International Journal of Chemical and Biochemical Sciences
(ISSN 2226-9614)

Journal Home page: www.iscientific.org/Journal.html

Stimulating impact of silicon supplementation on the growth and biochemical parameters of *Lycopersicon esculentum* Mill.

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Abstract

The present paper deals with the impact of sodium silicate on the morphological and biochemical parameters of tomato seedlings. The high concentration of sodium silicate (3mM) significantly increased the growth parameters and biochemical components such as pigment content, sugar, proline, protein and total antioxidant contents in the seedlings of *Lycopersicon esculentum* Mill. variety Pusa Sheetal. Maximum seed germination 98% was observed in T_3 treatment. Increase in seed germination percentage and other growth characteristics followed the order: T_3> T_2> T_1> control. Maximum increase 97.06% in total antioxidant content was recorded in the tomato seedlings treated with 3 mM concentration of sodium silicate. The results of the present investigation clearly indicate that sodium silicate acts as a plant growth promoter at higher concentration and it can be used as fertilizer for tomato crop.

Key words: Biochemical parameters, Growth, *Lycopersicon esculentum*, Sodium silicate.

Full length article Received: 23-10-2015 Revised: 25-11-2015 Accepted: 26-12-2015 Available online: 31-12-2015

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1. Introduction

Silicon is an important element of earth's crust and it is tetravalent metalloid compound. It is an essential element for higher plants because its deficiency may cause various abnormalities in the plants during vegetative and reproductive phases of growth and development. Silicon also acts as an agronomically important fertilizer element that enhances tolerance capacity of plants to abiotic and biotic stresses (Ma,2004; Liang et al., 2005). Silicon alleviates the adverse effects of salt stress, high temperature and heavy metal toxicity in plants (Liang et al., 2007; Epstein, 2009; Shen et al., 2010). Datnoff et al. (2001) reported that the plants deprived of silicon show significant reduction in growth and yield as well as increases susceptibility to both abiotic and biotic stresses. The presence of silicon in the cell wall fibre makes the cell wall tough and resistant to pest and pathogen attack (Hamayun et al., 2010). Silicon performes structural and metabolic functions in the plants and generates many benefits which may result in increase of the productivity of several plant species (Almeida et al., 2009).Silicon can reduce the transpiration rate, increases chlorophyll content, photosynthetic rate, intercellular CO_2 concentration, stomatal conductance, maintains a high leaf area index and improves canopy structure, energy efficiency and increases dry matter accumulation in rice (Fengying et al., 2014). According to Jiaojiao et al. (2013) silicon improves morphological structure of plants, enhances root activity, reduces the transpiration rate, improves plant resistance to biotic and abiotic stress and also enhances the adaptation capacity of plants to adverse environmental conditions.

Lycopersicon esculentum Mill.is popularly known as tomato and it is an important, popular and nutritious vegetable all over the world. It belongs to the Solanaceae family. The fruits can be eaten raw or cooked and it is used to make several valuable products such as juice, ketchup, sauce, paste and powder etc. (Bose and Som, 1986). *Lycopersicon esculentum* Mill. is important source of minerals, fiber and antioxidants such as carotenoids, lycopene, phenolic compounds and vitamins. The antioxidants like lycopene present in tomato play significant role in prevention of cancer and cardiovascular diseases (Rao and Agarwal, 2000). Silicon promotes plant growth and has a unique role in conferring tolerance in plants to various abiotic and biotic stresses (Liang et al., 2007). Growth of plants and yield improvement by silicon application have been documented in many monocot and dicot species including wheat (Gong et al., 2005), soybean (Shen et al., 2010) and rice (Liang et al.,2013) plants. Several authors have also reported that silicon improves the water use efficiency of the plants and stimulates enzymatic and non-enzymatic antioxidative defense system (Cooke and

Leishman, 2011). The survey of pertinent literature reveals that no studies have been done till date to know the impact of sodium silicate on the growth and biochemical parameters of tomato. Hence, the present study was designed to test the above hypotheses and to provide first-hand data on the effect of sodium silicate on the seed germination, growth and biochemical parameters of *Lycopersicon esculentum* Mill.

2. Material and Methods

The present experiment was conducted during February - April, 2015 in the Plant Physiology Laboratory, Amity Institute of Biotechnology, Amity University, Noida, India.

2.1. Geographical position of the study site

Noida is an administrative headquarters of the Gautam Budh Nagar district (latitude 28° 32' N and longitude 77° 28' E, 200 m above the sea level). The district occupies an area of about 1442 sq km and the total population of the region is approximately 1,674,714 as per the 2011 census.

2.2. Collection of the tomato seeds

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

2.3. Experimental design

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 such as 1mM (T_1), 2mM (T_2) and 3mM (T_3) were prepared with distilled water and used for the treatment.

2.4. Petri plate culture

Before seed germination test, empty and undeveloped tomato seeds were discarded by floating in tap water. Seeds of tomato were thoroughly washed with tap water to remove dirt and dust for 5 min. To avoid the inhibition caused by toxins of fungi or bacteria, seeds were surface sterilized with 10:1 distilled water/ bleach (commercial NaOCl) solution for 5 min and then washed 6-7 times with distilled water. Thirty seeds were divided into three replicates of 10 seeds each were soaked for 6 hours in 10 ml of different concentrations of sodium silicate. Control seeds were soaked in 10 ml distilled water. The tomato seeds were allowed to germinate in 20 cm diameter petridishes with a tight - fitting lid and seedling were maintained in a growth chamber under the controlled temperature (23±2°C), photoperiod 16/8 hrs and photon flux density was kept 240 µmol $m^{-2}s^{-1}$. The petridishes were covered and placed in sterilized polythene bags for 10 days. Petridishes were kept moist by adding 1 ml of different concentrations of sodium silicate or distilled water as and when required according to the treatments. Germination was determined by counting the number of germinated seeds at 24 hours interval till 10 days.

2.5. Determination of growth parameters

Different growth characteristics of tomato (*Lycopersicon esculentum* Mill. var. Pusa Sheetal) such as germination percentage, relative germination rate, germination index, seedling length, biomass and vigour index were determined in control and treatment by the following formula (Li, 2008):

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

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

(3). 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.

(4). Speed of germination index

The number of tomato seedlings emerging daily were 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).

$S = (N_1/1+N_2/2+ N_3/3…..N_n/n)$

where N_1, N_2, N_3……Nn, proportion of seeds which germinated on day 1, 2, 3 .....n

following setup of the experiment.

2.6. Seedling length

The radicle and plumule length were measured with a measuring scale and values were expressed in cms (ISTA, 2008). Seeds were considered to be germinated with the emergence of both plumule and radicle.

2.7. Vigour index

Vigour index of the tomato seedlings was estimated by the formula of Abdul - Baki and Anderson (1973).

Vigour index (VI) = Total seedling length (mm) x germination percentage

2.8. Biomass estimation

Fresh weight of the tomato seedlings of control and treatment was measured after 10 days of seed sowing. After that, the seedlings were oven dried at 65^0C for 72 hours and dry weight was also estimated.

2.9. Relative water content

For the measurement of relative water content (RWC), the fresh weight (FW) of the seedlings was measured and these seedlings were immediately floated on distilled water at 25°C in the darkness. After 12 h, the turgid weight (TW) was measured and then seedlings were dried in an oven at 80°C for 48 h for the dry weight (DW). The RWC was calculated by the modified method of Bars and Weatherly (1962).

RWC (%) = (FW-DW) / (TW-DW) × 100

2.10. Estimation of photosynthetic pigment

The amount of chlorophyll can be determined in the tomato seedlings by the method of Lichtenthaler (1987). The leaves (10 mg) of control and treatment were grounded with 10 ml of 80% acetone and centrifuged at 3000 rpm for 10 minutes. The optical density of the supernatant was measured at 645 and 663 nm and the amount of carotenoids was determined at 470nm.

The determination of chlorophyll a, chlorophyll b and total chlorophyll can be done by applying the following formula:

$$\textbf{Total Chlorophyll}\ (\text{mg/g}) = \frac{20.2 \times \text{OD645} + 8.02 \times \text{OD663} \times \text{V}}{100 \times \text{W}}$$

$$\textbf{Chlorophyll a}\ (\text{mg/g}) = \frac{12.7 \times \text{OD663} - 2.69 \times \text{OD645} \times \text{V}}{100 \times \text{W}}$$

$$\textbf{Chlorophyll b}\ (\text{mg/g}) = \frac{22.9 \times \text{OD645} - 4.68 \times \text{OD663} \times \text{V}}{100 \times \text{W}}$$

Where, V = volume of the supernatant in ml, W = fresh weight of the leaves in g and OD = optical density.

Chlorophyll stability index (CSI)

Chlorophyll stability index (CSI) was determined according to the method of Sairam et al. (1997) and calculated by the formula: CSI = Total chlorophyll under treatment/ Total chlorophyll under control x 100

2.11. Measurement of sugar content

Total soluble sugar present in the tomato seedlings was quantified according to the method of Hedge and Hofreiter (1962). Tomato seedlings (100 mg) were homogenized in 5 ml 95% ethanol. The homogenate was centrifuged at 4000*g* for 15min. The supernatant (0.1ml) was mixed with 0.9 ml distilled water and 4ml anthrone solution. The reaction mixture was boiled in the water bath for 15 min. Absorbance was recorded at 620nm after cooling and the amount of sugar was calculated with reference to standard curve prepared from glucose.

2.12. Estimation of free proline

Determination of proline was performed according to the method of Bates et al. (1973). Leaf samples were extracted with 3% sulphosalicylic acid. An aliquot was treated with acid-ninhydrin and acetic acid and boiled for 1 h at 100°C. The reaction mixture was extracted with 4 ml of toluene. The absorbance of chromophore containing toluene was determined at 520 nm. Proline content was expressed as µmol g^{-1}FW using a standard curve.

2.13. Estimation of protein

Quantitative estimation of protein was done following the method of Lowry et al. (1951).

Stock solution of the following reagents were prepared :

(a) Alkaline sodium carbonate solution (0.2 % Na_2CO_3 in 0.1 N NaOH).

(b) Copper sulphate - sodium potassium tartarate solution (0.5% $CuSO_4$. $5H_2O$ in 1% sodium potassium tartarate).

(c) Alkaline copper reagent: Mixed 50 ml of reagent A and 1 ml of reagent B.

(d) Folin - Ciocalteu reagent, dilute the reagent with equal volume of water just before use.

(e) 1 N NaOH

The dried tomato seedlings of control and treatment were homogenized with 1 ml of 1 N NaOH for 5 min at 100^0C. Alkaline copper reagent (5 ml) was added to it and allowed the mixture to stand at room temperature for 10 min. 0.5 ml of Folin - Ciocalteu reagent was added immediately and mixed the contents in the tube. The absorbance of the solution was measured at 650 nm after 30 min. The amount of protein was calculated with reference to standard curve of lysozyme.

2.14. Evaluation of total antioxidant content

The total antioxidant content in the tomato seedlings was evaluated by the method of Prieto et al.(1999). Total antioxidant capacity was quantified in a sample solution containing 0.1 ml of sample prepared by incubating tomato seedlings (150 mg) in 3 ml of ethanol, 3 ml of reagent solution (0.6 M sulphuric acid, 28 mM sodium phosphate and 4 mM ammonium molybdate).The absorbance of the test sample was measured at 695 nm.

Statistical analysis

All the treatments were 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 means were analyzed by Duncan's multiple range test (DMRT) at $p < 0.05$.

3. Results and Discussion

3.1. Effect of experiment variables

Effect of different concentrations of sodium silicate was studied on the growth and biochemical parameters of *Lycopersicon esculentum* Mill.

Seed germination and growth parameters

The significant differences were observed among various treatments for all the parameters studied i.e. seed germination, relative germination rate, germination index and other growth characteristics such as radicle and plumule length, vigour index, fresh and dry weight of the tomato seedlings. Significant increase in seed germination and growth parameters of tomato was observed with the increase in concentration of sodium silicate. 82% tomato seeds were germinated in control. Maximum seed germination 98% was observed in T_3 treatment and it was 19.51% more than control. Germination index and speed of germination index were also higher in T_3 treatment in comparison to other treatments and control (Table 1). The radicle and plumule length, fresh and dry weight and vigour index were recorded in control and treatment. The seedlings of tomato showed significant increase in fresh and dry weight with different concentrations of sodium silicate in comparison to control (Table 2). 6.43g fresh weight of tomato seedlings was observed in control and it was further increased to 8.17, 9.35 and 12.82g in T_1, T_2 and T_3 treatments respectively. Similarly highest dry weight (4.88g) was observed in T_3

treatment. Higher vigour index was observed in treatment in comparison to control. Relative water content was also higher in different treatments over control and maximum 91.16% relative water content was observed in tomato seedlings in T_3 treatment. Increase in seed germination percentage and other growth characteristics followed the order: $T_3 > T_2 > T_1 >$ control(Table 1 and 2).

Pigment content

The amount of chlorophyll was increased in the seedlings of *Lycopersicon esculentum* Mill. treated with different concentrations of sodium silicate and maximum increase was observed with 3 mM concentration of aqueous sodium silicate solution. 2.87 mg/g, 3.63 mg/g and 3.95 mg/g total chlorophyll content were recorded in tomato seedlings treated with 1 mM, 2 mM and 3 mM concentrations of sodium silicate respectively as compared with 2.26 mg/g in control. Maximum increase 74.78% in total chlorophyll content was recorded in T_3 treatment (Table 3). The chlorophyll stability index (CSI) was also measured and it was highest in T_3 treatment. Significant increase in carotenoids was observed in T_3 treatment over the control. The increase in pigment content (Chlorophyll a, b, total chlorophyll content and carotenoids) was in order: $T_3 > T_2 > T_1 >$ control.

Proline content

Significant increase has been observed in proline content in *Lycopersicon esculentum* Mill. seedlings by increase in the concentration of sodium silicate. Maximum increase (77.94%) was observed in proline content in T_3 treatment over control (Table 4).

Sugar content

The aqueous solution of sodium silicate significantly increased sugar content in the seedlings of *Lycopersicon esculentum* Mill. The sugar content 84.72 mg/g, 89.31 mg/g and 92.54 mg/g were recorded in tomato seedlings with 1 mM, 2 mM and 3 mM concentrations of sodium silicate respectively as compared with 78.84 mg/g in control. Maximum increase 17.38% in sugar content was recorded in tomato seedlings with 3 mM concentration of sodium silicate (Table 4).

Protein content

The aqueous solution of sodium silicate significantly increased total protein content in the seedlings of *Lycopersicon esculentum* Mill. The total protein content 52.86 mg/g, 61.04 mg/g and 64.52 mg/g were recorded in tomato seedlings with 1 mM, 2 mM and 3 mM concentrations of sodium silicate respectively as compared with 49.24 mg/g in control. Maximum increase 31.03% in protein content was recorded in tomato seedlings with 3 mM concentration of sodium silicate (Table 4).

Total antioxidant content

Total antioxidants can be considered as plant defense against oxidative stress. Significant increase in total antioxidant contents in seedlings of *Lycopersicon esculentum* Mill. was observed and it followed the order: $T_3 > T_2 > T_1 >$ control (Figure 1).Maximum increase 97.06% was recorded in total antioxidant content of tomato seedlings with 3 mM concentration of sodium silicate.

During seed germination process, resumption of metabolic activities and growth of the seed tissues starts with the water absorption. Sufficient water absorption is essential for proper seed germination, without which seedling growth and development is severely affected (Debeaujan et al., 2000). The absorbed water in the seed is used for activation of hydrolytic enzymes, which breaks the complex seed reserves into the simple molecules needed for various metabolic activities such as cell division, differentiation and cell elongation (Groot and Karssen, 1992).Growth of the cells is measured as an increasing cell number or fresh weight of the packed cells. The treatment of tomato seeds with aqueous sodium silicate solution promotes the seed germination in comparison to control. It may be due to the nutritional properties of sodium silicate which promotes the division, elongation and expansion of the cells which is a prerequisite for seedling growth. Sodium silicate promotes the absorption of water and ions from the soil which may protect the cells from the loss of turgidity and also activate the metabolic activities of cells. Silicon may deposited in the plant cell wall which improves the structural rigidity of cell wall and provides strength to the plant architecture. It has been well documented that silicon positively affect plant growth and stress resistance (Broadley et al., 2012). Silicon fertilization leads to increased volume and weight of roots (Sonobe et al., 2011) and it also increases 35-40% water retention capacity of the soil. The utilization of silicon increases root water uptake capacity of sorghum plants (Sonobe et al., 2011).Silicon has been proven to be beneficial element for the healthy growth and development of many plant species (Broadley et al., 2012). Silicon stimulates growth of rice plants and other Poaceae family members by increasing cell wall extensibility (Hossain et al., 2002).Positive correlation was observed between the concentration of sodium silicate and seed germination and other growth parameters of tomato in the present study (Table 1 and 2). Data of the present paper clearly indicates that sodium silicate may act as plant growth promoter at higher concentration and may enhance the seed germination and other growth parameters. Enhancement in germination and growth parameters may be due to the increase in the synthesis of indole acetic acid and gibberellins. The sodium silicate might have increased the protease and α-amylase activity in the tomato seeds which results in increase of protein and carbohydrates which promotes the seed germination. Lim et al. (2012) found that supplementation of potassium silicate enhances fresh and dry weight of begonia and pansy plants. Our results are in accordance to Bae et al. (2010), who reported that fresh and dry weights of kalanchoe and carnation plants were higher with silicate fertilizers.

Table 1: Effect of different concentrations of sodium silicate on the seed germination of *Lycopersicon esculentum* L.Mill.

Treatment	Germination (%)	Relative germination rate (RGR)	Germination Index (GI)	Speed of Germination Index (GI)
C	82 ± 0.98	-	8.2± 0.02	62.54± 0.73
T_1	86± 0.96 (4.88)	1.05 ± 0.02[a]	8.6± 0.04	74.62± 0.81[a]
T_2	90± 0.84[b] (9.76)	1.09 ± 0.06[a]	9± 0.08[d]	77.74± 0.87[a]
T_3	98± 0.72[b] (19.51)	1.19 ± 0.09[a]	9.8± 0.17[d]	87.32± 0.93

Where; C=Control, T_1=1mM sodium silicate, T_2=2mM sodium silicate, T_3= 3 mM sodium silicate
Data are mean of three replicates ± sem
Mean ± sem values followed by same letters within each column are not significantly different at 0.05 (ANOVA and Duncan's multiple range test).

Table 2: Effect of different concentrations of sodium silicate on the growth parameters of *Lycopersicon esculentum* L.Mill.

Treatment	Radicle length (cms)	Plumule length (cms)	Vigour index	Fresh weight (gm)	Dry weight (gm)	Relative water content (%)
C	4.9± 0.01	8.3± 0.02	10824	6.43± 0.52	1.91± 0.09	76.48± 0.54
T_1	5.3± 0.03	9.8± 0.06	12986	8.17± 0.63[b]	2.39± 0.54	86.01± 0.68[d]
T_2	7.5± 0.06	13.6± 0.09[a]	18990	9.35± 0.81[b]	3.68± 0.75[a]	83.63± 0.79[d]
T_3	8.2± 0.08	15.9± 1.04[a]	23618	12.82± 0.92	4.88± 0.89[a]	91.16± 0.80

Where; C=Control, T_1=1mM sodium silicate, T_2=2mM sodium silicate, T_3= 3 mM sodium silicate.
Data are mean of three replicates ± sem
Mean ± sem values followed by same letters within each column are not significantly different at 0.05 (ANOVA and Duncan's multiple range test).

Table 3: Effect of different concentrations of sodium silicate on the pigment content of *Lycopersicon esculentum* L.Mill.

Treatment	Chlorophyll a (mg/g FW)	Chlorophyll b (mg/g FW)	Chlorophyll a/b ratio	Total chlorophyll (mg/g FW)	Chlorophyll stability index (CSI)	Carotenoids (mg/g FW)
C	1.32 ± 0.03	0.94 ± 0.01	1.40 ± 0.06	2.26 ± 0.58	-	1.14 ± 0.05
T_1	1.85 ± 0.19	1.02 ± 0.07	1.81 ± 0.21	2.87 ± 0.63 (26.99)	126.99	1.93 ± 0.17 (69.29)
T_2	2.29 ± 0.28[a]	1.34 ± 0.16	1.71 ± 0.32[b]	3.63 ± 0.79[c] (60.62)	160.62	2.10 ± 0.23[e] (84.21)
T_3	2.45 ± 0.75[a]	1.50 ± 0.22	1.63 ± 0.49[b]	3.95 ± 0.92[c] (74.78)	174.78	2.22 ± 0.64[e] (94.74)

Where; C=Control, T_1=1mM sodium silicate, T_2=2mM sodium silicate, T_3= 3 mM sodium silicate.
Data are mean of three replicates ± sem
Mean ± sem values followed by same letters within each column are not significantly different at 0.05 (ANOVA and Duncan's multiple range test).

Table 4: Effect of different concentrations of sodium silicate on the biochemical components of *Lycopersicon esculentum* L.Mill.

Treatment	Sugar (mg/g FW)	Proline (µmol/g FW)	Protein (mg/g FW)
C	78.84± 0.32	0.68± 0.02[a]	49.24± 0.24
T_1	84.72± 0.45 (7.46)	0.75± 0.04[a] (10.29)	52.86± 0.31 (7.35)
T_2	89.31± 0.58[a] (13.28)	0.92± 0.05 (35.29)	61.04± 0.62[d] (23.96)
T_3	92.54± 0.62[a] (17.38)	1.21± 0.46 (77.94)	64.52± 0.79[d] (31.03)

Where; C=Control, T_1=1mM sodium silicate, T_2=2mM sodium silicate, T_3= 3 mM sodium silicate.
Data are mean of three replicates ± sem
Mean± sem values followed by same letters within each column are not significantly different at 0.05 (ANOVA and Duncan's multiple range test).

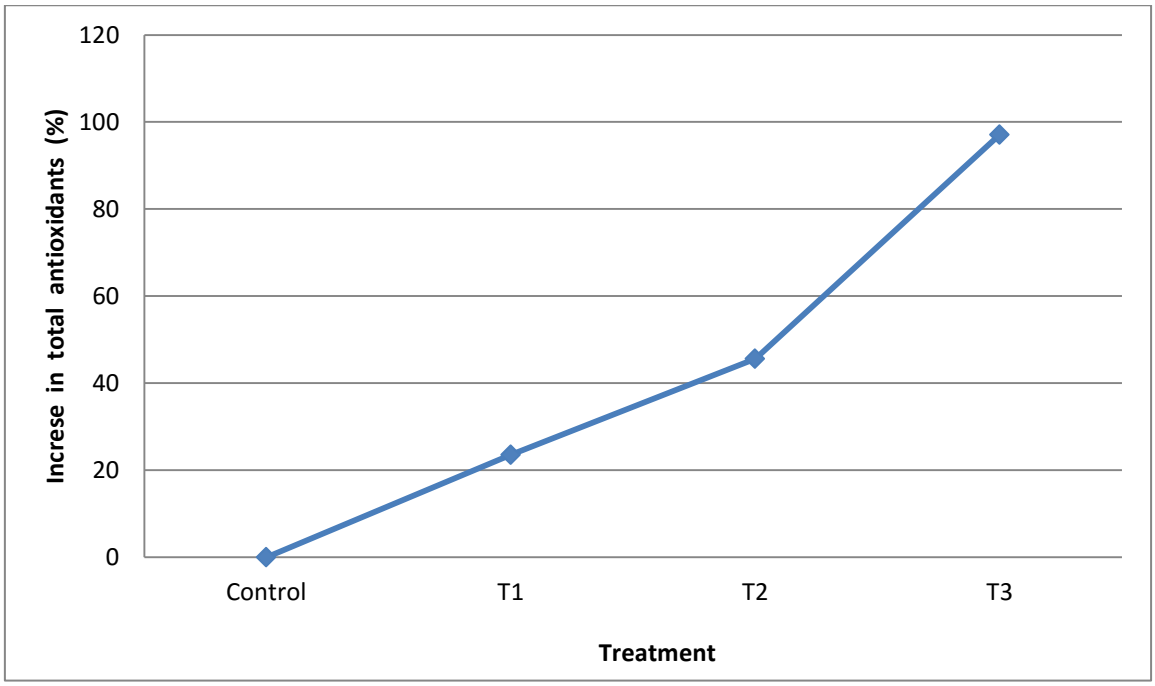

Figure 1: Effect of different concentrations of sodium silicate on the total antioxidant content in the seedlings of *Lycopersicon esculentum* L. Mill.

Where; C=Control, T_1=1mM sodium silicate, T_2=2mM sodium silicate, T_3= 3 mM sodium silicate

Our results are in conformity with the results of Mali and Arey (2007), who observed that silicon addition increases the root and shoot lengths and leaf area of *Vigna unguiculata*.Gillman and Zlesak (2000) reported that silicon application increased root fresh and dry weights in mist-applied rose cuttings.

It is generally known that increased photosynthetic rate leads to increased plant growth in most of the plants. Donega (2009) found that use of silicon improves the plant architecture and increases photosynthesis.The deposition of silicon in the cell wall increases tissue resistance and promotes better performing plants due to leaf position due to better plant architecture (Lana et al., 2003). Silicon maintains stability of the leaves and increases leaf surface area that may provide more availability of light for photosynthesis process (Quanzhi and Erming, 1998). This is in confirmation with the findings of Agarie et al. (1993) who observed that silicon has a significant effect on photosynthetic rate and it also prevents the destruction of chlorophyll.The increase in chlorophyll content might be due to the interaction of sodium silicate with phosphorylation pathway or activation of Mg^{2+} and ATPase activity or other metabolic activities. The increase in growth parameters of tomato seedlings treated with aqueous solution of sodium silicate was due to enhancement of different plant growth processes like cell division and cell enlargement, increase in nutrient uptake, increase in dry matter production due to enhancement of metabolic processes such as photosynthesis and respiration.Silicon increases photosynthetic efficiency of the plants resulting in

greater accumulation of solids in leaf tissues (Al-Aghabary et al., 2004). The increase in growth parameters of tomato seedlings may be positively associated with the plant photosynthetic attributes. The increase in tomato seedling growth might be due to increase in CO_2 - fixing efficiency or promotion in germination capacity coupled with higher efficiency in dry matter production. In the present study increase in the amount of chlorophyll in different treatments might be due to increase in synthesis of enzymes, proteins and cofactors required for synthesis of chlorophyll or increase in synthesis of chlorophyll under the influence of sodium silicate. Increase in photosynthesis process due to increased amount of photosynthates might be due to increased biosynthesis of chlorophyll or increase in photosynthesis by sodium silicate resulting in increase in dry matter production.The increased net photosynthetic rate due to silicon treatment was observed in the leaves of sorghum (Ahmed et al., 2011) wheat (Gong et al., 2005) and soybean (Shen et al., 2010) plants which might be associated with an increase in the activity of photosynthetic enzymes such as RuBP carboxylase (Adatia and Besford, 1986).Rafi et al. (1997) and Hattori et al. (2005) reported significant improvement in plant biomass by silicon application under drought stress. Adequate nutrition with silicon interferes in the plant architecture by providing erect leaves, increasing solar radiation, interception and photosynthetic efficiency (Al-Aghabary et al., 2004) and high chlorophyll content (Braga et al., 2009). Protein serves as respiratory substrate when the carbohydrates and other compounds are inadequate. The increase in biochemical constituents such as chlorophyll and protein under the influence of higher concentration of sodium silicate might cause increase in germination and growth of tested crop *Lycopersicon esculentum* Mill. Carotenoid a lipid soluble antioxidant which plays a multitude of functions in plant metabolism including oxidative stress tolerance. Significant increase (94.74%) has been observed in carotenoid content in the tomato seedlings with T_3treatment (Table 3). As an osmoprotectant, proline accumulates in high concentration in plant cells and it plays an important role in osmotic adjustment, detoxification of ROS and maintenance of membrane integrity in plants (Demiralay et al., 2013). The organic molecules such as sugar and proline play an important role in osmotic adjustment in plants (Ullah et al., 1997). The sugar and proline content was also increased in different treatments over control. Maximum increase 77.94% in proline content was observed in the tomato seedlings treated with 3 mM of sodium silicate. As a consequence of the accumulation of sugar and proline, the osmotic potential of the cell is lowered, which in turn attracts water into the cell and tends to maintain turgor pressure. Proline is also considered as a potent antioxidant and potential inhibitor of programme cell death (Pireivatloum et al., 2010).The increased concentration of total antioxidants acts as damage control system and thus provide protection to the cells from oxidative stress, lower lipid peroxidation and higher membrane stability in plants. Marodin et al. (2014) also found that the use of silicon increases commercial productivity of tomato plants and reduces the occurrence of cracked fruits. Growth enhancement of tomato seedlings and increase in biochemical parameters is an indication of positive effect of sodium silicate hence silicon is beneficial for the tomato crop.

Conclusion

The change in the physiological processes enhanced the seed germination and growth characteristics of tomato seedlings under the influence of aqueous solution of sodium silicate. In the present study silicon supplementation acts as stimulating agent and enhances the germination, growth and biochemical parameters of *Lycopersicon esculentum* Mill. Hence, it can be recommended that seeds of crop plants should be sown in the fields after the treatment with sodium silicate. Further detailed studies are required to explore the biochemical nature of sodium silicate and its role as fertilizer for the plants which suffer from environmental stresses during their growth and developmental stage.

Acknowledgements

The authors are thankful to Prof. Chanderdeep Tandon, Director, Amity Institute of Biotechnology, Amity University, Noida for providing the library and laboratory facilities to carry out this study.

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