recorded

2.2.1. Growth Parameters

To measure the growth parameters were measured by randomly selecting and uprooting the two plants from each replicated pot. The roots were cleaned by using distilled water and the length of plant roots and shoots measured of the same two plants by using a meter rod. The fresh weights of roots and shoots and plant dry weight were measured of the same randomly selected plants with a digital balance. Root and shoot dry weight were measured by drying them at 65°C in an oven after sun drying until constant weight.

2.2.2. Water Relations

The fully expanded and youngest leaves of camelina and canola were harvested from each biological replicate to measure the water relations. A scholande-type pressure chamber was used to measure the water potential ψ_w . The osmotic potential ψ_o was measured with an osmometer (Wescor-5500, USA) from the frozen leaves. The turgor potential (ψ_p) was calculated using the following equation:

$$\psi_p = \psi_w - \psi_s$$

The water status of plant leaves was determined by measuring the plant's RWC. The topmost and fully expanded leaves were selected and detached from randomly selected plants and fresh weight (FW) was recorded instantly. Then, the turgid weight (TW) was recorded by dipping the samples in distilled

water for 24 hours. Finally, the samples were dried at 70°C for 24 hours to record dry weight (DW). Finally, RWC was calculated using the following equation as used by Ahmad et al. [9];

$$RWC = \left[\frac{FW - DW}{TW - DW} \right] \times 100$$

2.2.3. Gas Exchange Attributes

The photosynthetic rate (A), intercellular CO₂ concentration (C_i), stomatal conductance (g_s), and transpiration rate (E) were measured by following the mechanism used in Ahmad et al. [9] by using portable infrared gas analyzer (IRGA) (Analytical Development Company, Hoddesdon, England).

2.2.4. Photosynthetic pigments

The canola and camelina samples were randomly selected to measure chlorophyll content. Using a scissor, the leaves of randomly selected plants were cut off. Arnon [57] and Davies [58] described the method to measure the chlorophyll contents of fresh plant leaves. The fresh plant samples weighing 0.1 g of 0.5 cm pieces and crushed in acetone (80%; 10 mL) at 0°C. The supernatants were then centrifuged for five minutes at 15,000 rpm. By using a spectrophotometer (Hitachi, 220, Japan), the absorbance of chlorophyll content was measured at wavelengths 663, 645, and 652 nm, respectively.

2.2.5. Electrolyte Leakage and Antioxidants

Electrolyte leakage was determined by following the procedure of Dionisio-Sese and Tobita [59]. Samples were chopped into pieces of 4 mm and placed them in a test tube after filling it with distilled water and heated them at 32°C and electrical conductivity (EC₁) was noted and over again the sample was heated at 121°C and EC₂ was noted to measure EL.

The procedure proposed by Giannopolitis and Ries [60] was used to measure the activity of superoxide dismutase (SOD). The sample solution was prepared methionine, nitroblue tetrazolium (NBT), ethylenediaminetetraacetic acid (EDTA), riboflavin, and potassium phosphate buffer with enzyme extract (20–50 µL) at 7.8 pH. the fluorescent lamp was used to irradiate the reaction solution in test tubes for 15 minutes. The absorbance was read by using a spectrophotometer at 560 nm to note the activity of SOD.

Chance and Maehly [61] proposed a procedure to measure the activity of catalase (CAT) and peroxidase (POD). Plant samples and potassium phosphate (50 mM) were homogenized. The assay solution was made by mixing C₆H₄ (20 mM), KH₂PO₄ buffer (pH 7.0; 50 mM), enzyme extract (0.1 mL), and H₂O₂ (40 mM) to measure POD activity. The spectrophotometer was used to measure the absorbance at 470 nm at every 20s. Catalase activity was measured by preparing the assay solutions by mixing phosphate buffer (pH 7.0; 50 mM), H₂O₂ (5.9 mM), and enzyme extract (0.1 M). The absorbance was measured by using a spectrophotometer at 470 to note CAT activity was noted at every 20s.

2.3. Statistical Analysis

Analysis of variance (ANOVA) technique was used to analyze data by using Statistix 10.0 in a factorial experiment, laid out under completely randomized design (CRD) and three replications. The mean comparison at 5% level of significance was performed by using the least significant difference test [62]. The Sigma-Plot 10.0 software was used to draw figures.

3. Results

Results have revealed that drought stress negatively affected the performance of canola and camelina genotypes. However, Si applications improved the performance of canola and camelina genotypes under drought stressed conditions. Furthermore, the combination of Si application under drought stress has shown a significant effect on plant performance in canola and camelina genotypes (Figs. 1-4; Tables 2-7).

3.1 Growth attributes

The results have stated that the growth attributes were significantly ($P \leq 0.05$) affected under Si applications and drought stress in canola and camelina genotypes (Tables 2-3). Plant growth attributes were decreased, including shoot length, shoot and root fresh weight, and shoot and root dry weight by (25, 23, 23, 26, and 22%) in canola and (28, 20, 21, 22, and 19%) in camelina, respectively relative to control-no drought stress, while root length was increased. However, supplementation of Si has shown an ameliorative role in canola and camelina genotypes under drought compared to NS (Tables 2-3). Results have revealed that growth attributes, including shoot and root length, shoot and root fresh weight, and shoot root dry weight were increased by (23, 13, 34, 10, 23, 20, and 20%) in canola and (30, 19, 32, 9, 20, 18, and 25%) in camelina, respectively, as compared to NS. Though, the highest increase in growth attributes was shown in the treatment where Si was foliar applied @ 4.0 mM as compared to 6.0 mM and 2.0 mM. The interaction between silicon foliar applications (Si) × drought stress (D) was significant ($P \leq 0.05$) for all the growth parameters, in canola and camelina except root length in canola which was non-significant. However, higher-order interaction, silicon applications (Si) × drought stress (D) × genotypes (G) was significant for root and shoot dry weight in camelina and shoot fresh weight and root dry weight in canola while other attributes were non-significant.

3.2. Water relations

The water relation parameters were significantly ($P \leq 0.05$) affected by Si foliar applications and drought stress in canola and camelina genotypes (Tables 4-5). Plant water relation parameters, including water potential, osmotic potential, turgor potential, and RWC were decreased by 48 and 40%, 21 and 19%, 29 and 30%, 38 and 45%, and 19 and 23% in camelina and canola relative to control. Though, Si foliar applications ameliorated the harmful effect of drought stress in canola and camelina genotypes as compared to no Si application. Results have revealed that water relations were increased under Si applications as water potential and RWC were improved by 15 and 21% in canola and 18 and 22% in camelina, respectively as compared to control-no Si applied. Nevertheless, the most significant improvement in water relations was observed in the treatment where silicon was foliarly applied @ 4.0 mM as compared to 6.0 mM and 2.0 mM. The interaction Si $\times$ D was significant ($P \leq 0.05$) for water relations in canola and camelina. However, higher-order interaction, Si $\times$ D $\times$ G was significant for water potential in canola and turgor potential in canola and camelina.

3.3 Gas exchange parameters

Results have revealed that gas exchange attributes were significantly ($P \leq 0.05$) affected by Si applications and drought-stressed conditions in canola and camelina genotypes (Tables 4-5). Gas exchange parameters, including photosynthetic rate (P_n), stomatal conductance (g_s), transpiration rate (T_r), and sub-stomatal CO_2 concentration (C_i) were decreased by 39, 25, 26, and 32% in canola and 35, 24, 22, and 22% in camelina, respectively as compared to control-no drought stress. However, Si applications enhanced the photosynthetic pigments in canola and camelina genotypes as compared to NSs (Tables 4-5). Results have revealed that gas exchange parameters, including P_n , g_s , T_r , and C_i were increased by 9, 8, 8, and 10% in canola and 16, 9, 8, and 7% in camelina as compared to NS. Nevertheless, the most significant improvement in water relations was observed in the treatment where silicon was foliarly applied @ 4.0 mM as compared to 6.0 mM and 2.0 mM. The interaction Si $\times$ D was significant ($P \leq 0.05$) for T_r in canola and P_n in camelina. However, higher-order interaction, Si $\times$ D $\times$ G was non-significant for gas exchange attributes in canola and camelina.

3.4 Photosynthetic pigments

Photosynthetic pigments were significantly affected by Si applications and drought-stressed conditions in canola and camelina genotypes (Tables 6-7). Results have revealed that photosynthetic pigments, including total chlorophyll and carotenoid contents, were decreased by 42 and 18% in canola and 39 and 14% in camelina, respectively compared to drought conditions. However, Si applications attenuated the negative effect of drought stress in canola and camelina genotypes as compared to control-no Si applied. Results have revealed that photosynthetic pigments, including total chlorophyll and carotenoid contents, were increased by 20 and 35% in canola and 18 and 23% in camelina, respectively as compared to control-no Si applied (Tables 6-7). Nevertheless, the most significant improvement in photosynthetic pigments was observed in the treatment where silicon was foliarly applied @ 4.0 mM as compared to 6.0 mM and 2.0 mM. The interaction Si $\times$ D was significant ($P \leq 0.05$) for photosynthetic pigments in canola and camelina. However, higher-order interaction, Si $\times$ D $\times$ G was significant for total chlorophyll content in camelina, while, non-significant for other photosynthetic pigments in canola and camelina.

3.5 Electrolyte leakage

Electrolyte leakage (EL) was significantly affected by Si applications under drought-stressed conditions in canola and camelina genotypes (Tables 6-7). Results have revealed that EL was increased in canola and camelina under drought stress conditions. However, Si applications reduced the EL in canola and camelina genotypes as compared to NSs. Results have revealed that EL was decreased by 12% in canola and 12% in camelina, respectively as compared to NS (Tables 6-7). Nevertheless, the most significant reduction in EL was observed in the treatment where silicon was foliarly applied at 4.0 mM as compared to 6.0 mM and 2.0 mM. The interaction G $\times$ D was significant ($P \leq 0.05$) for EL in canola and camelina. However, higher order interaction, Si $\times$ D $\times$ G was non-significant for EL in canola and camelina.

3.6 Antioxidants

The activities of antioxidants were significantly affected by Si applications under drought-stressed conditions in canola and camelina genotypes (Tables 6-7). Results have revealed that the activity of SOD, POD, and CAT improved in canola and camelina as compared to drought stress. In addition, Si applications improved the activities of SOD, POD, and CAT as compared to NSs. Results have revealed that SOD, POD, and CAT activities were increased by 13, 9, and 11% in canola and 10, 11, and 14% in camelina, respectively as compared to NS (Tables 6-7). Nevertheless, the most significant improvement in antioxidants was observed in the treatment where silicon was foliarly applied @ 4.0 mM as compared to 6.0 mM and 2.0 mM. The interaction Si $\times$ D was significant ($P \leq 0.05$) for SOD in canola and POD in camelina. However, higher order interaction, Si $\times$ D $\times$ G was non-significant for antioxidants activities in canola and camelina.

4. Discussion

Maintenance of morphophysiological parameters under the challenge of climate change is a critical approach for successful crop production [63, 64]. Plant growth and physiological parameters were reduced under drought-stressed conditions in camelina and canola genotypes and maximum reduction was observed in sensitive genotypes. Silicon improves plant hydration and water use efficiency while shielding plants from the damaging effects of intermittent drought stress due to the upregulation in the activities of antioxidants [65]. The drought stress disrupted several plant biological processes, including the rate of carbon assimilation, turgor pressure, and leaf gas exchange parameters, which ultimately led to disturbed plant functioning [66]. Foliar applications of Si significantly improved the morphology of the shoots and roots (length and weight) by improving the physiological and biochemical characteristics of the two oilseeds. Silicon has a vital role in controlling carbon assimilation in addition to physiological changes by enhancing the antioxidant defense system [67, 68].

Drought stress at the vegetative stage of plants showed a rigorously harmful impact on growth attributes as compared to control-100% FC and maximum reduction was observed in growth attributes observed at no Si applications. Among the genotypes, more reduction in plant growth parameters was observed in canola genotype-Super and camelina genotype-611 as compared to Rachna and 618, respectively. Plant growth was reduced due to drought stress by impairing photosynthetic pigments and disturbing the water relation parameters in both crops leading to reduce photosynthetic rate, cell expansion, and assimilate partitioning [69, 70]. Li et al. [71] results manifest the harmful impact of drought stress on shoot length due to the impairment in plant water status and photosynthates formation. The biomass production was significantly decreased due to the reduction in cell division, decreased enzymatic activities, and photosynthetic rate [72, 73]. However, applications of Si played an important role to counteract the harmful effects of drought stress. Results have revealed that Si application improved the growth and development in canola and camelina genotypes with more improvement observed in tolerate genotypes including Rachna in canola and 618 in camelina as compared to control-no Si applied. Silicon applications induced plant protection by regulating the biochemical mechanism which induces metabolic alterations under to stress conditions [74, 75]. Among Si concentrations, maximum improvement was observed when Si was applied @ 4 mM followed by 6 mM and 2 mM, respectively, as shoot length was increased by 20, 12, 8% in canola and 26, 19, and 12% in camelina at 4 mM, 6 mM and 2 mM Si applications, respectively. Silicon application improved biomass production in both drought-resistant and sensitive genotypes [76, 77].

The gas exchange attributes were significantly affected under drought conditions in canola and camelina genotypes as compared to control-100% field capacity. More reduction in gas exchange attributes was observed in sensitive genotypes of canola-Super and camelina-611 as compared to tolerance genotypes Rachna and 618, respectively. Drought stress led to reduced crop growth and yield due to a significant reduction in photosynthetic efficiencies of plants predominantly occurred due to a reduction in the availability of CO₂ in response to the closure of stomata (limitations in stomata functioning) and the inhibitions in carbon assimilation metabolism (limitations in plant metabolism) due to reduced plant water status [78, 79]. Stomatal closure was widely believed to be the primary factor contributing to reduced photosynthesis during mild to moderate drought throughout the previous ten years [47]. However, it also reduces CO₂ diffusion into the leaves, lowering the net photosynthetic rate [80,81]. Silicon applications improved the gas exchange, including *gs*, *A*, and *E* as compared to the plants with no silicon under drought. Silicon treatment resulted in an increase in photosynthetic efficiency under stressful conditions due to the upregulation of RuBP carboxylase activities [82, 83]. By maintaining gas exchange parameters and the construction of xylem vessels despite high transpiration rates, plants under Si applications demonstrated high tolerance to drought conditions [84, 85]. Results have revealed that all of these characteristics can be employed as physiological markers for the tolerant genotype selections [86, 87]. Under conditions of low water availability, however, *Pn* increased under Si applications due to the improvement in chlorophyll levels and the activity of photosynthetic enzymes like Rubisco and Nicotinamide adenine dinucleotide phosphate (NADP⁺) dependent glyceraldehyde-3-phosphate dehydrogenase (GAPDH) [88, 89]. Results have revealed that drought stress led to reducing plant water status in canola and camelina genotypes. However, Si applications helped to impart the drought stress in canola and camelina genotypes as compared to NSs with a significant increase observed when Si was applied at 4 mM as compared to 6 mM and 2 mM. Additionally, Si substantially influences stomata movement, which influences transpiration rate [90, 91]. The stomatal regulation under drought-stressed conditions to reduce transpirational losses allows the plants to regulate hydraulic conductance but limits the intake of carbon dioxide ultimately reducing the production of carbon assimilates and their translocation in canola [92, 93]. Zargar et al. [94] also observed a significant reduction in photosynthetic efficiency by 50% due to the reduction in plant water status. The interaction between stomatal regulation and cuticular water permeability is primarily responsible for this decrease in water loss under drought conditions [95, 96]. Foliar applications of Si can be used safely because they create a motorized barricade on the leaf surface to maintain plant water status to support plant growth and development [97].

Photosynthetic pigments were reduced under drought-stressed conditions as compared to control-100% FC. Drought stress often damages chlorophyll contents which led to reduced photosynthetic efficiency due to the damage to photosystem-I and photosystem-II [98]. The common observation of drought stress is the reduction in chlorophyll content in plant parts; furthermore, drought stress causes a decline in other photosynthetic pigments, including carotenoid biosynthesis [99]. Furthermore, sensitive genotypes showed minimum chlorophyll content due to photo-inhibition in photosystem II as compared to tolerant genotypes which showed maximum chlorophyll contents [100, 88]. However, foliar applications of Si improved the stomatal conductance in plant leaves helped the plants to regulate the rate of photosynthesis improving drought stress tolerance (Results have revealed that Si applications improved the photosynthetic efficiency of plants by upregulating gaseous exchange parameters under drought stress [82]. The supplementation of Si may attenuate the negative impact of drought stress by upregulating the accumulation of ROS due to the activities of ROS detoxification systems and improving the photosynthetic pigments [101] due to the conductance of mesophyll and photoassimilate translocation [84, 102].

Drought stress increased the electrolyte leakage in camelina and canola plants due to drought stress-induced oxidative damages. This might happen due to the damages to cell membrane / lipid bilayer. Results have revealed that sensitive genotypes has showed maximum leakages of electrons across membrane as compared to tolerance genotypes in both crops. The maintainance of proper amount of reactive oxygen species due to the active antioxidant defense in lants may help to maintain electrolyte leakages under oxidative damage [103, 104]. However, electrolyte leakage was reduced under Si applications in both crops as highest reduction was observed when Si was applied at 4 mM as compared to 2 mM and 4 mM. The applications of Si improved the cell membrane stability that resulted to reduce cell leakages [105]. The applications of Si helps to increase calcium content in plant leaves, which is necessary to strength the integrity of plasma membrane by regulating oxygen radicles by upregulating axtiioxidant enzymes [106].

Results have revealed that the antioxidant defense system was upregulated under Si applications. Maximum improvement in SOD, POD, and CAT was observed when Si was applied @ 4 mM followed by 2 mM and 6 mM. Results have revealed that the optimum dose of Si was more beneficial as compared to low (2 mM) and high doses (6 mM). Drought-induced overaccumulation of radical oxygens causes in an oxidative explosion. The antioxidant enzymes, including SOD, POD, and CAT keep an balance among the production of ROS and its detoxification processes. Increased antioxidant

enzyme activity is known to help plants protect themselves against drought stress [107]. Results have shown an elevated SOD, POX, and CAT isoform activity during drought stress to help the plants to thrive under anxious conditions caused by drought stress. Nevertheless, the concurrent rise in MDA and H_2O_2 levels cannot be controlled due to enhanced enzymatic activities due to oxidative damage [108]. However, applications of Si under drought stress may act as the best supplement to maintain the ROS accumulation by upregulating the antioxidant defence system even maintaining the oxidative damages under drought stress [109]. Desoky et al. [110] successfully stated that the supplementation of Si improved the antioxidant enzyme activities in plants which helped the plants to cope with the oxidative stress caused by drought stress by scavenging the ROS to maintain plant growth and development. The canola genotype-Rachna and camelina genotype-618 showed a response about plant morpho-physiological parameters under drought-stressed conditions and were identified as drought-tolerant genotypes as compared to the sensitive genotypes; canola genotype-Super and camelina genotype-611 which showed a drastic reduction in plant growth. Hu et al. [111] revealed that Si responses had a favorable impact on development in tolerant genotypes under both control and stressful settings, suggesting that they could be yet another significant component. The applications of Si upregulate stomatal functions which permit some carbon fixation by drought-tolerant cultivars as compared to sensitive genotypes may lead to increased water use effectiveness [112, 113]. According to De Camargo et al. [114], only one out of the four examined genotypes was drought tolerant and showed a significant positive effect on dry matter production when Si was applied under water-deficient conditions. Oilseed crops have also shown similar, genotype-specific effects of Si applications under drought [115, 116].

Rising air and surface temperatures, shifting precipitation patterns, and more frequent and persistent drought events have traditionally been used to describe the prevailing climate-changing patterns [117, 118]. Understanding how Rubisco and its associated properties respond to Si application under drought stress and whether changes in the activity of Rubisco have an impact on net photosynthesis in plants is fundamentally important to forecast the latent effects of future climate change on agriculture and natural ecosystems.

5. Conclusions

Results revealed a significant reduction in the performance of oilseed crops under drought stress. Compared with control, drought severely hampered the plant growth, photosynthetic rate, leaf water status, and photosynthetic pigments. Silicon applications showed a significant effect on plant growth parameters including shoot and root due to the upregulation of plant physiological parameters, including photosynthetic rate and enhanced antioxidant enzyme activities as compared to NS. Among the genotypes, canola genotype-Rachna and camelina genotype-618 were more tolerant as compared to Super and 618, respectively. Our results suggest that the Si applications at 4 mM improved the drought stress tolerance in canola and camelina genotypes. The better growth and greater stress tolerance in this treatment was attributed to maintenance of plant water status and photosynthetic pigments, lower oxidative damage, and higher activities of antioxidant enzymes under drought.

Declarations

Author Declarations

Ethics approval

The authors have no financial or proprietary interests in any material discussed in this article.

Consent to participate.

All authors have given the consent to participate to publish this version of the manuscript

Consent for publication.

All authors have read and agreed to publish this version of the manuscript.

Availability of data and materials.

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Conceptualization (Bilal Ahmad Shahzab and Ejaz Ahmad Waraich); methodology (Saddam Hussain and Muhammad Saleem); software (Bilal Ahmad Shahzab and Ejaz Ahmad Waraich); Formal analysis (Saifullah); Investigation (Bilal Ahmad Shahzab)

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Tables

Table 1: Physio-chemical properties of experimental soil

Characteristics of Soil	Values
Physical properties	
Saturation percentage (%)	39
Soil Texture	Sandy Loam
Chemical properties	
Soil Ph	7.5-7.7
EC (Sd M ⁻¹)	0.75-0.95
Organic matter (%)	0.37-0.60
Ca + Mg (meq L ⁻¹)	3.90-5.70
NO ₃ -N (mg kg ⁻¹)	11.8-13.9
HCO ₃ (meq L ⁻¹)	4.01-4.03
Available P (mg kg ⁻¹)	9.0-10.3
Available Si (mg kg ⁻¹)	40-45
Available K (mg kg ⁻¹)	105-204

Table 2. Impact of Si foliar applications on the growth parameters of two camelina genotypes under drought stress

Drought stress	Genotypes	Silicon	Root length (cm)	Shoot length (cm)	Shoot fresh weight (g)	Root fresh weight (g)	Shoot dry weight (g)	Root dry weight (g)
Control	611	NS	10.9i	39.2j	4.12hij	1.81h	0.60fg	0.059hi
		WS	11.6i	40.0j	4.27fghi	1.85g	0.62f	0.061gh
		Si-2	13.1h	43.8fghi	5.46d	1.92f	0.70de	0.068de
		Si-4	16.8e	50.6b	6.20c	2.05d	0.73c	0.074c
		Si-6	14.6g	46.9cd	5.58d	2.01e	0.68e	0.070d
	618	NS	15.8f	44.4efgh	4.32fghi	1.94f	0.71cde	0.063g
		WS	16.6ef	45.6defg	4.5efg	1.98e	0.72cd	0.066ef
		Si-2	16.7ef	46.3de	5.99c	2.09c	0.77b	0.075bc
		Si-4	22.1b	53.6a	7.87a	2.22a	0.83a	0.086a
		Si-6	19.2cd	48.9bc	7.44b	2.18b	0.78b	0.077b
Drought	611	NS	16.2ef	34.3k	3.87j	1.44o	0.43j	0.048k
		WS	16.6ef	35.6k	4.03ij	1.47no	0.43j	0.049k
		Si-2	18.4d	39.3j	4.28fghi	1.53lm	0.48i	0.054j
		Si-4	21.9b	42.9hi	4.62ef	1.63j	0.62f	0.060hi
		Si-6	19.6c	40.2j	4.46efgh	1.57k	0.57g	0.054j
	618	NS	19.7c	42.4i	3.97ij	1.48n	0.47i	0.050k
		WS	20.1c	43.6ghi	4.19ghij	1.50mn	0.48i	0.054j
		Si-2	21.5b	44.2fghi	4.46efgh	1.57kl	0.53h	0.058i
		Si-4	25.3a	45.8def	4.78e	1.71i	0.68e	0.064fg
		Si-6	22.3b	44.7efgh	4.61ef	1.58k	0.61f	0.058i
LSD (<i>P</i> ≤ 0.05)			0.97	2.01	0.37	0.036	0.031	2.7E ⁻⁰³

Control=no stress, Drought=Drought stress, NS=No Si applied, WS=Distilled water spray, Si-2= Silicon applied at 2.0 mM, Si-4= Silicon applied at 4.0 mM, Si-6= Silicon applied at 6.0 mM, G₁=611, G₂=618, LSD= Least significant difference; ns=Non-significant, * significance at $P \leq$ at 0.05, ** significance at $P \leq$ at 0.01, *** significance at $P \leq$ at 0.001, respectively; Values that have the same case letter or do not have letters do not substantially differ ($P \leq 0.05$).

Table 3. Impact of Si foliar applications on the growth parameters of two canola genotypes under drought stress

Drought stress	Genotypes	Silicon	Root length (cm)	Shoot length (cm)	Shoot fresh weight (g)	Root fresh weight (g)	Shoot dry weight (g)	Root dry weight (g)
Control	Super	NS	12.3j	39.7ij	4.37ijkl	1.58g	0.65fg	0.047fg
		WS	13.1j	41.4hi	4.44hijk	1.62fg	0.68f	0.050ef
		Si-2	16.0i	45.2f	5.65d	1.70d	0.76de	0.055d
		Si-4	20.3f	52.2c	6.45c	1.77bc	0.78cd	0.061c
		Si-6	18.7h	48.4e	6.14c	1.72cd	0.73e	0.057d
	Rachna	NS	15.9i	43.3g	4.57fghi	1.64ef	0.76de	0.049ef
		WS	16.5i	45.1f	4.65fghi	1.68de	0.77d	0.051e
		Si-2	20.3f	51.0cd	6.23c	1.76bc	0.81bc	0.062bc
		Si-4	25.2bc	57.2a	8.11a	1.86a	0.88a	0.073a
		Si-6	22.8d	54.3b	7.51b	1.79b	0.83b	0.064b
Drought	Super	NS	19.2gh	38.2j	4.09l	1.29m	0.49k	0.039j
		WS	19.7fg	39.2j	4.16kl	1.32klm	0.49jk	0.041ij
		Si-2	21.5e	41.4hi	4.52ghij	1.37ijk	0.53i	0.045gh
		Si-4	25.3bc	45.1f	4.87ef	1.40hi	0.67f	0.051e
		Si-6	23.0d	42.6gh	4.71efgh	1.37ijk	0.63gh	0.045gh
	Rachna	NS	22.4de	41.2hi	4.22jkl	1.31lm	0.52ij	0.041ij
		WS	23.2d	42.1gh	4.41hijkl	1.34jkl	0.55i	0.043hi
		Si-2	24.8c	45.4f	4.71efgh	1.39hij	0.61h	0.049ef
		Si-4	28.8a	50.3d	5.03e	1.43h	0.73e	0.055d
		Si-6	25.9b	48.0e	4.86efg	1.38hij	0.66f	0.049ef
LSD (P ≤ 0.05)			0.91	1.78	0.33	0.04	0.03	2.5E ⁻⁰³

Control=no stress, Drought=Drought stress, NS=No spray, WS=Distilled water spray, Si-2= Silicon applied at 2.0 mM, Si-4= Silicon applied at 4.0 mM, Si-6= Silicon applied at 6.0 mM, G₁=Super, G₂=Rachna, LSD= Least significant difference; ns=Non-significant, * significance at $P \leq$ at 0.05, ** significance at $P \leq$ at 0.01, *** significance at $P \leq$ at 0.001, respectively; Values that have the same case letter or do not have letters do not substantially differ ($P \leq 0.05$).

Table 4. Impact of Si foliar applications on the physiological parameters of two camelina genotypes under drought stress

Drought stress	Genotypes	Silicon	Water potential (-MPa)	Osmotic potential (-MPa)	Turgor potential (MPa)	Leaf relative water content (%)	Photosynthetic rate ($\mu\text{mol H}_2\text{O m}^{-2} \text{ s}^{-1}$)	Stomatal conductance ($\mu\text{mol mol}^{-1}$)	Transpiration rate ($\text{mmol H}_2\text{O m}^{-2} \text{ s}^{-1}$)	Sub stomatal CO ₂ concentration ($\mu\text{mol mol}^{-1}$)
Control	611	NS	0.89i	1.13e	0.23hi	59.0ijkl	9.47g	0.168e	3.66f	239.5e
		WS	0.89hi	1.34e	0.24hi	60.8hij	9.62fg	0.170e	3.69f	243.2de
		Si-2	0.62e	1.13c	0.40d	65.1gh	10.0ef	0.176de	3.89de	249.3cd
		Si-4	0.54c	1.33b	0.43c	77.5bc	11.5ab	0.187ab	4.02cd	262.1b
		Si-6	0.68f	1.02d	0.38d	72.5de	10.6cd	0.185bc	3.89de	257.6bc
	618	NS	0.81g	1.26d	0.26fgh	66.9fg	10.4de	0.179cd	3.75ef	250.0cd
		WS	0.79g	0.98d	0.27fg	69.5ef	10.5de	0.184bcd	3.82ef	252.2c
		Si-2	0.51b	1.23b	0.46b	74.2cd	11.1bc	0.186abc	4.14bc	256.6bc
		Si-4	0.42a	1.07a	0.49a	86.0a	11.9a	0.193a	4.36a	272.5a
		Si-6	0.58d	1.27c	0.43c	81.2b	11.7a	0.190ab	4.26ab	263.6b
Drought	611	NS	1.16n	1.08l	0.18j	50.1n	5.83l	0.125k	2.83l	180.1k
		WS	1.14n	1.29l	0.19j	52.2mn	5.91kl	0.127jk	2.86kl	182.9jk
		Si-2	0.99k	1.06i	0.26fgh	55.6klm	7.03i	0.132ijk	2.98ijkl	187.6ijk
		Si-4	0.95j	1.28h	0.28ef	59.8ijk	7.49hi	0.145fg	3.10ghij	207.5g
		Si-6	1.05m	0.98ij	0.22i	58.5jkl	7.19hi	0.139ghi	3.01hijk	190.5ij
	618	NS	1.04lm	1.21k	0.25ghi	55.0lm	6.36jk	0.134ij	2.95jkl	194.3hi
		WS	1.01kl	0.92jk	0.26fgh	56.5kl	6.46j	0.136hi	2.98ijkl	196.2hi
		Si-2	0.90i	1.17g	0.31e	59.2ijkl	7.39hi	0.143fgh	3.13ghi	200.4gh
		Si-4	0.86h	1.02f	0.30e	66.5fg	7.71h	0.149f	3.21g	217.7f
		Si-6	0.93j	1.22gh	0.28ef	63.1ghi	7.52hi	0.148f	3.15gh	205.8g
LSD ($P \leq 0.05$)			0.027	0.018	0.029	4.31	0.53	8.18E ⁻⁰³	0.15	8.77

Control=no stress, Drought=Drought stress, NS=No spray, WS=Distilled water spray, Si-2= Silicon applied at 2.0 mM, Si-4= Silicon applied at 4.0 mM, Si-6= Silicon applied at 6.0 mM, G₁=611, G₂=618, LSD= Least significant difference; ns=Non-significant, * significance at $P \leq$ at 0.05, ** significance at $P \leq$ at 0.01, *** significance at $P \leq$ at 0.001, respectively; Values that have the same case letter or do not have letters do not substantially differ ($P \leq 0.05$).

Table 5. Impact of Si foliar applications on the physiological parameters of two canola genotypes under drought stress

Drought stress	Genotypes	Silicon	Water potential (-MPa)	Osmotic potential (-MPa)	Turgor potential (MPa)	Leaf relative water content (%)	Photosynthetic rate ($\mu\text{mol H}_2\text{O m}^{-2} \text{ s}^{-1}$)	Stomatal conductance ($\mu\text{mol mol}^{-1}$)	Transpiration rate ($\text{mmol H}_2\text{O m}^{-2} \text{ s}^{-1}$)	Sub stomatal CO_2 concentration ($\mu\text{mol mol}^{-1}$)
Control	Super	NS	0.99ij	1.22g	0.23jk	52.7fgh	8.78e	0.150g	3.24g	232.6g
		WS	0.96i	1.21g	0.24hij	53.4efg	8.86de	0.154fg	2.48fg	235.4fg
		Si-2	0.79e	1.16e	0.37cd	56.4def	9.16c	0.159ef	3.30ef	243.2ef
		Si-4	0.74d	1.12cd	0.37c	65.5bc	9.38bc	0.169bc	2.50cd	268.4ab
		Si-6	0.82f	1.17f	0.35d	60.9cd	9.23c	0.163cde	3.41de	247.3de
	Rachna	NS	0.90h	1.16ef	0.26fgh	57.8de	9.12cd	0.162de	2.56ef	242.7ef
		WS	0.86g	1.14d	0.27fg	60.1d	9.22c	0.167cd	3.57de	244.8def
		Si-2	0.64b	1.09b	0.45ab	60.8d	9.37bc	0.169bcd	2.71bc	253.1cd
		Si-4	0.59a	1.06a	0.47a	75.9a	9.72a	0.181a	3.45a	273.5a
		Si-6	0.68c	1.11c	0.43b	67.6b	9.51ab	0.174b	2.59ab	259.6bc
Drought	Super	NS	1.31n	1.49o	0.17l	40.9l	5.01i	0.116l	3.40j	152.1n
		WS	1.29n	1.47n	0.17l	43.4kl	5.10i	0.120jkl	2.56j	154.1mn
		Si-2	1.06k	1.32k	0.25ghi	46.0jk	5.68h	0.122ijkl	3.49j	162.8lm
		Si-4	1.01j	1.29j	0.28f	49.8ghij	6.00fg	0.127ij	2.59hi	176.3jk
		Si-6	1.11l	1.34l	0.23ijk	48.3hij	5.81gh	0.123ijk	3.68ij	169.4kl
	Rachna	NS	1.21m	1.43m	0.22k	46.2jk	5.24i	0.120kl	2.72j	165.6l
		WS	1.19m	1.43m	0.23jk	47.4ijk	5.24i	0.121ijkl	3.87ij	168.4kl
		Si-2	0.96i	1.27i	0.30e	49.6ghij	5.93fgh	0.124ijk	2.79hi	180.7ij
		Si-4	0.91h	1.23h	0.32e	53.5efg	6.15f	0.134h	3.76h	195.0h
		Si-6	1.00j	1.28ij	0.28f	51.3ghi	5.96fg	0.128i	2.75h	187.3hi
LSD ($P \leq 0.05$)			0.023	0.014	0.22	4.59	0.27	6.5E ⁻⁰³	0.12	9.43

Control=no stress, Drought=Drought stress, NS=No spray, WS=Distilled water spray, Si-2= Silicon applied at 2.0 mM, Si-4= Silicon applied at 4.0 mM, Si-6= Silicon applied at 6.0 mM, G₁=Super, G₂=Rachna, LSD= Least significant difference; ns=Non-significant, * significance at $P \leq 0.05$, ** significance at $P \leq 0.01$, *** significance at $P \leq 0.001$, respectively; Values that have the same case letter or do not have letters do not substantially differ ($P \leq 0.05$).

Table 6. Impact of Si foliar applications on the biochemical parameters of two camelina genotypes under drought stress

Drought stress	Genotypes	Silicon	Total chlorophyll content (mg g ⁻¹ FW)	Carotenoid (mg g ⁻¹ FW)	SOD (Unit g ⁻¹ FW)	CAT (Unit g ⁻¹ FW)	POD (Unit g ⁻¹ FW)	Electrolyte leakage (%)
Control	611	NS	2.18f	0.39ij	48.6h	46.0o	62.0l	35.3g
		WS	2.21ef	0.39ij	72.7h	49.4n	63.8kl	34.8g
		Si-2	2.39cd	0.44ef	49.4de	56.4l	67.2ij	28.7ij
		Si-4	2.73b	0.50ab	75.1ab	59.6k	68.9hi	27.6jk
		Si-6	2.71b	0.48bc	51.8bc	53.1m	65.5jk	30.1hi
	618	NS	2.29de	0.41hi	81.2gh	60.6k	65.6jk	31.0h
		WS	2.32d	0.41ghi	54.8fgh	61.2k	67.7ij	30.5hi
		Si-2	2.62b	0.45de	83.4d	67.5j	71.1gh	24.3l
		Si-4	2.88a	0.52a	50.7a	70.0i	74.4f	22.8l
		Si-6	2.50c	0.50b	79.3b	66.3j	68.9hi	26.5k
Drought	611	NS	1.26m	0.31n	54.7j	71.1hi	72.7fg	66.3a
		WS	1.28lm	0.32mn	88.9j	73.2h	75.1f	65.8a
		Si-2	1.39kl	0.40hij	56.1fgh	81.2f	80.2e	61.2bc
		Si-4	1.65gh	0.43efg	91.0de	84.2e	83.4d	58.5d
		Si-6	1.56hi	0.38jk	60.2gh	78.1g	78.4e	62.3b
	618	NS	1.43jk	0.34lm	96.5i	85.0de	85.5cd	60.3bcd
		WS	1.46ijk	0.36kl	62.5i	87.1d	87.2e	60.2cd
		Si-2	1.54hij	0.43fgh	101.0ef	94.3b	98.2b	54.5ef
		Si-4	1.76g	0.47cd	58.0c	98.0a	102.6a	54.0f
		Si-6	1.69g	0.40ij	95.3fg	91.7c	96.6b	56.1e
LSD (P ≤ 0.05)			0.11	0.024	3.39	2.47	3.12	2.10

Control=no stress, Drought=Drought stress, NS=No spray, WS=Distilled water spray, Si-2= Silicon applied at 2.0 mM, Si-4= Silicon applied at 4.0 mM, Si-6= Silicon applied at 6.0 mM, G₁=611, G₂=618, LSD= Least significant difference; ns=Non-significant, * significance at $P \leq$ at 0.05, ** significance at $P \leq$ at 0.01, *** significance at $P \leq$ at 0.001, respectively; Values that have the same case letter or do not have letters do not substantially differ ($P \leq 0.05$).

Table 7. Impact of Si foliar applications on the biochemical parameters of two canola genotypes under drought stress

Drought stress	Genotypes	Silicon	Total chlorophyll content (mg g ⁻¹ FW)	Carotenoid (mg g ⁻¹ FW)	SOD (Unit g ⁻¹ FW)	CAT (Unit g ⁻¹ FW)	POD (Unit g ⁻¹ FW)	Electrolyte leakage (%)
Control	Super	NS	2.10g	0.31h	45.1o	45.2n	56.7o	38.6
		WS	2.13fg	0.31h	46.3no	47.1n	58.4no	38.1
		Si-2	2.32e	0.37de	51.3lm	52.9m	62.1lm	31.6
		Si-4	2.67b	0.44ab	52.6kl	56.1l	63.2kl	30.4
		Si-6	2.65bc	0.42bc	48.9mn	52.0m	60.6mn	33.3
	Rachna	NS	2.21ef	0.33gh	53.4kl	57.0l	60.9lmn	34.3
		WS	2.24e	0.33fgh	55.1jk	59.9k	63.1lm	33.2
		Si-2	2.55cd	0.38d	58.6hi	66.0i	66.9ij	26.5
		Si-4	2.82a	0.46a	61.0h	68.1i	69.2hi	24.8
		Si-6	2.44d	0.44b	57.1ij	62.8j	65.7jk	28.84
Drought	Super	NS	1.18m	0.23j	68.5g	73.0gh	71.5gh	78.0
		WS	1.20m	0.24j	70.5g	71.1h	72.7g	77.0
		Si-2	1.32l	0.33fgh	78.3ef	76.3ef	79.2e	71.6
		Si-4	1.59hi	0.37de	84.5cd	79.0cd	82.1d	69.2
		Si-6	1.50ij	0.32gh	75.1f	74.0fg	76.2f	72.8
	Rachna	NS	1.35l	0.26i	80.5e	75.5ef	90.8c	71.0
		WS	1.38kl	0.27i	84.0d	77.1de	92.0c	70.7
		Si-2	1.47jk	0.35ef	91.0b	82.7b	97.4b	64.4
		Si-4	1.70h	0.41c	96.0a	88.1a	100.7a	63.0
		Si-6	1.63h	0.34fg	87.4c	81.0bc	95.3b	66.6
LSD (P ≤ 0.05)			0.10	0.02	3.30	2.35	2.27	1.56

Control=no stress, Drought=Drought stress, NS=No spray, WS=Distilled water spray, Si-2= Silicon applied at 2.0 mM, Si-4= Silicon applied at 4.0 mM, Si-6= Silicon applied at 6.0 mM, G₁=Super, G₂=Rachna, LSD= Least significant difference; ns=Non-significant, * significance at $P \leq$ at 0.05, ** significance at $P \leq$ at 0.01, *** significance at $P \leq$ at 0.001, respectively; Values that have the same case letter or do not have letters do not substantially differ ($P \leq 0.05$).