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Assessment of efficacy of sodium silicate on morphological parameters of *Lycopersicon esculentum* Mill. under water deficit conditions

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Abstract

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The effect of sodium silicate on the morphological parameters of tomato (*Lycopersicon esculentum* Mill. var. Pusa Sheetal) was analyzed at vegetative, flowering and fruiting stages. The significant increase in morphological parameters of tomato plants was observed with sodium silicate treatment in comparison to control. The increase in the height of tomato plants 34.27 and 14.61% was observed with 5 g and 7 g sodium silicate treatment respectively in comparison to control. The findings of the present study revealed that sodium silicate stimulated tomato plant growth under water deficit conditions and it can be used in drought prone areas for the protection of tomato crop against water stress.

Keywords: Lycopersicon esculentum Mill.; morphological parameters; sodium silicate

Introduction

The development in agriculture sector is essential for the progress of nation. Agriculture is a primary source of food but modern intensive agricultural practices are burden on the environment and responsible for contamination of water, soil degradation and loss of biodiversity (Frison et al., 2011). The population of world is about seven billion and it has been predicted that it will increase by ten billion in the next fifty years (Goswami et al., 2016). The population of India is still increasing alarmingly which put a significant pressure on the agricultural land. Abiotic stresses adversely affect crop production (Meena et al., 2017). Among various environmental stresses, water stress is one of the most confining factors for crop production and plays a critical role in a world´s food security (Lipiec et al., 2013; Noman et al., 2018). Nezhadahmadi et al. (2013) reported that approximately two billion people will suffer with acute water shortage and 67% of the world's population will survive under water stressed environment by the year 2025. Drought as a consequence of deficient soil moisture may induce various changes in morphological and biochemical parameters of plants which severely restricts crop growth (Zhang et al., 2014; Bodner et al., 2015). Forty to sixty percent loss in total crop yield has been reported due to water deficiency in crop fields (Shao et al., 2008). Silicon, a tetravalent metalloid, is most abundant element after oxygen which is approximately 68% of soil mass (Ma &Yamaji, 2006; Epstein, 2009). It has been observed that the plants that have low silicon contents are structurally weaker and more prone to abnormal growth, development and reproduction (Epstein, 1999). Silicon acts as an agronomical important fertilizer that enhances tolerance capacity of plants against abiotic and biotic stresses (Zhu & Gong, 2014; Keller et al., 2015; Malhotra et al., 2016; Etesami & Beattie, 2017; Etesami & Jeong, 2018). Silicon is proven as stress reliever and it improves plant abilities to survive under stress conditions due to its anti-stress mechanism (Marafon & Endres, 2013; Van Bockhaven et al., 2013; Sapre and Vakharia, 2016).

Lycopersicon esculentum Mill. (*Solanum lycopersicum* L.) is popularly known as tomato and it belongs to *Solanaceae* family. It is a popular and economically important vegetable all over the world. Tomato is consumed in a form of salad, soup, juice, sun-dried tomato, ingredients in different recipes and processed products etc (Frusciante et al., 2007). *Lycopersicon esculentum* Mill. is an excellent source of bioactive compounds such as minerals, fiber, vitamins and antioxidants such as β-carotene and lycopene (Gundersen et al., 2001). Lycopene is a main carotenoid in tomato, is known for its anti-carcinogenic properties (Krauss et al., 2006). Silicon promotes the growth of plants under water deficit condition (Sacala, 2009; Son et al., 2011) and increases 35-40% water retention capacity of the soil (Hattori et al. 2005; Sonobe et al. 2011). Silicon increased water stress resistance capacity in sunflower (Gunes et al., 2008), pepper (Lobato et al., 2009), sorghum (Sonobe et al., 2011) and wheat (Gong & Chen, 2012) etc. The survey of pertinent literature revealed that no study has been done till date to study the impact of sodium silicate on the morphological parameters of tomato and its role in alleviation of water stress. In order to bridge this gap, the present study was designed to test the above hypotheses and to provide first-hand data on the effect of water stress treatment (3d and 6d) on the morphological parameters of tomato (*Lycopersicon esculentum* Mill. var. Pusa Sheetal) and alleviation of adverse effect of water stress by supplementation of sodium silicate. Tomato excludes silicon due to its less silicon accumulation capacity. Hence, tomato plant was selected to find out the mechanism for sodium silicate mediated water stress resistance.

Materials and Methods

The experiments were conducted in Plant Physiology Laboratory, Amity Institute of Biotechnology, Amity University, Noida.

Geographical position of the study site

Noida is an administrative headquarters of Gautam Budh Nagar district, Uttar Pradesh. The study site was located at latitude 28° 32′ N and longitude 77° 28′ E, 200 m above the sea level.

Collection of the tomato seeds

The certified, healthy and uniform tomato (*Lycopersicon esculentum* Mill. var. Pusa Sheetal) seeds were procured from Indian Agricultural Research Institute (IARI), New Delhi. The seeds were stored in sterilized polythene bags to avoid contamination.

Experimental design

Tomato (*Lycopersicon esculentum* Mill. var. Pusa Sheetal) seeds were taken for seed germination test. The empty and undeveloped tomato seeds were discarded by floating in tap water before seed germination test. Seeds of tomato were thoroughly washed with tap water to remove dirt and dust for 5 min. The surface of tomato seeds were sterilized with 10:1 distilled water/ bleach (commercial NaOCl) solution for 5 min to avoid fungal and bacterial infections and then washed 5-6 times with distilled water. The seeds were soaked in distilled water for 5 hours before sowing.

Preparation of different concentrations of sodium silicate

Sodium silicate [$Na_2O_3Si.9H_2O$] (molecular weight: 284.20 g/mol) was purchased from LOBA Chemie private limited, Mumbai. Different concentrations of sodium silicate were prepared with distilled water and mixed thoroughly with the growth medium [2 g/10 kg (T_1), 3 g/10 kg (T_2), 5 g/10 kg (T_3), 7g/10 kg (T_4) and 9 g/10 kg (T_5)] in different pots for the treatment in comparison to control.

Determination of morphological parameters

Determination of growth parameters at 10 DAS

Seed germination percentage was determined regularly till 10 days after seed sowing. Germination was determined by counting the number of germinated seeds at 24 hours interval till 10 days. Different growth characteristics of tomato such as germination percentage, relative germination rate, germination index and speed of germination index were determined in control and treatment by the following formula (Li, 2008):

• Germination percentage (G%) = Total number of seeds germinated / total number of seeds taken for germination x 100

• Relative germination rate (RGR) = germination percentage in treatment/ germination percentage in corresponding control.

• Germination index (GI) = $\Sigma G_t / D_t$,

where G_t is the number of seeds germinated in t days; D_t is the number of corresponding germination days.

• Speed of germination index

The number of tomato seedlings emerging daily was counted from day of sowing till the ten days of seed germination. Speed of germination index was calculated by following the formula of Khandakar and Bradbear (1983).

$$S = (N_1/1+N_2/2+ N_3/3\ldots\ldots N_n/n),$$

where N_1, N_2, N_3……N_n, proportion of seeds which germinated on day 1, 2, 3 .... n following setup of the experiment.

Determination of morphological parameters at 40 DAS and 60 DAS

Tomato (*Lycopersicon esculentum* Mill. Pusa Sheetal) seeds were sown in the earthen pots. The earthen pots of 30 cm deep and 30 cm in diameter were filled with equal weights 10 kg of soil. The growth medium (soil) was comprised of garden soil: cow manure (3:1). For the treatment, effective concentrations of sodium silicate such as 5 g and 7 g were added in 10 kg of growth medium (soil : cow manure). Tomato plants were thinned to one plant per pot at 10 DAS and uniform watering (400 ml/pot) was continued for 55 days till flowering.

At vegetative stage (40 DAS), different growth parameters of tomato (*Lycopersicon esculentum* Mill. var. Pusa Sheetal) such as number of leaves/plant, length of the leaves, number of branches per plant and plant height (cm) were recorded.

Water stress treatment

Following water stress treatment was given at 55 DAS in tomato plants:

Control: Normal watering in which tomato plants receive adequate water to maintain the soil moisture level at field capacity throughout their growth period.

Sodium silicate treatment: In sodium silicate treated pots, normal watering in which plants receive adequate water to maintain the soil moisture level at field capacity throughout their growth period.

Water stress treatment: Water stress treatment was given to the control tomato plants at flowering stage by withholding the water supply for 3 and 6 days respectively.

Water stress treatment in sodium silicate treated pots: In the pots containing sodium silicate, water stress treatment was given to the tomato plants by withholding the water supply for 3 and 6 days respectively.

At flowering stage (60 DAS), number of leaves/plant, length of the leaves, number of branches per plant, plant height (cm) and number of flowers/plant were measured. At fruiting stage (70 DAS) total number of fruits/plant of *Lycopersicon esculentum* Mill. (var. Pusa Sheetal) were recorded in control and different treatment.

Statistical analysis

All the treatment was arranged in a randomized block design with three replications. Data were statistically analyzed using analysis of variance (ANOVA) by using SPSS software (Ver. 10; SPSS Inc., Chicago, IL, USA). The treatment mean was analyzed by Duncan's multiple range test (DMRT) at $p < 0.05$.

Results and Discussion

The effect of sodium silicate on the morphological parameters of tomato (*Lycopersicon esculentum* Mill. var. Pusa Sheetal) was analyzed at vegetative, flowering and fruiting stages.

Determination of effective concentration of sodium silicate on *Lycopersicon esculentum* Mill. var. Pusa Sheetal

Significant increase in germination of tomato (*Lycopersicon esculentum* Mill. var. Pusa Sheetal) seeds was observed with higher sodium silicate concentration in comparison to control at 10 DAS. 78% tomato seeds were germinated in control and maximum 88% seed germination was observed in T_4 treatment. The increase in tomato seed germination percentage was observed in the following order: $T_4 > T_3 > T_2 > T_5 > T_1 >$ Control (Figure 1). The sodium silicate treatment (T_3 = 5 g/10 kg soil and T_4 = 7 g/10 kg soil) which showed significant increase in seed germination, relative germination rate and germination index over control and other treatment were selected for further study.

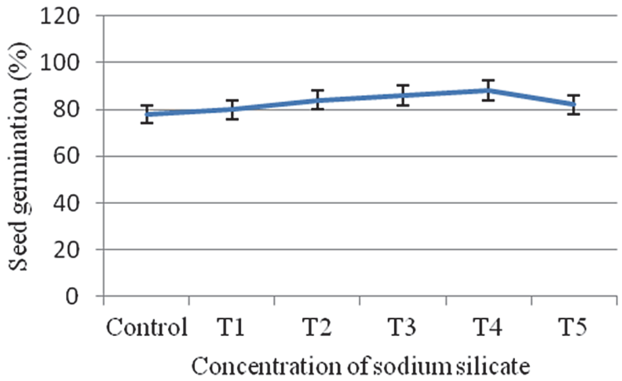

Fig. 1. Determination of effective concentration of sodium silicate on seed germination of *Lycopersicon esculentum* Mill. var. Pusa Sheetal at 10 DAS

Legend: C = Control, T = Pots containing sodium silicate (T_1 = 2 g, T_2 = 3 g, T_3 = 5 g, T_4 = 7 g and T_5 = 9 g/10 kg soil)

Determination of morphological parameters

The effect of sodium silicate on morphological parameters of tomato (*Lycopersicon esculentum* Mill. var. Pusa Sheetal) was analyzed at three different stages such as 10 DAS, 40 DAS and 60 DAS.

Determination of growth parameters at 10 DAS

The seed germination and growth parameters of tomato (*Lycopersicon esculentum* Mill. var. Pusa Sheetal) such as relative germination rate, germination index and speed of germination

Table 1. Effect of sodium silicate on growth parameters of *Lycopersicon esculentum* Mill. var. Pusa Sheetal at 10 DAS

Growth parameters (Treatments)	Germination percentage (%)	Relative germination rate	Germination index	Speed of germination index
C	$80^{a} \pm 0.91$	$0.00^{a} \pm 0.00$	$8^{b} \pm 0.12$	$58.81^{a} \pm 0.21$
T_1	$89^{b} \pm 0.72$ (11.25)*	$1.11^{a} \pm 0.03$	$8.9^{c} \pm 0.08$	$67.86^{b} \pm 0.64$
T_2	$84^{b} \pm 0.23$ (5)*	$1.05^{c} \pm 0.06$	$8.4^{d} \pm 0.02$	$62.34^{b} \pm 0.98$

Legend: C = Control, T_1 = Pots containing sodium silicate (5 g/10 kg soil); T_2 = Pots containing sodium silicate (7 g/10 kg soil);
*Stimulation percentage over control
Data are mean of three replicates ± sem. Different letters in each group show significant differences at $P < 0.05$

Index was recorded at 10 DAS (Table 1). Significant increase in seed germination 11.25 and 5% was observed in T_1 and T_2 treatment. The relative germination rate, germination index and speed of germination index showed the following trend: $T_1 > T_2 >$ Control.

Determination of morphological parameters at 40 DAS and 60 DAS

Morphological parameters of tomato (*Lycopersicon esculentum* Mill. var. Pusa Sheetal) such as leaf length, plant height, number of leaves, branches and flowers/plant were recorded in two stages such as vegetative (40 DAS) and flowering stages (60 DAS). Total number of fruits/plant was determined at 70 DAS (fruiting stage).

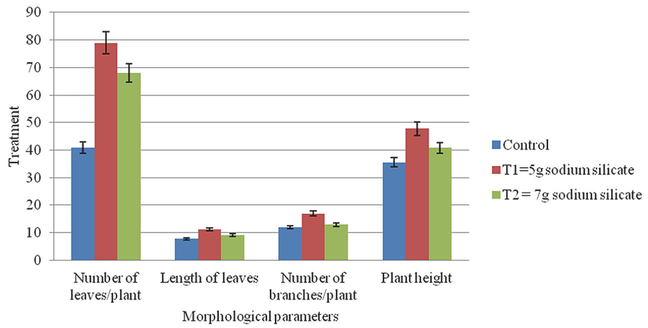

Fig. 2. Effect of sodium silicate on morphological parameters of *Lycopersicon esculentum* Mill.var. Pusa Sheetal at 40 DAS

At 40 DAS, silicon supplemented pots showed significant increase 92.68% in number of leaves/plant and 43.59% in leaf length in T_1 treatment (Figure 2). More number of branches/plant and plant height were observed in silicon supplemented pots in comparison to control. The increase in the height of tomato plants 34.27% and 14.61% was observed in T_1 and T_2 treatment respectively in comparison to control (Table 2).

At 60 DAS, silicon supplemented pots showed significant increase 29.72% in plant height and 21.43% in number of flowers/plant in T_1 treatment (Table 3). Significant increase 7.14% in number of flowers/plant and 9.71% increase in plant height were observed in T_2 treatment over control (Table 4). Water stress (3d and 6d) reduced different morphological parameters in tomato plants but inhibitory effect of water stress was significantly alleviated in the presence of sodium silicate (Figures 3 and 4).

Effect of sodium silicate on tomato fruit development

Maximum number of tomato fruits was developed in T_1 treatment in comparison to T_2 treatment and control. The number of tomato fruits was significantly reduced after water stress treatment and maximum reduction in number of tomato fruits was observed with 6d water stress treatment (Figure 5).

During seed germination process, resumption of metabolic activities and growth of seed tissues starts with water absorption. Sufficient water absorption is essential for proper seed germination and seedling growth (Debeaujan et al., 2000).

Table 2. Effect of sodium silicate on morphological parameters of *Lycopersicon esculentum* Mill. var. Pusa Sheetal at vegetative stage (40 DAS)

Growth parameters	Control	T_1	T_2
Number of leaves /plant	$41^{a} \pm 0.12$	$79^{a} \pm 0.82$ (92.68)*	$68^{a} \pm 0.81$ (65.85)*
Length of leaves	$7.8^{a} \pm 0.05$	$11.2^{a} \pm 0.03$ (43.59)*	$9.2^{b} \pm 0.05$ (17.95)*
Number of branches/plant	$12^{b} \pm 0.07$	$17^{c} \pm 0.09$ (41.67)*	$13^{b} \pm 0.10$ (8.33)*
Plant height	$35.6^{c} \pm 0.27$	$47.8^{c} \pm 0.51$ (34.27)*	$40.8^{c} \pm 0.58$ (14.61)*

Legend: C = Control, T_1 = Pots containing sodium silicate (5 g/10 kg soil); T_2 = Pots containing sodium silicate (7 g/10 kg soil);
*Stimulation percentage over control
Data are mean of three replicates ± sem. Different letters in each group show significant differences at $P < 0.05$

Table 3. Effect of water stress and sodium silicate treatment (T_1) on morphological parameters of *Lycopersicon esculentum* Mill. var. Pusa Sheetal at flowering stage (60 DAS)

Growth parameters	Control	T_1	Water stress treatment in control plants		Water stress (WS_3) + sodium silicate	Water stress (WS_6) +sodium silicate
			(WS_3)	(WS_6)		
Number of leaves /plant	87^{a} ± 0.21	116^{a} ± 0.92 (33.33)*	78^{a} ± 0.12	70^{a} ± 0.02	83^{b} ± 0.82	80^{b} ± 0.24
Length of leaves	12.5^{a} ± 0.09	13.8^{a} ± 0.05 (10.4)*	8.2^{a} ± 0.14	5.9^{a} ± 0.16	9.5^{a} ± 0.04	9.2^{a} ± 0.02
Number of branches/plant	19^{a} ± 0.03	22^{b} ± 0.16 (15.79)*	13^{b} ± 0.02	12^{b} ± 0.10	13^{c} ± 0.21	12^{c} ± 0.12
Plant height	38.7^{b} ± 0.14	50.2^{b} ± 0.21 (29.72)*	37.1^{b} ± 0.74	34.8^{b} ± 0.94	36.8^{a} ± 0.32	34.3^{b} ± 0.81
Number of flowers/plant	14^{c} ± 0.05	17^{c} ± 0.08 (21.43)*	12^{c} ± 0.09	10^{c} ± 0.02	13^{c} ± 0.05	9^{c} ± 0.02

Legend: C = Control, T_1 = Pots containing sodium silicate (5 g/10 kg soil);
*Stimulation percentage over control
Data are mean of three replicates ± sem. Different letters in each group show significant differences at $P < 0.05$

Table 4. Effect of water stress and sodium silicate treatment (T_2) on morphological parameters of *Lycopersicon esculentum* Mill. var. Pusa Sheetal at flowering stage (60 DAS)

Growth parameters	Control	T_2	Water stress treatment in control plants		Water stress (WS_3) + sodium silicate	Water stress (WS_6) + sodium silicate
			(WS_3)	(WS_6)		
Number of leaves /plant	88^{a} ± 0.24	105^{a} ± 0.97 (19.32)*	76^{a} ± 0.09	71^{a} ± 0.02	83^{a} ± 0.91	77^{a} ± 0.12
Length of leaves	11.7^{a} ± 0.05	12.2^{a} ± 0.05 (4.27)*	8.6^{a} ± 0.12	4.9^{a} ± 0.18	9.6^{a} ± 0.05	8.1^{a} ± 0.02
Number of branches/plant	18^{b} ± 0.03	21^{b} ± 0.09 (16.67)*	13^{b} ± 0.09	10^{b} ± 0.14	12^{b} ± 0.21	9^{b} ± 0.16
Plant height	41.2^{c} ± 0.02	45.2^{b} ± 0.24 (9.71)*	35.6^{c} ± 0.72	31.8^{c} ± 0.92	35.2^{d} ± 0.32	31.9^{c} ± 0.72
Number of flowers/plant	14^{c} ± 0.01	15^{c} ± 0.06 (7.14)*	11^{d} ± 0.04	9^{c} ± 0.09	11^{d} ± 0.04	8^{d} ± 0.05

Legend: C = Control, T_2 = Pots containing sodium silicate (7 g/10 kg soil);
*Stimulation percentage over control.
Data are mean of three replicates ± sem. Different letters in each group show significant differences at $P < 0.05$

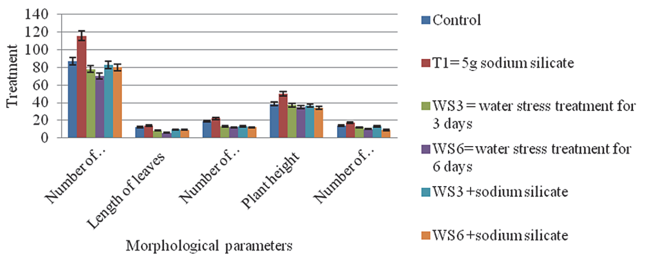

Fig. 3. Effect of sodium silicate (5 g) on the morphological parameters of *Lycopersicon esculentum* Mill. var. Pusa Sheetal at 60 DAS

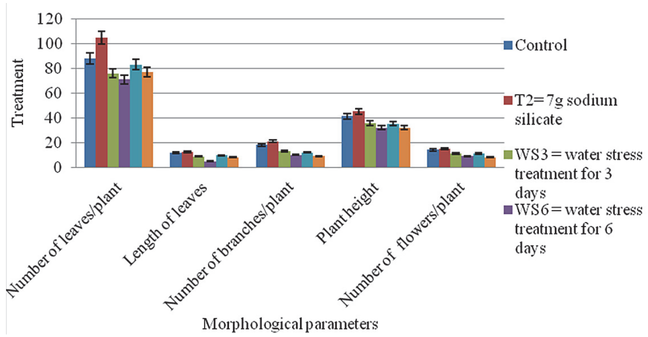

Fig. 4. Effect of sodium silicate (7 g) on the morphological parameters of *Lycopersicon esculentum* Mill. var. Pusa Sheetal at 60 DAS

The absorbed water in the tomato seed is used for activation of hydrolytic enzymes which breaks the complex seed reserves into simple molecules required for cell division, cell differentiation and elongation. The embryonic axis produces gibberellic acid which might have induced the synthesis of amylase, protease, lipase, tryptophan and precursor of IAA (Van Overbeek, 1966). The embryonic cells become turgid by absorption of water and increased turgor pressure caused extension of cell wall. The decrease in water availability has an immediate effect on water status and growth parameters of plants via adverse effect on water absorption transport of water and solute to growing plant organs. Under severe water deficiency, cell elongation can be inhibited by interruption of water flow from xylem to the surrounding elongating cells (Nonami, 1998). The water stress is known to inhibit the water uptake which is required for the synthesis of number of organic compounds i.e. chlorophyll, amino acids, proteins,

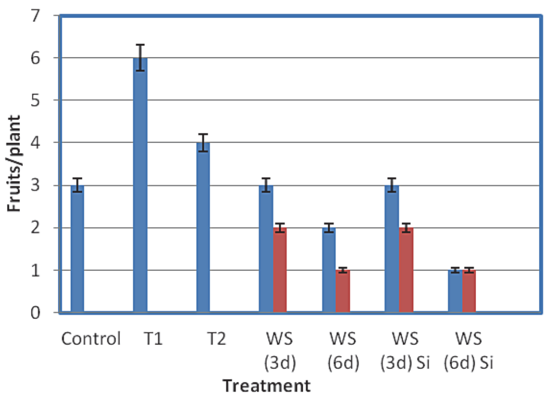

Fig. 5. Effect of sodium silicate treatment on tomato fruit development (*L. esculentum* Mill. var. Pusa Sheetal) at 70 DAS

Legend: *C* = Control, T_1 = Pots containing sodium silicate (5 g/10 kg soil); T_2 = Pots containing sodium silicate (7 g/10 kg soil), *WS* = Water stress

Data are mean of three replicates ± sem. Different letters in each group show significant differences at $P < 0.05$

sugars, phospholipids, growth hormones and nucleotides etc. thereby inhibiting growth of tomato plants under 3d and 6d water stress (Figures 3 and 4). In tomato plants, 3d and 6d water stress might have interfered physiological processes such as photosynthesis, respiration, phosphorylation pathway and inhibition of the activation of Mg^{++} and ATPase activity (Moreland & Novitzky, 1987) which decreased the synthesis of carbohydrate, protein, nucleic acid and mobilization of food reserves. The inhibition in tomato seed germination might be due to inhibition of cell growth which may impede the activation of enzymes responsible for cell growth under water stress (Malhotra et al., 2017). Zargar & Agnihotri (2013) reported that calcium silicate application in the soil increased maize seed germination under water stress.

Plant growth is the outcome of cell division, cell enlargement and differentiation which involves various physiological processes and their interaction. Seed germination and seedling growth are important plant growth stages and these stages are extremely affected by water stress (Siddiqui & Al-Whaibi, 2014). Water stress restricts plant growth due to impaired mitosis, inhibition of cell division and cell enlargement (Sheltal & Balke, 1983; Osakabe et al., 2014). Malcolm & Doug (2002) reported that water deficit condition resulted less number of branches, number of pods/plant, fewer flowers and small sized seeds in *Brassica*. The positive effect of silicon on biomass and yield has been observed in various crops under water deficit condition (Zuccarini, 2008; Pei et al., 2010; Nolla et al., 2012). Similar findings have been reported in the present study (Malhotra et al., 2018). It may be due to greater solubility of sodium silicate in the water which favours its absorption by the tomato plants (Marodin et al., 2014).

In the present study, effect of sodium silicate was concentration dependent. The nutritional properties of sodium silicate promote cell division and expansion of the cells which is a prerequisite for tomato seedling growth. Sodium silicate promoted the absorption of water and ions from the soil which may protect tomato leaves from loss of turgidity. The sodium silicate might stimulate metabolic processes responsible for the biosynthesis of gibberellic acid, protease, amylase, IAA and ATP there by resulting in promotion of tomato seed germination. The increased uptake of Ca^{++} and K^{+} might be attributed to decrease in plasma membrane permeability by added sodium silicate (Kaya et al., 2006). Data of the present investigation clearly indicated that sodium silicate might act as plant growth promoter at higher concentration and enhanced seed germination and growth parameters of tomato (Table 1).

The reduced growth of tomato plants in water stress (3d and 6d) was due to reduced cell division and elongation (Avers and Goodwin, 1956), inhibition in nutrient absorption (Balke & Hodges, 1977), interference with respiration, oxidative phosphorylation (Demos et al., 1975), inhibition in photosynthesis (Colton & Einhellig, 1980) and reduction in dry matter production. The decreased growth of tomato plants might be due to inhibition in synthesis or decreased activity of growth hormones (Borell et al., 1997). Dry matter is an index of productivity (Velu & Thangaraj, 1997) and reduction in tomato plant height might be due to inhibition of germination coupled with low efficiency in dry matter accumulation or inhibition in CO_2 fixation pathway (Uniyal & Nautiyal, 1996). Water stress inhibited dry matter production mainly through its inhibitory effect on leaf expansion which reduced light interception. The reduction in tomato plant height was associated with decline in cell elongation, leaf senescence and turgor loss under 3d and 6d water stress (Manivannan & Ahn, 2017).

Lim et al. (2012) found that supplementation of potassium silicate enhanced fresh and dry weight of Begonia and Pansy plants. Hattori et al. (2005) reported significant improvement in plant biomass by silicon application under water stress. Our results are in conformity with the results of Bae et al. (2010), who reported significant increase in fresh and dry weight of kalanchoe and carnation plants with silicate fertilizers. The use of silicon improved growth and yield of maize under water deficiency (Kaya et al., 2006). A positive impact of silicon on crop yield under water deficit condition has been reported by Silva et al. (2012). Gerami et al. (2012) found that dry weight, plant height and number of tillers of rice plants were increased with increase in silicon content. Datnoff et al. (2001) reported that plants deprived of silicon showed significant reduction in growth and yield as well as increased susceptibility to environmental stresses. Gong et al. (2003) reported that wheat seeds treated with silicon before sowing showed higher plant height, leaf area and dry matter as compared to those without silicon applied in well-watered condition. Water stress during vegetative or early reproductive growth stages reduced soybean (Brevedan & Egli, 2003) and canola (Sinaki et al. 2007) yield by reducing the number of seeds. Water stress exhibited few pods, less seeds/ pod with low biomass of seeds and reduction in seed quality in soybean (Dornbos et al., 1989) and pea (Fougereux et al., 1997) plants.

Reezi et al. (2009) found that addition of potassium silicate to nutrient medium increased number of flowers in *Rosa x hybrida*. Silicon synchronized crop growth and yield as beneficial effects of silicon on plant biomass under water abridged condition were reported in sugarcane (Bokhtiar et al., 2012) and soybean (Shen et al., 2010). Ali et al. (2009) reported that effect of silicon on plant growth was dose and crop specific. Earl & Davis (2003) stated that water stress reduced leaf area, root proliferation, stem elongation, upset plant water relation and subsequently reduced plant growth and yield. The number of leaves, tillers, panicle, and number of spikelet, grain weight and yield were increased due to silicon fertilization in rice (Liang et al., 1994). The positive impact of silicon on rice, barley, wheat, cotton, cucumber, tomato, pumpkin and citrus has been observed in field experiments (Gorecki & Danielski, 2009). Silicon significantly improved the growth of canola; soybean and sorghum seedlings under water stress (Gao et al., 2011; Ahmed et al., 2013). Yin et al. (2014) observed that sodium silicate delayed water stress induced senescence in *Sorghum* by inhibiting ethylene biosynthesis. Markovich et al. (2017) reported that silicon increased cytokinin biosynthesis in *Sorghum* and *Arabidopsis* which was responsible for delay in senescence. Thus, results of the present study strengthen the observations of earlier workers that sodium silicate improves tolerance capacity against water deficit stress in tomato plant.

Conclusion

There is an urgent need that crop growers must be aware about the application of sodium silicate on plants against abiotic stresses. Sodium silicate is non-corrosive and pollution free eco-friendly fertilizer which may help the agriculture sector by increasing the crop production and control of diseases. These efforts will ensure production of safe food with adequate environmental protection.

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References

Ahmed, M., Kamran, A., Asif, M., Qadeer, U., Ahmed, Z. I. & Goyal, A. (2013). Silicon priming: a potential source to impart abiotic stress tolerance in wheat: a review. *Australian Journal of Crop Science, 7,* 484-491.

Ali, A., Basra, S. M. A., Ahmad, R. & Wahid, A. (2009). Optimizing silicon application to improve salinity tolerance in wheat. *Soil and Environment, 28 (2),* 136-144.

Avers, C. J. & Goodwin, R. H. (1956). Studies on roots. IV. Effect of coumarin and scopoletin on the standard root growth pattern of *Phleum pratense*. *American Journal of Botany*, *43*, 612 - 621.

Bae, M. J., Park, Y. G. & Jeong, B. R. (2010). Effect of a silicate fertilizer supplemented to the medium on rooting and subsequent growth of potted plants. *Horticulture, Environment and Biotechnology, 51,* 355-359.

Balke, N. E. & Hodges, T. K. (1977). Inhibition of ion absorption in oat roots: comparison of diethyl-stilbestrol and oligomycin. *Plant Science Letters, 10,* 319-325.

Bodner, G., Nakhforoosh, A. & Kaul, P. (2015). Management of crop water under drought: a review. *Agronomy for Sustainable Development, 35,* 401-442.

Bokhtiar, S. M., Huang, H., Li, Y. & Dalvi, V. A. (2012). Effects of silicon on yield contributing parameters and its accumulation in abaxial epidermis of sugarcane leaf blades using energy dispersive x-ray analysis. *Journal of Plant Nutrition, 35,* 1255-1275.

Borell, A., Garside, A. & Shu, F. K. (1997). Improving efficiency of water for irrigation rice in semi-arid tropical environment. *Field Crop Research, 52,* 231-248.

Brevedan, R. E. & Egli, D. B. (2003). Short periods of water stress during seed filling, leaf senescence and yield of soybean. *Crop Science, 43,* 2083-2088.

Colton, C. E. & Einhellig, E. A. (1980). Allelopathic mechanisms of velvetleaf (*Abutilon theophrasti*) on soybean. *American Journal of Botany, 67,* 1407-1413.

Datnoff, L. E., Snyder, G. H. & Korndorfer, G. H. (2001). Silicon in agriculture. Studies in Plant Science 8. *Elsevier,* Amsterdam.

Debeaujan, I., Karen, M. & Koorneef, L. M. (2000). Influence of the testa on seed dormancy, germination and longevity in *Arabidopsis. Plant Physiology, 122,* 403-413.

Demos, E. K., Woolwine, M., Wilson, R. H. & McMillan, C. (1975). The effect of ten phenolic compounds on hypocotyl growth and mitochondrial metabolism of mungbean. *American Journal of Botany, 62,* 97 - 102.

Dornbos, D. L., Mullen, R. E. & Shibles, R. M. (1989). Drought stress effects during seed fill on soybean seed germination and vigour. *Crop Science, 29,* 476-480.

Earl, H. & Davis, R. F. (2003). Effect of drought stress on leaf and whole canopy radiation use efficiency and yield of maize. *Agronomy Journal, 95,* 688-696.

Epstein, E. (1999). Silicon. *Annual Review of Plant Physiology and Plant Molecular Biology, 50,* 641-664.

Epstein, E. (2009). Silicon: its manifold roles in plants. *Annals of Applied Biology, 155,* 155-160.

Etesami, H. & Beattie, G. A. (2017). Plant-microbe interactions in adaptation of agricultural crops to abiotic stress conditions. *Probiotics and Plant Health, Springer,* 163-200.

Etesami, H. & Jeong, B. R. (2018). Silicon (Si): review and future prospects on the action mechanisms in alleviating biotic and abiotic stresses in plants. *Ecotoxicology and Environmental Safety, 147,* 881-896.

Fougereux, J., Labdonne, F. & Fleury, A. (1997). Water stress during reproductive stages affects seed quality and yield of pea (*Pisum sativum* L.). *Crop Science, 37,* 1247-1252.

Frison, E., Cherfas, J. & Hodgkin, T. (2011). Agricultural biodiversity is essential for a sustainable improvement in food and nutrition security. *Sustainability, 3*, 238-253.

Frusciante, L., Carli, P., Maria, R., Ercolano, S., Pernice, R., Matteo, A. D., Fogliano, V. & Pellegrini, N. (2007). Antioxidant nutritional quality of tomato. *Molecular Nutrition and Food Research, 51,* 609-617.

Gao, D., Cai, K., Chen, J., Luo, S., Zeng, R., Yang, J. & Zhu, X. (2011). Silicon enhances photochemical efficiency and adjusts mineral nutrient absorption in *Magnaporthe oryzae* infected rice plants. *Acta Physiologiae Plantarum, 33(3),* 675-682.

Gerami, M., Fallah, A. & Khatami Moghadam, M. R. (2012). Study of potassium and sodium silicate on the morphological and chlorophyll content on the rice plant in pot experiment (*Oryza sativa* L.). *International Journal of Agriculture and Crop Sciences. 4(10),* 658-661.

Gong, H. J. & Chen, K. M. (2012). The regulatory role of silicon on water relations, photosynthetic gas exchange and carboxylation activities of wheat leaves in field drought conditions. *Acta Physiologiae Plantarum, 34,* 1589-1594.

Gong, H. J., Chen, K. M., Chen, C. C., Wang, S. M. & Zhang, C. L. (2003). Effect of silicon on growth of wheat under drought. *Journal of Plant Nutrition, 26,* 1055-1063.

Gorecki, R. S. & Danielski, B. W. (2009). Effect of silicate fertilizers on yielding of greenhouse cucumber (*Cucumis sativus* L.) in container cultivation. *Journal of Elementology, 14(1),* 71-78.

Goswami, D., Thakker, J. N. & Dhandhukia, P. C. (2016). Portraying mechanics of plant growth promoting rhizobacteria: A review. *Cogent Food and Agriculture, 2,* 1-19.

Gundersen, K., Orcutt, K. M., Purdie, D. A., Michaels, A. F. & Knap, A. H. (2001). Particulate organic carbon mass distribution at the Bermuda Atlantic Time-series Study (BATS) site, *Deep Sea Research. Part II. 48,* 1697 - 1718.

Gunes, A., Pilbeam, D. J., Inal, A. & Coban, S. (2008). Influence of silicon on sunflower cultivars under drought stress. I: growth, antioxidant mechanisms and lipid peroxidation. *Communications in Soil Science and Plant Analysis, 39,* 1885-1903.

Hattori, T., Inanaga, S., Araki, H., An, P., Morita, S., Luxov, M. & Lux, A. (2005). Application of silicon enhanced drought tolerance in *Sorghum bicolor*. *Physiologia Plantarium, 123,* 459-466.

Kaya, C., Tuna, L. & Higgs, D. (2006). Effect of silicon on plant growth and mineral nutrition of maize grown under water-stress conditions. *Journal of Plant Nutrition, 29,* 1469-1480.

Keller, C., Rizwan, M., Davidian, J. C., Pokrovsky, O. S., Bovet, N. & Chaurand, P. (2015). Effect of silicon on wheat seedlings (*Triticum turgidum* L.) grown in hydroponics and exposed to 0 to 30 μM Cu. *Planta, 241,* 847-860.

Khandakar, A. I. & Bradbear, J. W. (1983). Jute seed quantity. *Bangladesh Agriculture Research Council,* Dhaka.

Li, Y. (2008). Effect of salt stress on seed germination and seedling growth of three salinity plants. *Pakistan Journal of Biological Sciences, 11,* 1268-1272.

Liang, Y. C., Ma, T. S., Li, F. J. & Feng, Y. J. (1994). Silicon availability and response of rice and wheat to silicon in calcareous soils. *Communications in Soil Science and Plant Analysis, 25,* 2285-2297.

Lim, M. Y., Lee, E. J., Jana, S., Sivanesan, I. & Jeong, B. R. (2012). Effect of potassium silicate on growth and leaf epidermal characteristics of begonia and pansy grown *in vitro*. *Korean Journal of Horticultural Science and Technology, 30,* 579-585.

Lipiec, J., Doussan, C., Nosalewicz, A. & Kondracka, K. (2013). Effect of drought and heat stresses on plant growth and yield: a review. *International Agrophysics, 27(4),* 463-477.

Lobato, A. K. S., Coimbra, G. K., Neto, M. A. M., Costa, R. C. L., Santos Filho, B. G., Oliveira Neto, C. F., Luz, L. M., Barreto, A. G. T., Pereira, B. W. F., Alves, G. A. R., Monteiro, B. S. & Marochio, C. A. (2009). Protective action of silicon on relations and photosynthetic pigments in pepper plants induced to water deficit. *Research Journal of Biological Sciences, 4,* 617-623.

Ma, J. F. & Yamaji, N. (2006). Silicon uptake and accumulation in higher plants. *Trends in Plant Science, 11,* 392-397.

Malcolm, J. M. & Doug, W. S. (2002). Heat stress during flowering in summer *Brassica*. *Crop Sciences, 42,* 797-803.

Malhotra, C., Kapoor, R. T., Ganjewala, D. & Singh, N. B. (2017). Sodium silicate mediated response of antioxidative defense system in *Lycopersicon esculentum* Mill. under water stress. *International Journal of Phytomedicine, 9,* 364-378.

Malhotra, C., Kapoor, R. T., Ganjewala, D. & Singh, N. B. (2018). Effect of sodium silicate on the growth and physiological attributes of tomato. *International Journal of Applied Agricultural and Horticultural Sciences, 9 (2),* 290-295.

Manivannan, A. & Ahn, Y. K. (2017). Silicon regulates potential genes involved in major physiological processes in plants to combat stress. *Frontiers in Plant Science, 8(1346),* 1-13.

Marafon, A. C. & Endres, L. (2013). Silicon: fertilization and nutrition in higher plants. *Revista de cienciasagrarias, 6,* 80-88.

Markovich, O., Steiner, E., Kouřil, S., Tarkowski, P., Aharoni, A. & Elbaum, R. (2017). Silicon promotes cytokinin biosynthesis and delays senescence in *Arabidopsis* and *Sorghum*. *Plant, Cell and Environment, 40,* 1189-1196.

Marodin, J. C., Resende, J. T. V., Morales, R. G. F., Silva, M. L. S., Galvao, A. G. & Zanin, D. S. (2014). Yield of tomato fruits in relation to silicon sources and rates. *Horticultura Brasileira, 32,* 220-224.

Meena, K. K., Sorty, A. M., Bitla, U. M., Choudhary, K., Gupta, P., Pareek, A., Singh, D. P., Prabha, R., Sahu, P. K., Gup-

ta, V. K., Singh, H. B., Krishanani, K. K. & Minhas, P. S. (2017). Abiotic stress responses and microbe-mediated mitigation in plants: The omics strategies. *Frontiers in Plant Science, 8(172),* 1-25.

Moreland, D. E. & Novitzky, W. P. (1987). Effects of phenolic acids, coumarins and flavonoids on isolated chloroplasts and mitochondria. In: *Allelochemicals: Role in Agriculture and Forestry* (Ed. Waller, G. R.), ACS Symposium Series, 330. American Chemical Society. Washington, DC. 247 - 261.

Nezhadahmadi, A., Prodhan, Z. & Faruq, G. (2013). Drought tolerance in wheat. *The Scientific World Journal, 13,* 1-12.

Nolla, A., Faria, R. J., Korndorfer, G. H. & Silva, T. R. B. (2012). Effect of silicon on drought tolerance of upland rice. *Journal of Food Agriculture and Environment, 10,* 269-272.

Noman, A., Ali, Q., Naseem, J., Javed, M. T., Kanwal, H., Islam, W., Aqeel, M., Khalid, N., Zafar, S., Tayyeb, M., Iqbal, N., Buriro, M., Maqsood, J. & Shahid, S. (2018). Sugar beet extract acts as a natural bio-stimulant for physiobiochemical attributes in water stressed wheat (*Triticum aestivum* L.*). Acta Physiologiae Plantarum, 40,* 1-17.

Nonami, H. (1998). Plant water relations and control of cell elongation at low water potentials. *Journal of Plant Research, 111,* 373-382.

Osakabe, Y., Osakabe, K., Shinozaki, K. & Tran, L. S. P. (2014). Response of plants to water stress. *Frontiers in Plant Science, 5,* 1-8.

Pei, Z. F., Ming, D. F., Liu, D., Wan, G.L., Geng, X. X., Gong, H. J. & Zhou, W. J. (2010). Silicon improves the tolerance to water-deficit stress induced by polyethylene glycol in wheat (*Triticum aestivum* L.) seedlings. *Journal of Plant Growth Regulation, 29,* 106-115.

Reezi, S., Babalar, M. & Kalantari, S. (2009). Silicon alleviates salt stress, decreases malondialdehyde content and affects petal color of salt-stressed cut rose (*Rosa x hybrida* L.) "Hot Lady". *African Journal of Biotechnology, 8:* 1502-1508.

Sacala, E. (2009). Role of silicon in plant resistance to water stress. *Journal of Elementology. 14,* 619-630.

SapreSarang, S. & Vakharia Dinesh, N. (2016). Role of silicon under water deficit stress in wheat (Biochemical perspective): A review. *Agricultural Reviews, 37(2),* 109-116.

Shao, H., Chu, L., Jaleel, C. A. & Zhao, C. (2008). Water deficit stress-induced anatomical changes in higher plant. *Comptes Rendus Biologies, 331,* 215-225.

Sheltel, N. L. & Balke, N. E. (1983). Plant growth response to several allelopathic chemicals. *Weed Science, 31,* 293- 298.

Shen, X., Zhou, Y., Duan, L., Li, Z., Eneji, A. E. and Li, J. (2010). Silicon effects on photosynthesis and antioxidant parameters of soybean seedlings under drought and ultraviolet-B radiation. *Journal of Plant Physiology, 167(15),* 1248-1252.

Siddiqui, M. H. & Al-Whaibi, M. H. (2014). Role of nano-SiO_2 in germination of tomato (*Lycopersicum esculentum* Mill.). *Saudi Journal of Biological Sciences, 21,* 13-17.

Silva, O. N., Lobato, A. K. S., Avila, F. W., Costa, R. C. L., Oliveira Neto, C. F., Santos Filho, B. G., A. P., Martins Filho, Lemos, R. P., Pinho, J. M., Medeiros, M. B. C. L., Cardoso, M. S. & Andrade, I. P. (2012). Silicon-induced increase in chlorophyll is modulated by the leaf water potential in two water-deficient tomato cultivars. *Plant, Soil and Environment, 58,* 481- 486.

Sinaki, J. M., Majidi Heravan, E., Shirani Rad, A. H., Noormohamadi, G. & Zarei, G. (2007). The effects of water deficit during growth stages of canola (*Brassica napus* L.). *American-Eurasian Journal of Agricultural and Environmental Sciences, 2(4),* 417- 424.

Son, M. S., Song, J. Y., Lim, M. Y., Sivanesan, I. & Jeong, B. R. (2011). Effect of silicon on tolerance to high temperature and drought stress in *Euphorbia pulcherrima* wild. Ichiban. In: *Proceedings of the 5th International Conference on Silicon in Agriculture.* September 13-18, Beijing, China. 1-188.

Sonobe, K., Hattori, T., An, P., Tsuji, W., Eneji, A. E., Kobayashi, S., Kawamura, Y., Tanaka, K. & Inanaga, S. (2011). Effect of silicon application on sorghum root responses to water stress. *Journal of Plant Nutrition, 34,* 71-82.

Uniyal, R. C. & Nautiyal, A. R. (1996). Allelopathic interactions of tree species with crops. In: Narwal, S. S. and Tauro, P. (Eds.) *Allelopathy: Field Observation and Methodology Scientific Publishers, Jodhpur, India,* 303-307.

Van Bockhaven, J., De Vleesschauwer, D. & Hofte, M. (2013). Towards establishing broad-spectrum disease resistance in plants: silicon leads the way. *Journal of Experimental Botany, 64*, 1281-1293.

Van Overbeek, J. (1966). Plant hormones and regulators. *Science, 152,* 721 - 731.

Velu, G. & Thangaraj, M. (1997). Allelopathic response of *Parthenium* to leaf leachates of certain plants. In: Mahadevappa, M. and Patil, V. C. (Eds.) *Proceedings of the First International Conference on Parthenium Management*. University of Agricultural Sciences, Dharwad, Karnataka, India*, 2,* 50-52.

Yin, L., Wang, S., Liu, P., Wang, W., Cao, D. & Deng, X. (2014). Silicon-mediated changes in polyamine and 1-aminocyclopropane-1-carboxylic acid are involved in silicon-induced drought resistance in *Sorghum bicolor* L. *Plant Physiology and Biochemistry, 80,* 268-277.

Zargar, S. M. & Agnihotri, **A.** (2013). Impact of silicon on various agro-morphological and physiological parameters in maize and revealing its role in enhancing water stress tolerance. *Emirates Journal of Food and Agriculture, 25 (2),* 138-141.

Zhang, J. Y., Cruz de Carvalho, M. H. & Torres-Jerez, I. (2014). Global reprogramming of transcription and metabolism in *Medicago truncatula* during progressive drought and after rewatering. *Plant, Cell and Environment, 37,* 2553-2576.

Zhu, Y. & Gong, H. (2014). Beneficial effects of silicon on salt and drought tolerance in plants. *Agronomy for Sustainable Development. 34,* 455-472.

Zuccarini, P. (2008). Effects of silicon on photosynthesis, water relations and nutrient uptake of *Phaseolus vulgaris* under NaCl stress. *Biologia Plantarum, 52,*157-160.

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