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Assessment Effect of Silicon on Physiological and Biochemical Traits of Corn (*Zea mays L.*) Under Salinity Stress Conditions

Afsaneh Bolbol sharifloo[1] and Mojtaba Yousefi Rad[2*]

1- Department of Agronomy, Saveh Branch, Islamic Azad University, Saveh, Iran.
2- Department of Agronomy, Faculty of Agriculture, Saveh Branch, Islamic Azad University, Saveh, Iran.

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ABSTRACT

BACKGROUND: Silicon is a suitable solution to alleviate salinity stress and improve crop production.

OBJECTIVES: Investigation physiological and biochemical traits of Single Cross 704 corn affected foliar application of silicon (from a Sodium silicate source) under salinity stress.

METHODS: This research was carried out according split plot experiment based on randomized complete blocks design with three replications. The main factor included salinity at three level (a_1: control or 0.34 ds.m^{-1}, a_2: 4 ds.m^{-1}, a_3: 8 ds.m^{-1}) and foliar application of silicon (from a Sodium silicate source) belonged to subplot at three level (b_1: control or non-spraying, b_2: 1 mM b_3: 2 mM silicon).

RESULT: Salinity stress reduced leaf dry weight, plant dry weight, root dry weight, and decreased stem height. It also increased levels of malondialdehyde (MDA), proline and sodium, and reduced potassium concentration in the plant. Foliar application of Silicon improved the growth traits, such that foliar application of 2 mM silicon brought about the highest dry weight of leaves and plants (21.73 and 120.85 gr). Foliar application of 1 and 2 mM silicone reduced MDA concentration by 12.93% and 13.7% at 8 ds.m^{-1} salinity compared to the control. The foliar application of silicon (1 and 2 mM) also led to 13.78 and 17.79% reduction in amount of proline at control salinity level and 28.51% and 21.08% reduction of proline levels at 8 ds.m^{-1} salinity levels compared to the control. Application of 1 and 2 mM silicon led to reduction of the leaf sodium concentration and increased Leaf potassium concentration at all salinity levels compared to the control. So the consumption of silicon reduced the effects of salt stress on corn.

CONCLUSION: Finally according result of this research foliar application of silicone in amount of 2 mM can be recommended.

KEYWORDS: *Leaf dry weight, Malondialdehyde, Potassium, Proline.*

***Corresponding Author:** Mojtaba Yousefi Rad ✉ m.yousefirad@iau-saveh.ac.ir

1. BACKGROUND

Environmental stresses generally reduce about 70% of crop yields, with high temperatures, low temperature, drought stress and salinity stress accounting for 15%, 40%, 17% and 20% of corn yield reductions (Ashraf and Harris, 2005). Among the environmental stresses soil salinity is a widespread environmental problem that has been found to affect more than 77 million hectares or 5% of the cultivable land of the universe (Athar and Ashraf, 2009). Salinity adversely affects the plant growth and productivity. The yield reduction due to salt stress may account for substantial reduction of the average yield of major crops by more than 50% (Bray *et al*., 2000). The nature of damages due to salt stress is very complex because it causes both osmotic stress and ionic toxicity (Hasanuzzaman *et al*., 2013). Soil salinity is a global problem that adversely affects 20% of irrigated land and reduces crop yields (Qadir *et al*., 2014). According to a research about ciumin (*Cuminum cyminum L.*) salinity prevents germination at high concentrations and induces sleep in seeds at lower concentrations. This phenomenon could also reduce water absorption by reducing the osmotic potential and change metabolic processes (Mohamadizadeh *et al.,* 2014). In study on soybean, salinity significantly increased the Na^+ content but the contents of K^+ and as well as antioxidant enzymes activities significantly decreased (Amirjani, 2010). The results of a study showed that salinity stress could reduce plant height and number of branches and also increase malondialdehyde levels in Amaranth (Yarnia and Khorshidi Benam, 2017). Gunes *et al.* (2007) reported an increase in leaf malondialdehyde concentration due to salinity stress in corn. Also, some studies have reported an increase in proline amino acids for intracellular osmotic regulation under salinity stress condition in durum wheat (Carillo *et al.,* 2008) and cowpea (Patel *et al.,* 2010). Moreover, salinity increased the sodium concentration of the plant tissues, and showed that abundance of sodium in the soil would impair potassium absorption by the plant (Anburaj *et al.,* 2012). Silicon (Si) is the second most abundant element in the soil and alleviates the biotic and abiotic stresses in plants (Ma and Takahashi, 1990). In response to various environmental stresses, plants demonstrate variety of adaptive mechanisms to counteract them. Since one of the primary responses under salt stress is osmotic adjustment, compatible solutes such as proline and glycine betaine are very common to be accumulated during salt stress and play a fundamental role in osmotic adjustment in plants (Szabados and Savoure, 2010). These compatible solutes are accumulated in the cytosol without disturbing intracellular biochemistry, which ameliorate the detrimental effects of salinity (Patade *et al*., 2014). Despite the abundance of this material on the ground since it is accompanied by other elements, it is accessible to plants, and therefore it is not included in the category of essential elements for plant growth and has not paid much attention to its biological role (Epstein, 1999). Many studies have been conducted on the effect of silicon on plant growth, both under ideal and stress conditions, and all of these studies have shown positive effect of silicon on wheat growth and yield under both conditions, especially under stress conditions (Tahir *et al.,* 2006). Silicon (Si) is the second most abundant element existing on earth (Silva *et al.,* 2012). Although it is not considered as an essential element, nevertheless, there is increasing evidence regarding its positive effects on plant growth and development (Karmollachaab *et al.,* 2014). Si acts as a mechanical or physical obstacle in plants and not only acts as cell wall strengthening, but is also actively involved in many physiological processes. Studies have displayed that positive impacts of Si are more prominent under stressful conditions as it can increase plant defense systems against low (Epstein, 1999) and high temperature (Hattori *et al.*, 2005), UV-radiation (Shen *et al.*, 2010), salinity (Biel *et al.*, 2008) and heavy metal toxicity (Shi *et al.*, 2005). Remus-Borel *et al.* (2005) reported mechanism was that Si might decrease the oxidative damage in plants subjected to environmental stresses. Si is also found to enhance water stress tolerance in plants by retaining leaf water potential, leaves erectness, stomatal conductance, structure of xylem vessels under high transpiration rates, and photosynthetic activity (Gong *et al.*, 2003). Si can diminish the electrolyte leakage from plant leaves and therefore raised photosynthetic activity in plants grown under water stress conditions (Epstein, 1999). Asgharipour and Mosapour (2016) reported silicon application increased concentration of proline, soluble sugars in seed, leaf area index, seed yield, essential oil percentage, concentration of sodium and potassium in fennel seed by 24, 13, 20, 17, 31, 41, 24 and 9%, respectively, over those of the control (non-application of Si). Silicon significantly reduces the effects of non-volatile stresses such as salinity stress, water stress, coldness, as well as toxicity of heavy metals, aluminum and manganese (Liang *et al.,* 2006). Salinity studies have been conducted in the country for over 50 years, but these studies have always been facing some challenges. Foliar application of micro and macro nutrients, as an effective way to improve and speed up absorption of these elements by the leaves and the shoot has been established, because these elements are simply absorbed by leaves through the cuticle and apertures without being affected by the limiting factors of soil in the root zone, and find their way to vascular bundle, mesophilic cells and the apoptosis (Emadi, 2011). Kardoni *et al.* (2013) reported the highest and lower yield seen has been in consumption 1mM silicon concentration under 1 $ds.m^{-1}$ salinity stress and without Silicon treatments in 5 $ds.m^{-1}$ salinity stress. Silicon application significantly increased 100 seed weight and yield of faba bean under saline environments. Finally it could be concluded that using of silicon in salinity condition reduced harmful effects of salinity on the yield component in bean plant. The formation of Si-organic complexes was reported in rice shoots (Munns and James, 2003). Mera and Beveridge (1993) suggested that Si can modify the cation-binding properties of cell walls. Different mechanisms for Si-mediated stress alleviation have been proposed by researchers. Si deposition in leaves was reported to be able to decrease transpiration (Hattori *et al.*, 2007) and so, alleviating salt stress. The most widely reported mechanism was that silicon might decrease the oxidative damage in plants subjected to environmental stresses (Remus-Borel *et al.*, 2005). Silicon matter has the ability to ameliorate salt stress due to its high efficiency to increase the relative water content (RWC), membrane stability index (MSI), antioxidant enzyme activity such as the peroxidase and catalase and decline proline content so it's the foliar application in the form of silicate liquid solutions can be used as a promising alternative to the mitigate abiotic stress-induced damage in the wheat crop (Sapre and Vakharia, 2017).

2. OBJECTIVES

Therefore, in the present study, attempts are made to investigate the effect of silicon foliar application on corn plant under salinity stress conditions to determine the appropriate dose for different stress conditions.

3. MATERIALS AND METHODS

3.1. Field and Treatment Information

This research was curried out to evaluate effect of foliar application of silicon (from a Sodium silicate source) on physiological and biochemical traits of Single Cross 704 corn under salinity stress conditions via split plot experiment based on randomized complete blocks design with three replications in Saveh, Markazi Province, central of Iran during 2017-2018. The main factor included salinity at three level (a_1: control or 0.34 $ds.m^{-1}$, a_2: 4 $ds.m^{-1}$, a_3: 8 $ds.m^{-1}$) and foliar application of silicon (from a Sodium silicate source) belonged to subplot at three level (b_1: control or non-spraying, b_2: 1 mM b_3: 2 mM silicon).

3.2. Farm Management

30 cm diameter pots were used for the planting seeds, and the soil composition included: two parts of soil, one part of manure and one part of coco peat. Corn seeds were soaked in water and sprouted about two days before planting. 10 seeds were planted in each pot and at least four plants were kept in each pot. In this study, Single Cross 704 corn seeds were used and the seeds were planted on 2017.4.10. Salinity stress was applied 50 days after cultivation, and in order to prevent the increase in salinity of the soil, each pot was sprinkled with saline water so that the inlet and outlet water salinity was equivalent. To this end, the electrical conductivity of water in saucers was measured once every two weeks.

3.3. Measured Traits

1 and 2 mM of silicon were used for foliar application at the ear formation stage and two weeks later, corn crops were harvested at the dough stage to determine their physiological traits. Harvest was carried out by manual weeding. Malondialdehyde was measured as the final product of lipid peroxidation of membrane (De Vos *et al.,* 1991). The method proposed by (Bates *et al.,* 1973) was used to measure proline content of leaf tissue and flame emission spectrometry was used to measure sodium and potassium (Tandon, 1995).

3.4. Statistical Analysis

Analysis of variance was carried out by SAS statistical software and mean comparison was compared by Duncan's multiple range test at 5% probability level.

4. RESULTS AND DISCUSSION

4.1. Leaf dry weight

The results of analysis of variance indicated that effect of salinity stress on leaf dry weight was significant ($P<0.05$) while the effect of foliar application of silicon and interaction effect of treatments was not significant (Table 1). Salinity stress, the dry weight of corn leaves decreased significantly compared to the control, such that the leaf dry weight decreased 13.43% and 30.07% at the first and second salinity levels respectively (Table 2). Salinity also decreased plant dry weight, stem and root length, plant height and leaf area in basil plant (Tarchoune *et al.,* 2012). The results also showed that foliar application of 2 mM silicone caused a 16.01% increase in leaf dry weight compared to the non-spraying, but foliar application of 1 mM silicone caused no significant difference compared to non-spraying (Table 3).

The use of silicon in soybean plant under salinity stresses increased the length of stems and roots, and the dry and fresh weight of the plant (Lee *et al.,* 2010). Samuels *et al.* (1993) also suggested that silicon could increase the cucumber fruit growth and yield by improving the mechanical ability of stems and leaves in absorbing light and improving the photosynthetic capacity of the plant.

4.2. Plant dry weight

The results of analysis of variance indicated that the effect of salinity stress on plant dry weight was significant ($P<0.05$) but the effect of foliar application of silicon and the interaction effect of treatments was not significant (Table 1). Salinity stress led to a significant decrease in the dry weight of the corn compared to the control, such that in the first and second levels of salinity, the plant dry weight was reduced by 29.60 and 21.07% respectively (Table 2). Foliar application of 1 and 2 mM silicone led to 10.02 and 22.28% increase in dry weight of the plant compared to the non-spraying (Table 3). The results of another study showed that the reduction of water in rice cells leads to abruption of cell division and subsequently reduced dry weight of the root and shoots. Reduction of water in leaf cells under salinity stress reduces leaf area and damages photosynthetic sources of rice plant growth, resulted in decreased photo assimilates and, eventually, in decreased dry weight (Moradi and Abdelbagi, 2007).

Table 1. ANOVA Results the effect of salinity and silicon foliar application on measured traits

S.O.V	df	Leaf dry weight	Plant Dry weight	Root dry weight	Stem height
Block	2	0.1178^{ns}	308.47^{ns}	189.33^{*}	101.33^{ns}
Salinity (A)	2	115.22^{*}	6055.11^{*}	603.35^{**}	691.77^{*}
Error I	4	10.44	607.07	133.72	102.11
Silicon (B)	2	20.38^{ns}	2950.66^{ns}	17.45^{*}	70.64^{ns}
A*B	4	40.05^{ns}	2622.81^{ns}	48.49^{*}	28.42^{ns}
Error II	12	13.88	1047.40	11.15	40.72
CV (%)	-	8.33	12.88	11.22	6.30

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

Continue table 1.

S.O.V	df	MDA	Proline	Sodium concentration of leaf	Potassium concentration of leaf
Block	2	22.07^{*}	0.0117^{ns}	1.4240^{**}	9.1002^{**}
Salinity (A)	2	463.54^{**}	3256^{**}	40.56^{**}	95.78^{**}
Error I	4	14.36	2.3372	0.0853	0.1565
Silicon (B)	2	10.80^{*}	107.89^{**}	2.2734^{**}	4.8422^{**}
A*B	4	33.98^{**}	111.46^{**}	0.1364^{**}	0.8776^{**}
Error II	12	1.9730	1.9320	0.0019	0.0032
CV (%)	-	2.82	3.73	2.87	2.39

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

4.3. Root dry weight

According result of analysis of variance effect of salinity stress on root dry weight was significant ($P<0.01$) also effect of foliar application of silicon and the interaction effect of treatments was significant ($P<0.05$). But the effect of foliar application on root dry weight was not significant (Table 1). Under non-stress and first level of salinity stress condition, application of 2 mM Silicon increased root weight compared to control condition (32.68 and 25.81 gr respectively). However, in the second salinity level, application of silicon did not have a significant effect on root dry weight (Table 4). Adatia and Besford (1986) reported that silicone improved cucumber plant growth traits such as leaf thickness, dry matter per unit of leaf area, fresh and dry weight of the root, and reduced leaf inclination to wilting.

4.4. Stem height

The results of analysis of variance indicated that the effect of salinity stress on stem height was significant ($P<0.05$) but the effect of foliar application of silicon and the interaction effect of treatments was not significant (Table 1). The effect of salt stress indicated application of salt stress, leads to significant reduction of stem height compared to the control, so that the plant height decreased 16.5% in the second level of salinity, but no significant difference was observed between the first level of salinity and control (Table 2). The results of another study showed that, growth factors such as stem and root length, fresh and dry weight of stems and roots and total biomass of black cumin were significantly decreased with increase in salinity levels (Safarnejad *et al.,* 2007). The results of this study showed that foliar application of silicone had no effect on stem height (Table 3). Of course, due to the fact that Silicon was applied at the time of the formation of the ear and after that, the lack of response to corn height (corn is determinate plant) is justifiable.

Table 2. Mean comparison effect of different level of salinity on measured traits

Treatment	Leaf dry weight (g)	Plant Dry weight (g)	Stem height (cm)
Control (0.34 ds.m^{-1})	23.777^{*a}	170.18^{a}	106.09^{a}
4 ds.m^{-1}	20.58^{b}	134.32^{b}	106.40^{ab}
8 ds.m^{-1}	16.62^{c}	119.79^{c}	91.06^{b}

*Similar letters in each column show non-significant difference at 5% probability level via Duncan test.

Table 3. Mean comparison effect of different level of silicon on measured traits

Treatment	Leaf dry weight (g)	Plant dry weight (g)	Stem height (cm)
Control	18.73^{*b}	125.44^{c}	99.39^{a}
Silicon 1 mM	20.51^{ab}	138.01^{b}	104.41^{a}
Silicon 2 mM	21.73^{a}	160.85^{a}	99.75^{a}

*Similar letters in each column show non-significant difference at 5% probability level via Duncan test.

4.5. Malondialdehyde (*MDA*)

According result of analysis of variance effect of foliar application of silicon on MDA was significant ($P<0.05$) also effect of salinity stress and the interaction effect of treatments was significant at 1% probability level (Table 1). In salinity stress of 8 ds.m^{-1}, foliar application of 1 and 2 mM Silicon significantly reduced MDA compared to the control. However, under 4 ds.m^{-1} salinity stress, foliar application of 1 mM Silicon increased MDA while under control salinity conditions, silicone application did not have any significant effect on MDA. However, with increasing salinity, the MDA concentration in the plant increased, such that the control treatment (with no stress and silicon application) had the lowest concentration of MDA (41.84 µmol. g.dry weight) while the highest MDA were observed under the salinity of 8 $ds.m^{-1}$ and without silicon application (62.73 µmol. g.dry weight) (Table 4). It seems that in high salinity, silicon has been able to modify the effect of salinity on plants and consequently reduce the amount of MDA. In another study, increased leaf MDA concentration in rice seedlings was reported under salinity stress conditions. This study showed that degradation of cell membranes due to salinity stress and the production of MDA in leaves as a result of degradation of cell membrane fat can be considered a suitable criterion for investigating the reaction of rice plant to salinity stress (Bandeoglu *et al.,* 2004). Silicon has anti stress effects on plants. The increase in silicon levels decreases the permeability of the leaf cells membrane. Silicone affects the structure, integrity and activity of plasma membrane by affecting stress-related peroxidation (Liang, 1999).

4.6. Proline

Proline matter is the non-protein amino acid that is create in the leaf tissues of plants in response to the water deficit and, together with the sugar, is readily metabolized in leaves after recovery from the water stress (Gideon *et al.*, 2016).

Table 4. Mean comparison interaction effect of treatments on measured traits

Salinity concentration	Foliar application concentration	Root dry weight of (gr)	MDA (µmol.g.dry weight^{-1})	Proline (mg.g.fresh weight^{-1})
Control (0.34 $ds.m^{-1}$)	control	28.13^{*b}	41.84^{f}	21.93 ^{f}
	1 mM silicon	25.86 ^{b}	44.17 ^{ef}	18.91 ^{g}
	2 mM silicon	32.68 ^{a}	42.51 ^{f}	18.03 ^{g}
4 $ds.m^{-1}$	control	17.13 ^{cd}	47.87 ^{d}	32.79 ^{e}
	1 mM silicon	16.96 ^{c}	50.34 ^{c}	35.95 ^{d}
	2 mM silicon	25.81^{b}	49.21 ^{cd}	35.14 ^{de}
8 $ds.m^{-1}$	control	11.81 ^{de}	62.73 ^{a}	76.68 ^{a}
	1 mM silicon	11.21 ^{e}	54.62 ^{b}	49.16 ^{c}
	2 mM silicon	14.55 ^{de}	54.14 ^{b}	54.27 ^{b}

*Similar letters in each column show non-significant difference at 5% probability level via Duncan test.

Continue Table 4.

Salinity concentration	Foliar application concentration	Sodium concentration of leaf (mg.g.dry weight^{-1})	Potassium concentration of leaf (mg.g.dry weight^{-1})
Control (0.34 $ds.m^{-1}$)	control	3.25^{*g}	16.97 ^{c}
	1 mM silicon	2.63^{h}	18.63 ^{a}
	2 mM silicon	2.47 ^{i}	18.15 ^{b}
4 $ds.m^{-1}$	control	5.65 ^{d}	13.11 ^{f}
	1 mM silicon	4.67^{f}	14.25 ^{d}
	2 mM silicon	5.11 ^{e}	13.78 ^{e}
8 $ds.m^{-1}$	control	7.73 ^{a}	10.51 ^{i}
	1 mM silicon	6.42 ^{c}	11.34^{h}
	2 mM silicon	6.91 ^{b}	12.63 ^{g}

*Similar letters in each column show non-significant difference at 5% probability level via Duncan test.

Accumulation of Pro is often suggested as a selection criterion for the stress tolerance of most plant species (Hayat *et al*., 2012). According to the results of the analysis of variance, effect of salinity stress, foliar application of silicon and interaction effect of treatments on proline was significant (P<0.01) (Table 1). Effect of salinity stress and foliar application on proline concentration showed that, under non-salinity stress conditions, 1 and 2 mM silicon significantly decreased proline concentration by 13.78 and 17.79%, respectively while under the second salinity stress level, foliar application of 1 and 2 mM silicon significantly reduced proline in the corn plant (28.51% and 21.08% respectively) (Table 4). Proline is one of the most important osmolytes that causes osmotic adaptation and its accumulation in response to osmotic stress is mainly reported (Ashraf and Foolad, 2007). In the present study, increased proline concentration in corn leaves was observed under salinity stress conditions, but the increase in proline concentration declined in salinity level of 8 ds / m, as well as non-salinity stress decreased with silicone application. Similar results have also been observed in sorghum (Yin *et al.,* 2013). There is a lot of controversy over the actual role of proline in osmotic adaptation. In some studies, proline accumulation under stress conditions indicates increased plant tolerance compared to susceptible genotypes (Nayyar and Walia, 2003). However, other research suggested that proline accumulation was a sign of stress damage in susceptible plants as compared to tolerant ones (De Lacerda *et al.,* 2003). In addition to its osmolytic role, Proline can be used as a source of carbon and nitrogen for coping with stress. The provision of silicon along with reduction of proline can always increases with tolerance to stress (Tuna *et al.,* 2008; Pei *et al.,* 2010). By reducing sodium absorption by root and also its transmission to shoots, Silicon can reduce osmotic stress, and consequently lead to reduction of proline content (Hajiboland and Cheraghvareh, 2014).

4.7. Sodium concentration of leaf

Results of the analysis of variance revealed that the effect of salinity stress, foliar application of silicon and interaction effect of treatments on sodium concentration of leaf was significant (P<0.01) (Table 1). Salinity increased the sodium concentration of leaf, such that the highest sodium concentration was observed in salinity of 8 $ds.m^{-1}$ with no application of silicon. It was also observed that at each salinity stress level, including control salinity, 4 and 8 $ds.m^{-1}$, foliar application of 1 and 2 mM silicon significantly reduced the sodium concentration compared to the control condition (Table 4). Silicon increases potassium and decreases sodium by increasing the activity of proton pump tubes of cell membranes and tonoplast membrane, which are involved in potassium ion adsorption, sodium excretion into apoplastic space, and restriction of sodium in root canola cells (Liang *et al.,* 2006).

4.8. Potassium concentration of leaf

According to the results of the analysis of variance, effect of salinity stress, foliar application of silicon and interaction effect of treatments on potassium concentration of leaf was significant (P<0.01) (Table 1). The results obtained from the comparison of the average effect of salinity stress with foliar application of silicon on the potassium concentration of leaves in salinity stress, including the control, 4 and 8 $ds.m^{-1}$ salinity levels, foliar application of 1 and 2 mM silicon caused a significant increase in leaf potassium concentration compared to the control (Table 4). It is vital for the plant to preserve the optimum potassium content in saline environments, since potassium plays an important role in regulating the osmotic potential of plant cells. The ratio of potassium to sodium can be a good indicator of salinity tolerance. High levels of sodium ion in saline environments not only lead to competitive inhibition of potassium uptake, but also disrupts the selective ion absorption by damaging cell membranes (Marschner, 1995). Reduction of sodium content due to the application of silicon has also been reported in other experiments (Liang *et al.,* 2003). By sedimentation on root preventing adsorption, silicon can reduce sodium levels, and increases potassium uptake (Miao *et al.,* 2010).

5. CONCLUSION

The results of this study showed that 8 $ds.m^{-1}$ salinity stress had the highest effect on loss of dry weight of corn leaves, dry weight of root, as well as reduction of stem height. According to the obtained results, it can be concluded that foliar application of silicon has improved growth traits such as: dry weight of corn leaves, dry weight of corn and dry weight of roots, and application of 2 mM of silicon (as compared to 1 mM) improved the plant condition in terms of most traits, but had no significant effect on stem height, Also, both levels of silicon affected the biochemical traits of corn under salinity stress and reduced the level of malondialdehyde, proline and sodium concentration of leaf and increased potassium concentration of leaf, so the 2 mM dose of silicone is recommended.

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FOOTNOTES

AUTHORS' CONTRIBUTION: All authors are equally involved.

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