Effect of potassium silicate on growth and biochemical attributes of tomato under salt stress

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Abstract

Salinity is one of the rising problems causing tremendous crop productivity losses in different parts of the globe. The present investigation deals with the impact of potassium silicate on the germination and biochemical parameters of *Solanum lycopersicum* L. under salt stress. Maximum seed germination of tomato seeds (98%) was observed with potassium silicate. Application of potassium silicate significantly increased biochemical components such as pigment content, sugar, proline, protein and total antioxidant contents in tomato seedlings. Maximum total antioxidant content (55%) was observed in NaCl (2mM)+PS treatment. The results revealed that potassium silicate acts as a plant growth promoter and it can be used as fertilizer for tomato under salt stress.

Keywords: Biochemical attributes, growth, potassium silicate, *Solanum lycopersicum*

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Introduction

Crop growth and yield stability under environmental stress conditions have always been a challenging task. The crop productivity is linked to the soil health and water quality (Hu and Schmidhalter, 2005). Salinity is an abiotic stress that affects agriculture by limiting crop growth and yield (Hoffmann et al., 2020). Approximately eight hundred million hectares of arable land are affected by soil salinity at global level (Aslam et al., 2017). Hafez et al. (2021) reported that around 40% of the irrigated land is influenced by salinity and 1.5 million hectare crop field falls outside of agricultural production every year. Due to the change in climatic conditions, salt-water intrusion in groundwater, excessive use of synthetic fertilizers, and irrigation of crops with saline water have increased soil salinity (Machado and Serralheiro, 2017). The soil texture is degraded with increased deposition of sodium in soil and it may result in low soil porosity, reduced soil aeration and water conductance which disrupts the formation of macro-aggregates and promotes colloidal dispersion. The continuous accumulation of salts in soil leads to physiological drought condition in which plants cannot absorb the water available in soil (Porcel et al., 2016). High salt concentration shows osmotic and ionic stresses in plants (Yang and Guo, 2018). Salt stress triggers nutrient imbalance, low soil water potential, high sodium and chloride concentration, and oxidative stress by ROS generation that impairs plant

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productivity (Hafez et al., 2021). Salt stress adversely affects morphological, biochemical, and molecular characteristics of plants (Farhangi-Abriz and Torabian, 2018). Hence, there is an urgent need to develop sustainable approaches to overcome the adverse impact of salt stress to maximize agricultural production.

Silicon can be regarded as multi-talented quasi-essential element due to its versatile role in providing several benefits for plant growth particularly under stress conditions (Mushtaq et al., 2020). Silicon is taken up by the plants as mono silicic acid which is a plant available form and its concentration in soil varies from 10-100 ppm but most of the soils are devoid of this form (Liang et al., 2015). International Plant Nutrition Institute has declared silicon as a nutritive element for plants and Association of American Plant Food Control Officials reported silicon as a plant beneficial substance (Zarger et al., 2019). Chen et al. (2014) reported that silicon supplementation reduces Na^+ uptake by plants and enhances K^+/Na^+ ratio under salt stress. Zargar et al. (2019) reported reduction in ion toxicity and oxidative stress, maintenance of water balance, increase in mineral uptake, regulation in biosynthesis of compatible solutes and phytohormones, and modification in gene expression due to the presence of silicon under salt stress. The utilization of silicon enhanced photosynthetic rate, stomatal conductance, water use efficiency, leaf water status, and root hydraulic conductance in sorghum (Yin et al., 2013), wheat (Chen et al., 2014), okra (Abbas et al., 2015) sweet pepper (Manivannan et al., 2016), and maize (Xie et al., 2015).

Tomato (*Solanum lycopersicum* L.; family: Solanaceae) fruits are rich in antioxidants, phenolic compounds (phenolic acids and flavonoids), carotenoids (lycopene and carotene), potassium, and vitamins (ascorbic acid and vitamin A) (Massaretto et al., 2018). Tomato is considered as a part of healthy diet as it is cholesterol free. The bioactive compounds present in tomato show antioxidant, anti-mutagenic, and anti-inflammatory properties which can prevent blindness, respiratory ailments, cardiovascular disorders, and cancer (Tan et al., 2010). Hazewindus et al. (2014) reported the role of tomato phytochemicals in prevention of DNA mutation. To the best of our knowledge, no reports are available in literature about the effect of potassium silicate in alleviation of salt stress in tomato as it has been considered as a silicon excluder (non-accumulator) plant. Hence, the present study was conducted to assess the role of potassium silicate on growth and biochemical parameters of tomato under salt stress conditions.

Material and Methods

Certified healthy seeds of tomato (*Solanum lycopersicum* L. variety Heera) were procured from seed agency of Ghaziabad, India. Seeds were stored in sterilized polythene bags to avoid contamination. Different concentrations of salt (NaCl) such as 1 mM, 1.5 mM, and 2 mM and also potassium silicate (K_2SiO_3; molecular weight: 154.28 g/mol) (1 mM) were used for the treatment.

Petri plate culture

The tomato seeds were washed with sterilized distilled water to remove dust for 5 min, then surface sterilized with 0.01% $HgCl_2$ solution and again washed with distilled water. Thirty seeds were divided into three replicates of 10 seeds and each were immersed in 10 ml of different concentrations of NaCl solution and potassium silicate for four hours. Tomato seeds soaked in distilled water were considered as control. Ten seeds of each treatment were placed at equal distance in sterilized petri plates lined with moistened Whatman No. 1 filter paper. The petri plates were kept in a growth chamber under temperature (25 ± 2℃), photoperiod 16/8 h and photon flux density was kept 240 µmol $m^{-2}s^{-1}$ for ten days. The dishes were kept moist by adding different concentrations of salt, potassium silicate, or distilled water as and when required according to the treatment.

Determination of growth parameters

Different growth characteristics of tomato were determined by the following formula (Li, 2008):

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

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

(3). Germination index (GI) = ΣGt / Dt

where Gt is the number of tomato seeds germinated in t days; Dt is the number of germination days.

Seedling length and vigour index

The radicle and plumule length were measured with a measuring scale (ISTA, 2008). Vigour index of the tomato seedlings was estimated by the formula presented in Abdul - Baki and Anderson (1973):

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

Biomass estimation

The fresh weight of the tomato seedlings was measured after ten days of seed sowing. After that, seedlings were oven dried at 65 °C for 72 hours and the dry weight was estimated.

Relative water content

The fresh weight of tomato seedlings was measured, then seedlings were immediately floated on distilled water at 25 ℃ under dark condition. After 12 h, turgid weight was taken and seedlings were dried in an oven at 80 ℃ for 48 h for the dry weight. RWC was calculated by the modified method of Barrs and Weatherly (1962):

RWC (%) = (FW-DW) / (TW-DW) × 100

Estimation of pigment content

Chlorophyll content was determined in tomato seedlings by the method of Lichtenthaler (1987). The leaves (10 mg) of control and treatment were ground 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 470 nm.

Determination of sugar content

Total sugar content present in tomato seedlings was analyzed by the method of Hedge and Hofreiter (1962). Tomato seedlings (100 mg) were homogenized in 5 ml 95% ethanol and centrifuged at 4000 g for 15 min. The supernatant (0.1 ml) was mixed with distilled water (0.9 ml) and 4 ml anthrone solution and mixture was kept on water bath for 15 min. Absorbance was recorded at 620 nm after cooling and sugar content was calculated with reference to standard curve of glucose.

Estimation of proline

Proline was analyzed by the method of Bates et al. (1973). Leaves were extracted with 3% sulphosalicylic acid and aliquot was treated with acid-ninhydrin and acetic acid and boiled for 1 h at 100 ℃. Reaction mixture was extracted with 4 ml of toluene and absorbance was measured at 520 nm. Proline content was expressed as µmol g^{-1} FW using a standard curve.

Estimation of protein

The protein content was measured by the method of Lowry et al. (1951). Tomato leaves were homogenized with 1 N NaOH for 5 min at 100 ℃. Alkaline copper reagent was added and the mixture was kept at room temperature for 10 min, then Folin - Ciocalteu reagent was added. Absorbance of the solution was measured at 650 nm after 30 min and the protein content was calculated with reference to BSA standard curve.

Total antioxidant content

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

Statistical Analysis

Treatments were organized with three replicates in randomized block design. The data were

Table 1
Effect of salt stress on seed germination, relative germination rate, and germination index of *Solanum lycopersicum* L. var. Heera with or without application of potassium silicate

Treatment	Germination (%)	Relative germination rate (RGR)	Germination Index (GI)
Control	96 ± 1.2^{a}	-	9.6 ± 0.52^{a}
NaCl (2 mM)	17 ± 0.70^{d}	0.18 ± 0.02^{d}	1.7 ± 0.13^{d}
PS (1 mM)	98 ± 2.1^{a}	1.02 ± 0.61^{a}	9.8 ± 0.59^{a}
NaCl (1 mM) + PS	62 ± 0.58^{b}	0.65 ± 0.38^{b}	6.2 ± 0.41^{b}
NaCl (1.5 mM) + PS	41 ± 1.4^{b}	0.43 ± 0.12^{b}	4.1 ± 0.22^{b}
NaCl (2 mM) + PS	28 ± 0.71^{c}	0.29 ± 0.05^{c}	2.8 ± 0.19^{c}

Data are means ± standard error of three independent experiments with three replicates. NaCl = salt and PS = potassium silicate

Table 2
Effect of salt stress on seedling length, biomass, and vigour index of *Solanum lycopersicum* L. var. Heera with or without application of potassium silicate

Treatment	Radicle length (cm)	Plumule length (cm)	Fresh weight (mg/g)	Dry weight (mg/g)	Relative water content (%)	Vigour Index
Control	8.17 ± 0.26^{a}	15.98 ± 0.42^{a}	5.42 ± 0.32^{a}	1.12 ± 0.09^{b}	95.27± 0.74^{a}	23184^{a}
NaCl (2 mM)	3.23 ± 0.18^{d}	7.14 ± 0.36^{c}	1.02 ± 0.41^{d}	0.21 ± 0.01^{d}	69.14 ± 0.42^{c}	1763^{d}
PS (1 mM)	9.72± 0.62^{a}	19.12 ± 0.47^{a}	7.95 ± 0.23^{a}	1.54 ± 0.17^{a}	96.31 ± 0.81^{a}	28263^{a}
NaCl (1 mM) + PS	7.12± 0.21^{b}	12.16± 0.75^{b}	4.34 ± 0.28^{b}	1.03 ± 0.09^{b}	87.26 ± 0.92^{b}	11954^{b}
NaCl (1.5 mM) + PS	6.61 ± 0.32^{b}	10.92 ± 0.32^{b}	3.76 ± 0.91^{b}	0.94 ± 0.05^{c}	84.32 ± 0.87^{b}	7187.3^{b}
NaCl (2 mM) + PS	5.83± 0.24^{b}	9.28 ± 0.04^{b}	2.19 ± 0.42^{c}	0.82 ± 0.02^{c}	81.42 ± 0.73^{b}	4231^{c}

Data are mean ± standard error of three independent experiments with three replicates. NaCl = salt and PS = potassium silicate

determined by using ANOVA and SPSS software (Version 16 SPSS, US). Means of treatments were assessed by DMRT at p≤0.05.

Results

Germination and seedling growth

Maximum seed germination (98%) was observed in tomato seeds with potassium silicate treatment whereas 96% germination was reported in control. Relative germination rate and germination index were more in treatment with potassium silicate as compared to the other treatment. Maximum reduction in seed germination (82%) was observed with NaCl treatment (Table 1). The seedling length, i.e. radicle and plumule length, showed the following trend: PS > C > NaCl (1 mM) + PS > NaCl (1.5 mM) + PS > NaCl (2 mM) + PS > NaCl. The relative water content and vigor index also reflected the same trend (Table 2). Significant reduction in fresh and dry weight of tomato seedlings was observed under salt stress.

Pigment content

Total chlorophyll content showed significant increase with potassium silicate treatment as compared to control and NaCl treatment. Total chlorophyll content reflected the following trend: PS > C > NaCl (1 mM) + PS > NaCl (1.5 mM) + PS > NaCl (2 mM) + PS > NaCl.

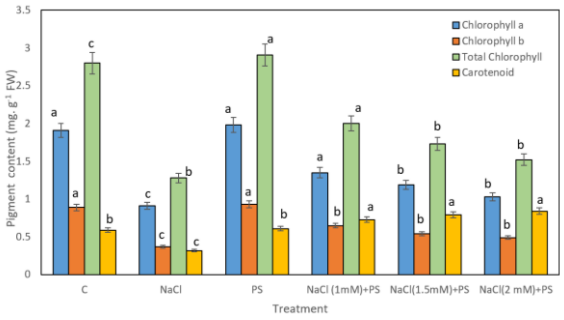

Fig.I. Effect of salt stress on pigment content of *Solanum lycopersicum* L. var. Heera with or without application of potassium silicate; data are means ± standard error of three independent experiments with three replicates. NaCl = salt and PS = potassium silicate

The carotenoid content was highest in NaCl (2 mM) + PS treatment (Fig. I).

Electrolyte leakage and lipid peroxidation

Membrane damage was evaluated through electrolyte leakage because cell membranes are the first targets of plant stressors. The electrolyte leakage was maximum (43%) in salt-treated

tomato seeds (Fig. II). MDA content showed the following trend: NaCl > NaCl (2 mM) + PS > NaCl (1.5 mM) + PS > NaCl (1 mM) + PS > C > PS (Fig. II). The gradual increase in MDA content was reflected in tomato seedlings under different concentrations of NaCl. The results revealed that application of potassium silicate reduced MDA content by 12%, signifying its protective role under salt stress.

Biochemical components

The biochemical components such as sugar, proline, and protein contents were also affected by salt stress. Maximum sugar (4.1 mg/g) and protein (15 mg/g) contents were observed in tomato seeds with potassium silicate treatment (Fig. III). Proline content showed following trend: NaCl (2 mM) + PS > NaCl (1.5 mM) + PS > NaCl (1 mM) + PS > NaCl > PS > C.

Total antioxidant content

During salinity, overproduction of reactive oxygen species shows cellular damage which may lead to programmed cell death. Antioxidants can be considered as plant defense system against oxidative stress. The effect of salt stress on total antioxidant content of *Solanum lycopersicum* L. seedlings was studied with or without application of potassium silicate. Findings showed following trend: NaCl (2mM) + PS > NaCl (1.5 mM) + PS > NaCl (1 mM) + PS > PS > NaCl > C. Maximum total antioxidant content (55%) was observed in NaCl (2 mM) + PS treatment (Fig. IV).

Discussion

Proline content of the plants under study was maximum in the treatment containing higher salinity. Proline acts as compatible solute which accumulates under stress conditions and plays a pivotal role in osmoregulation (Annunziata et al., 2019). It also provides protection to the plants against environmental stresses by maintaining osmoregulation and detoxification of free radicals and preserves membrane integrity and stabilizes proteins and enzymes (Salinas et al., 2013). Rahneshan et al. (2017) observed salinity induced significant increase in free proline content in leaves and roots of *Pistachio* cultivars which plays

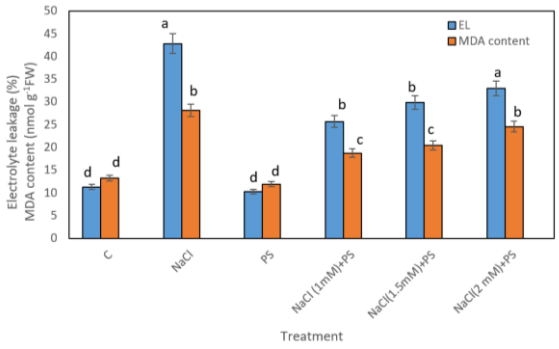

Fig. II. Effect of salt stress on electrolyte leakage and lipid peroxidation of *Solanum lycopersicum* L. var. Heera with or without application of potassium silicate; data are means ± standard error of three independent experiments with three replicates. NaCl = salt and PS = potassium silicate

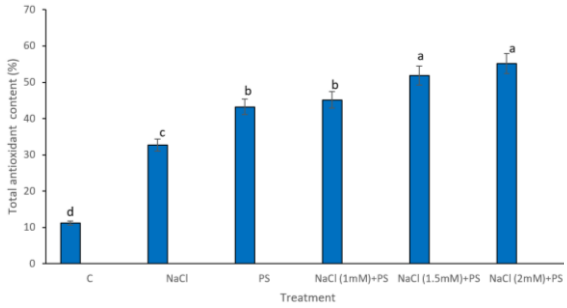

Fig. IV. Effect of salt stress on total antioxidant content of *Solanum lycopersicum* L. var. Heera with or without application of potassium silicate

a protective role against salt stress in plants. The increase in proline content reduces negative effect of salinity by decreasing the accumulation of Na^+ and Cl^- in plant cells (Kim and Nam, 2013).

The carotenoid content of the tomato plants in this study was highest under NaCl (2 mM) + PS treatment. This might be due to their role in protection of tomato seeds against salt stress. Carotenoids are important lipophilic antioxidants which can detoxify ROS in plants and protect photosynthetic apparatus (Young, 1991).

There was a gradual increase in MDA content of the tomato seedlings under different concentrations of NaCl. Malondialdehyde (MDA) is the product of lipid peroxidation and is used as an indicator of the degree of damage caused by environmental stress to cells (Ma et al., 2015).

Significant increase in sugar and protein contents has been reported in our investigation (Fig. III). Application of potassium silicate strengthens the

development of root cells (Seleiman et al., 2019). Foliar application of potassium silicate stimulated root growth and nodulation and increased water and nutrients uptake (Etesami and Adl, 2020). Potassium silicate addition promoted leaf erectnessand increased photosynthesis efficiency in grasses (Ahmad et al., 2013). Ali et al. (2020) observed that potassium silicate foliar application regulated stomatal conductance and promoted ATPase, DNA, and RNA synthesis as well as maintained ionic balance in fava bean leaves treated with saline water.

Salt stress primarily affects root and shoot development, leaf formation, delays flowering period and other metabolic processes in plants (Mushtaq et al., 2020). Salt stress adversely affects fresh and dry weight of the plants and finally shows decline in a crop yield (Zhang et al., 2018). The decrease in relative water content is the first symptom of the plants subjected to osmotic stress due to excessive amount of Na^+ ions which alters the mass flow water movement system from soil solution to the root xylem vessels. As a consequence, water absorption by roots from the soil will reduce and it will also decrease leaf cell turgor and relative water content. Soil solution with high Na^+ and Cl^- contents impedes K^+ and Ca^{2+} absorption, resulting in nutritional imbalance (Nadeem et al., 2019). The adverse effects of salinity are a result of complex interactions among morphological, physiological, and biochemical processes involved in seed germination, water and nutrient uptake, and plant growth (Soltabayeva et al., 2021).

Shao et al. (2015) observed that salt stress induced growth inhibition in cucumber and reduced nitrogen absorption and enzymes activities associated with nitrogen assimilation. Exposure to salinity leads to the closure of the stomata, which limits photosynthesis (Hnilickova et al., 2017). Salinity showed inhibition of electron transport and inactivation of photosystem II reaction centers (Mehta et al., 2010), degradation of oxygen-evolving complexes, and impairment of electron transfer capacity on the donor side of PSII (Kalaji et al., 2018). Tang et al. (2020) showed that with increase in NaCl concentration, chlorophyll a/b value and intercellular CO_2 concentration of purslane increased whereas photosynthesis rate, stomatal conductivity and chlorophyll contents decreased.

Silicon can be regarded as one of the most significant element in crop production, especially in minimizing the negative impacts of salt and oxidative stress (Liang et al., 2003). Silicon can improve root architecture, leaf erectness, photosynthesis, and survivability of crops (Garg and Singh, 2018; Gomaa et al., 2021). It provides strength to the plant by making their tissues rigid (Marxen et al., 2015). Silicon utilization enhanced salt tolerance capacity in okra plants by adjusting the level of osmolytes and total free amino acids (Abbas et al., 2015). Yaghubi et al. (2016) observed that silicon enhanced plant potential under salt stress by reducing Na^+ absorption and enhancing K^+ absorption by the leaves. According to Hafez et al. (2021) high K^+ uptake and lower Na^+ in leaf tissues can be one of the mechanism of salt tolerance in fava bean by potassium silicate supplementation. The growth and yield of maize were enhanced by silicon application under stressed conditions (Kandil et al., 2020). Rice yield was also improved with the application of silicon fertilizer (Gao et al., 2020). Muneer et al. (2014) observed positive effects of silicon supplementation on chlorophyll content and photosynthesis under high salinity. The proteomic analyses revealed an increased amount of PSI and PSII complexes, cytochrome b6/f and ATP-synthase in silicon supplemented plants as compared to non-supplemented salt-stressed tomato plants.

Potassium is an indispensable element for plants as it stimulates cell division, growth and physiological processes such as stomata movement and water status of plants and promotes biosynthesis of pigment, sugar, and protein (Hasanuzzaman et al., 2018). Potassium has been proven to improve ionic balance and antioxidant enzymatic activity (Ahmad et al., 2016).

Potassium silicate can be used as a plant biostimulant and it is a source of both potassium and highly soluble silicon (Laane, 2018). Foliar application of potassium silicate promoted proline, protein, and sugar contents and enhanced endogenous hormone synthesis which may

promote cell division and enlargement of fava bean plants (Hellal et al., 2012). Youssif et al. (2018) reported that exogenous application of potassium silicate had a positive role in enhancing plant growth and root length and alleviated deleterious effect of salinity in fava bean.

Utilization of salt-tolerant crops does not remove salt but they accumulate salts. Other agronomic practices, e.g. phytoremediation, for salt removal are expensive and labor-intensive. Application of potassium silicate is an environmentally benign, cost-effective, and convenient approach for alleviation of salt stress as compared to the use of other fertilizers (Artyszak, 2018). Its application does not release any hazardous or environmentally persistent by-products and it significantly reduces the negative effects of salinity on tomato plants. Therefore, potassium silicate can be used as a growth promoting fertilizer for tomato plants under saline conditions.

Conclusion

Salt stress inhibited seed germination and growth parameters of tomato. It reduced pigment, sugar, and protein contents but enhanced proline accumulation and showed electrolyte leakage and lipid peroxidation. Application of potassium silicate alleviated unfavorable effects of salt stress by triggering the upregulation of proline and total antioxidant content. Hence, it can be recommended that seeds of crop plants should be sown in the agricultural fields after the potassium silicate treatment. Further detailed investigations are required to explore the biochemical nature of potassium silicate, its optimum doses, and exposure time as fertilizer for growth and development of the crop plants under salt stress.

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