Influence of silicon and chitosan on growth and physiological attributes of maize in a saline field

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Abstract Soil salinity is the main constraint for crop productivity in many parts of the world. Application of silicon (Si) and chitosan (Chi) can improve crop growth under saline soil conditions. The current study was aimed to examine the effects of Si and Chi on mitigation of salinity, morphological and physiological attributes as well as the antioxidant system of maize (*Zea mays* L.) under saline soil conditions. A field experiment was conducted that comprised of nine treatments as follows: (i) Control (no amendment), (ii) Silicon 40 kg ha^{-1} (Si1), (iii) Chitosan 15 kg ha^{-1} (Chi1), (iv) Si1 + Chi1, (v) Silicon 80 kg ha^{-1} (Si2), (vi) Chitosan 30 kg ha^{-1} (Chi2), (vii) Si2 + Chi2, (viii) Si1 + Chi2 and (ix) Si2 + Chi1. Application of Si and Chi substantially improved the morphological and physiological attributes as well as antioxidant enzymes such as superoxide dismutase (SOD), peroxidase (POD) and catalase (CAT) of maize plants, and combined application of Si and Chi was more effective when compared with Si and Chi treatments separately. Membrane stability index was improved by 25%, relative water content by 26%, chlorophyll a by 69% and b by 56% with combined application of Si and chitosan (Si2 + Chi2) compared with control. The SOD, POD and CAT increased by 36%, 38% and 65% with Si2 + Chi2 compared with control. The results suggest that Si and Chi application is the possible option for alleviating salinity stress in maize plant. Further research is suggested to examine Si and Chi effects on various crop's growth.

Keywords Maize · Soil salinity · Silicon · Chitosan · Biochemical traits · Physiological processes

Introduction

Soil salinity is a devastating problem for crop production worldwide. Many crops are sensitive to soil salinity (Shaaban et al. 2013; Weil and Brady 2017). According to an estimate, more than 1 billion hectares of land area is affected by soil salinity all over the world (Ivushkin et al. 2019). Pitman and Läuchli (2002) reported that the average economic loss at global level due to soil salinity is worth about $US 12 billion per year. Multan (South Punjab, Pakistan) is also facing problem of soil salinity; about 6.9 Mha land area of Pakistan is salt-affected causing approximately $US 343 million loss per year (Qureshi et al. 2008; FPCCI, 2017). Excess of soluble salts in soils limits the productivity and growth of plants through physiological disorders and specific ion effect (Rios et al. 2017). The physiological disorders caused by the salt-stress impact several morpho-physiological characteristics of plants such as decreased chlorophyll content, disturbs the stomatal closure, and influence the partial pressure of CO_2 in the leaf (Hoffmann et al. 2020). Soil salinity interrupts the water status of plants by reducing membrane stability index (MSI) and relative water contents (RWC) (Zhu et al. 2019). The response of plant to salt stress depend upon various aspects such as amount and time of exposure, variety and growth stages of plant and environmental situations (Isayenkov and Maathuis 2019). Salinity induces nutrient deficiency, osmotic stress, toxicity and imbalance of ions in

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plants (Zhu et al. 2019). Ion toxicity and imbalance of ions results from the replacement of K^+ by Na^+ (Rios et al. 2017). Therefore, the plant's potential to tolerate a high level of K^+/Na^+ is the most significant characteristic regarding the tolerance mechanism of salinity (Hoffmann et al. 2020).

Moreover, the osmotic/water stress, imbalance of ions and salt stress are also involved in the oxidative stress system which may affect the development of reactive oxygen species (ROS) which are further involved in stimulating membrane lipid peroxidation and leakage of membranes (Zörb et al. 2019). In general, plants adopt various protective mechanisms to defuse destructive properties of ROS. The plants that contain higher levels of antioxidant enzymes, may also have more tolerance against oxidative stresses produced by ROS (Hernández 2019).

To counteract soil salinity stress on plants several techniques are being devised. For instance, the application of silicon (Si) has been reported to improve plant growth and dry matter production mostly under stress-conditions (Liu et al. 2020). Silicon mitigates the negative impact of salinity on plants by lowering the Na^+ uptake in plants (Garg and Bhandari 2016) possibly by binding Na^+ with Si-phytoliths and limiting its relocation to different plant parts (Ali et al. 2011). The uptake of Si by the plants under salinity stress enhances the mineral nutrition of plants (Liu et al. 2020). Tuna et al. (2008) reported improved concentration of Ca in wheat plants grown in Si-applied soil. Similarly, Tahir et al. (2011) documented improved uptake of K^+ and increased shoot growth in wheat plants with Si application under salinity-stress. The Si application has also been reported to enhance the antioxidant enzyme activities such as APX, CAT and SOD under salinity stress (Moussa 2006). The Si application to soil increased root exudation of organic acids from roots of wheat plants that mobilized P in the soil, resulting in higher uptake and plant growth (Kostic et al. 2017). In a recent study, the Si (200 mg kg^{-1} and 400 mg kg^{-1}) was applied to zinc (Zn) contaminated soil and higher dose was more effective to reduce the toxic effects of Zn on wheat plants, consequently increased plant biomass (Zajaczkowska et al. 2020). In a field experiment, the Si application improved the biomass of grass (598 g m^{-2}) compared to that under the same level of N addition without Si (Xu et al. 2020).

In addition to Si, certain organic substances are also used to mitigate salt stress on plants. Chitosan is one of such materials derived from the chitin (polysaccharide biopolymer). It is obtained from the outer shell of crustaceans like krill, crabs, and shrimps (Hidangmayum et al. 2019). Ma et al. (2012) reported better growth of wheat plants by the application of chitosan compared with plants without chitosan application under salt stress. The present study hypothesized that application of Si and chitosan may improve soil properties, compensate the uptake of Na, alleviate salt stress and ultimately improve plant growth under saline soil conditions. The aim of the present study was to examine the effects of silicon and chitosan alone and/or in combination on the growth and physiological attributes of maize (Zea mays L.) under saline soil conditions.

Material and methods

Experimental site and treatments

A field trial was conducted at the research area of Qasba Maral, the Research Farm of Bahauddin Zakariya University, Multan, Pakistan (30.15′31″ °N; 71.30′51′' °E, 130 m above sea level). The experimental site is characterized as arid climate with cold winters and hot summers, the average annual maximum and minimum temperatures are 31.5 °C and 16.7 °C, respectively. Annual average rainfall was 187 mm, while minimum and maximum relative humidity during the experiment were 36% and 60%, respectively. The minimum and maximum day lengths during the experiment trail were 13 h 9 min and 13 h 46 min, respectively. The field was irrigated with ground water [electrical conductivity: 1.13 dS m^{-1}, sodium adsorption ratio: 2.55 and residual sodium carbonate: 0.24 (mmol L^{-1})$^{1/2}$]. Soil had pH (1:5, soil:water): 8.04; electrical conductivity (EC): 5.03 dS m^{-1}; organic matter (OM): 0.43%; extractable silicon (Si): 12.25 mg kg^{-1}, soil texture: silt clay loam. The EC indicates that soil at the experimental site is slightly saline.

Seeds (25 kg ha^{-1}) of maize (Zea mays; variety Syngenta 8441) were sown on May 20, 2018 and harvested at maturity on August 18, 2018 (crop duration: 91 days). The variety of maize crop selected is very common among the farmers and is grown on a large area of Punjab province. A net plot size of 5 m^2 was made with spade. The treatment details are given in Table 1. There were total 27 plots and 3 blocks for this study. Each treatment was replicated three times. The Si and Chi were broadcasted and mixed at the sowing of crop. Fertilizer doses of N, P and K at the rate of 250 kg, 125 kg P_2O_5 and 125 kg K_2O ha^{-1}, respectively were applied. The post experimental soil sample was analyzed for soil $CaCl_2$-extractable Si. The Si in soil was extracted with 0.01 M $CaCl_2$ (1.0 g of soil in 50 mL for 30 min) and concentration determined using spectrophotometer (UV1602-BMS Canada) (Houba et al. 2000).

Table 1 Details of treatments for the current experiment

Sr. no	Treatment name	Code	Application dose
1	Control	C	No amendment
2	Silicon low dose	Si1	40 kg ha^{-1}
3	Chitosan low dose	Chi1	15 kg ha^{-1}
4	Silicon low dose + chitosan low dose	Si1 + Chi1	40 kg ha^{-1} + 15 kg ha^{-1}
5	Silicon high dose	Si2	80 kg ha^{-1}
6	Chitosan high dose	Chi2	30 kg ha^{-1}
7	Silicon high dose + chitosan high dose	Si2 + Chi2	80 kg ha^{-1} + 30 kg ha^{-1}
8	Silicon low dose + chitosan high dose	Si1 + Chi2	40 kg ha^{-1} + 30 kg ha^{-1}
9	Silicon high dose + chitosan low dose	Si2 + Chi1	80 kg ha^{-1} + 15 kg ha^{-1}

Plant growth parameters

Maize plants from each treatment plot were harvested after 91 days of sowing (August 18, 2018). Plants were uprooted, and different parts (cobs, roots and shoots) were collected in paper bags and brought to the laboratory. Shoot, root (from crown roots to downward 80 cm) and cob length were measured by rod meter. The fresh and dry mass of shoot and root was measured in grams. Plant material was dried in an oven at 65 °C for 48 h. Oven-dried shoots and roots were ground (0.42 mm) for further analyses.

Plant biochemical and physiological parameters

Assay for chlorophyll content

Extraction method for determination of chlorophyll a and b was followed as suggested by Porra (2002) and Strain and Svec (1966). About 1 g fully fresh young leaves (25-day old plants) was taken in 80% acetone for extraction of chlorophyll with the help of mortar and pestle. The chlorophyll contents a and b were determined by using spectrophotometer (UV1602-BMS Canada) at 663 nm and 644 nm wavelengths, respectively.

Relative water content

Flag leaves were taken, and fresh mass of leaves was measured for the determination of relative water content (RWC). Leaves were soaked in distilled water for turgid mass for four hours. The leaves were re-weighed, and then oven dried for constant mass at 65 °C. The RWC was calculated according to Sairam and Tyagi (2004).

$$RWC = \frac{Freshmass - drymass}{Turgidmass - drymass}$$

Membrane stability index

The membrane stability index (MSI) was determined following the procedure described by Sairam and Tyagi (2004) and Almeselmani et al. (2006). Briefly, about 0.2 g fresh leaf mass was taken into two different sets of test tubes having distilled water (10 ml). One set of the test tube was placed in a water bath at 40 °C for 30 min, while other test tube set was placed for 15 min at 100 °C. The electrical conductivity (EC) of the first test tube set (C1) and of the second set of the test tube (C2) was determined by an EC meter. The MSI was calculated according to the following formula.

$$MSI = \frac{1 - C1}{C2} \times 100$$

Assay for antioxidant enzyme activities

For the analysis of enzyme activities, plant tissues were extracted from the fresh leaves according to Biju et al. (2017) and Ma et al. (2016). A weight of 0.5 g fresh leaves frozen in liquid nitrogen was ground in 10 mL of phosphate buffer (according to its pH) and centrifuged at $15,000 \times g$ at 4 °C for 10 min. The supernatant was analyzed for superoxide dismutase (SOD), catalase (CAT) and peroxidase (POD). The reaction solution for the catalase enzyme consisted of 50 mM phosphate buffer with pH 7.0, 5.9 mM H_2O_2 and 0.1 mL enzyme extract. The activity of the enzyme was determined by using spectrophotometer with the 240 nm wavelength. For the determination of peroxidase activity, solution consisted of 50 mM phosphate buffer with pH 7.0, 20 mM of guaiacol, 40 mM of H_2O_2 and 0.1 mL enzyme extract. Peroxidase activity was determined by spectrophotometer at 470 nm wavelength.

The superoxide dismutase was determined by adding enzyme extraction to the solution containing riboflavin, nitro blue tetrazolium (NBT), ethylene diamine tetraacetic acid EDTA, phosphate buffer (pH 7.8) and methionine. The solution was kept in a chamber under fluorescent

lamps of 30 W. Sample was measured by using spectrophotometer at 560 nm. The activity of the enzyme was expressed in min^{-1} g^{-1} FW.

Determination of silicon, sodium and potassium concentration in plants

For the determination of Si in plant, oven dried shoot biomass of maize plant was ground and 0.1 g was digested in 50% NaOH and 50% H_2O_2 on a hot plate for 24 h at 150 °C (Elliott and Snyder 1991; Biju et al. 2017). A volume of 25 ml acetic acid and 10 ml of ammonium molybdate was added in filtrate. After developing yellow color, 2 ml oxalic acid was added, and final sample was run on a spectrophotometer at 650 nm with standards.

The concentration of Sodium (Na^+) and potassium (K^+) were determined by digesting the dried plant samples in a di-acid mixture (HNO_3:$HClO_4$ ratio of 2:1) (Jones and Case 2018). The digestate was filtered through Whatman filter paper No. 42 and stored at room temperature. The concentrations of Na^+ and K^+ were determined on flame photometer (Jenway PFP-7).

Statistical analysis

The treatments were arranged according to randomized complete block design (RCBD). The statistical analysis of collected data from experiment was performed using Statistix 8.1 (Tallahassee, Florida, USA), two-way factorial analysis of variance test was performed according to experiment layout RCBD. Tukey-HSD test was used to differentiate significant means of treatments (Tukey 1949).

Results

Growth parameters

Application of both silicon (Si) and chitosan (Chi) significantly ($p \leq 0.05$) influenced the length of plant shoot (Table 2). The plants grown under salt stress (in the control treatment) showed minimum shoot length (Table 3). There was significant increase in the shoot length with application of higher levels of Si and Chi compared to their lower levels. The Si1 and Si2 treatments significantly ($p \leq 0.05$) increased the shoot length by 3.7% and 7%, respectively compared to the control. The Chi1 and Chi2 treatments showed improvement in shoot length by 1.5% and 3.9%, respectively as compared to the control. The combined application of Si and Chi was more effective compared with separate application (the maximum shoot length observed in Si2 + Chi2 treatment). The shoot fresh mass of maize plants was also significantly ($p \leq 0.05$) affected

by application of Si and Chi (Table 2). Maximum fresh mass (3.6%) was noted in treatment of combined application of Si and Chi at their higher application doses (Si2 + Chi2) as compared to the control (Table 3).

The shoot dry mass of maize plants significantly ($p \leq 0.05$) decreased in the control under salt stress (Table 3). The Si and Chi applied plants showed higher shoot dry mass compared to those without application of Si and Chi under salinity (Table 2). Maximum shoot dry mass (12%) was noted in Si2 + Chi2 treatment as compared to the control. The root length of maize plants was significantly ($p \leq 0.05$) lower in control treatment, while application of Si and Chi improved the root length of maize plants in the control. Combined treatments of Si and Chi with higher dose (i.e. Si2 + Chi2) presented maximum root length (9.3%) compared to the control treatment (Table 3). Fresh mass of roots was also significantly ($p \leq 0.05$) decreased by salt stress. Root fresh mass subsequently increased (10%) in Si2 + Chi2 treatment compared to the control. Maize plants that were grown in soil which was treated with Si2 + Chi2 treatment showed maximum increase in root dry mass (50%) as compared to the control (Table 3).

Yield parameters

The length of cob was significantly ($p \leq 0.05$) affected by applications of Si and Chi (Table 2). The Si and Chi application significantly ($p \leq 0.05$) improved the cob length and higher doses of Si and Chi were more effective for improving cob length. The maize cob length showed maximum improvement by 50% in the combined application treatment of Si2 + Chi2. The grain rows per cob were lower in control plots, and application of Si and Chi increased their grain rows per cob (Table 4). The grain rows per cob were significantly increased by 49% with the combined application of Si and Chi (i.e. Si2 + Chi2) as compared to the control. Addition of Si and Chi enhanced 100-grain mass and the maximum 100-grain mass (11%) was found in the combined application of Si and Chi (Si2 + Chi2) as compared to the control. The number of grains per cob was significantly influenced by Si and Chi application (Table 2). Maximum number of grains per cob (30%) was recorded in the combined application of Si and Chi (i.e. Si2 + Chi2) as compared to the control.

Chlorophyll a and b

The application of Si and Chi increased the chlorophyll a and b contents relative to the control treatment (Fig. 1). Comparison between both application (alone and combined), combined application had more positive result compared to separate application of Si and Chi. Maximum chlorophyll a content (69%) was improved in the combined

Table 2 Results of analysis of variance of different parameters

Parameters	Chi		Si		Si × Chi	
	F value	P value	F value	P value	F value	P value
Shoot length	335.64	0.0000	908.42	0.0000	5.62	0.0051
Shoot fresh weight	118.37	0.0000	351.96	0.0000	5.91	0.0041
Shoot dry weight	213.70	0.0000	365.80	0.0000	4.65	0.0111
Root length	101.60	0.0000	284.40	0.0000	2.82	0.0602
Root fresh weight	75.23	0.0000	396.89	0.0000	20.39	0.0000
Root dry weight	165.33	0.0000	799.73	0.0000	10.80	0.0002
Cob length	241.01	0.0000	552.50	0.0000	1.66	0.2090
Grain rows per cob	81.53	0.0000	194.24	0.0000	5.68	0.0048
No. of grain per cob	133.90	0.0000	316.23	0.0000	12.37	0.0000
100 grain weight	58.74	0.0000	143.77	0.0000	5.37	0.0000
Chlorophyll a	137.65	0.0000	743.00	0.0000	30.70	0.0000
Chlorophyll b	91.62	0.0000	425.77	0.0000	10.41	0.0002
Membrane stability index	104.94	0.0000	237.39	0.0000	8.84	0.0006
Relative water content	289.87	0.0000	477.44	0.0000	12.38	0.0001
Sodium in shoot	831.71	0.0000	1616.78	0.0000	78.10	0.0000
Potassium in shoot	766.61	0.0000	2207.82	0.0000	5.07	0.0079
Si in shoot	425.97	0.0000	730.13	0.0000	24.94	0.0000
Superoxide dismutase	34.49	0.0000	151.82	0.0000	4.26	0.0115
Peroxidase	91.58	0.0000	302.09	0.0000	5.44	0.0058
Catalase	219.89	0.0000	515.54	0.0000	3.13	0.0445
Soluble protein	276.31	0.0000	926.77	0.0000	19.13	0.0000
Si in soil	377.21	0.0000	811.49	0.0000	50.26	0.0000

Table 3 Effect of silicon (Si) and chitosan (Chi) on growth parameters of maize under field conditions

Parameters	Treatments								
	C	Si1	Chi1	Si1 + Chi1	Si2	Chi2	Si2 + Chi2	Si1 + Chi2	Si2 + Chi1
Shoot length (cm)	128.5 i	130.4 g	129.6 h	132.6 e	133.5 d	131.4 f	136.5 a	134.5 c	135.5 b
Shoot fresh weight (g)	138.5 g	139.4 f	138.6 fg	140.7 de	141.7 c	140.6 e	143.5 a	141.4 cd	142.6 b
Shoot dry weight (g)	40.6 f	41.7 e	40.8 f	42.5 d	43.7 c	42.7 d	45.6 a	44.6 b	44.4 bc
Root length (cm)	54.3 e	55.6 d	54.7 e	56.5 cd	57.3 bc	56.4 d	59.4 a	57.5 b	58.6 a
Root fresh weight (g)	45.6 f	47.4 d	46.3 e	47.5 d	49.4 b	48.3 c	50.5 a	47.7 cd	49.8 b
Root dry weight (g)	10.5 f	12.2 d	11.4 e	13.4 c	14.4 b	12.6 d	15.6 a	13.6 c	14.6 b

C control; Si: silicon; Chi; chitosan. Different letters along the row show significant differences at $p \leq 0.05$

application of Si and Chi (Si2 + Chi2) compared to the control treatment. Similarly, plants treated with Si2 + Chi2 showed maximum chlorophyll b (56%) compared to the control treatment.

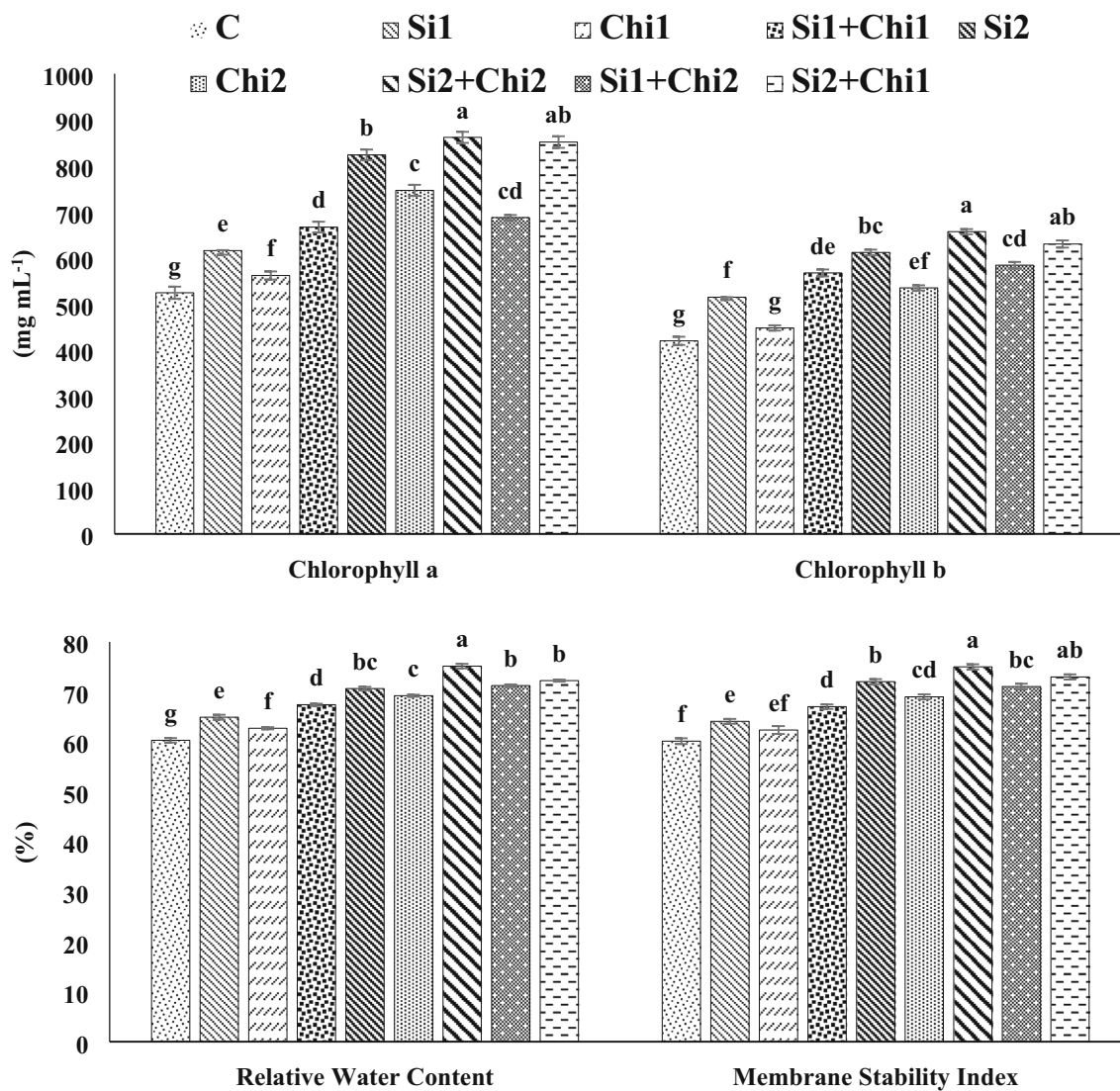**Relative water contents and membrane stability index**

Salt stress significantly declined relative water contents (RWC) in plants (Fig. 1). Addition of Si and Chi improved RWC under salinity conditions. Maximum RWC was found in Si and Chi treated plants of maize as compared to the control. The RWC was improved by 26% with combined application of Si2 + Chi2 as compared to the control. Maximum membrane stability index (25%) in maize plants was noted in Si2 + Chi2 treatment as compared to the control (Fig. 1).

Table 4 Effect of silicon (Si) and chitosan (Chi) on different parameters

Parameters	Treatments								
	C	Si1	Chi1	Si1 + Chi1	Si2	Chi2	Si2 + Chi2	Si1 + Chi2	Si2 + Chi1
Cob length	10.4 f	12.5 d	11.6 e	13.3 c	13.6 c	12.6 d	15.6 a	14.5 b	14.7 b
Grain rows per cob	10.3 f	12.3 de	11.4 e	13.4 c	14.3 bc	13.3 cd	15.5 a	14.6 ab	15.3 ab
No of grain per cob	235.7 g	237.5 e	236.6 f	238.4 d	239.5 b	238.6 cd	240.5 a	239.3 bc	239.7 b
100 grain weight	15.2 f	16.3 ef	15.4 f	17.3 de	18.5 bc	17.6 cd	19.6 a	18.6 ab	19.3 abc

C: control; Si: silicon; Chi; chitosan. Different letters along the row show significant differences. Different letters along the row show significant differences at $p \leq 0.05$

Fig. 1 Effect of various doses of Si and Chi on Chlorophyll a, b, relative water content and membrane stability index of maize plants. Control (C), Si1 = 40 kg ha^{-1}, Si2 = 80 kg ha^{-1}, Chi1 = 15 kg ha^{-1} and Chi2 = 30 kg ha^{-1}. Letters belong to each treatment separately and data are shown as means $\pm$ SE of three replicates using Turkey-HSD test

Sodium, potassium and silicon concentrations in shoot of maize plants

Sodium concentration (Na^+) in shoots was significantly ($p \leq 0.05$) influenced by the Si and Chi application (Table 2). The lowest concentration of Na^+ were observed in maize shoots where the plants were treated with the combined application of Si and Chi (i.e. Si2 + Chi2) and the highest concentration without application of Si and Chi in stressed maize plants i.e. the control (Fig. 2).

Potassium concentration (K^+) reduced in maize plants in the control (Fig. 2). Exogenously applied different levels of Si and Chi significantly improved the K^+ concentration. Maximum increase in K^+ concentration (73%) occurred in the combined application of Si2 + Chi2 as compared to the control.

Application of Si and Chi significantly ($p \leq 0.05$) increased the Si content in maize plants (Fig. 2). The combined application of Si2 + Chi2 markedly improved up to 52% Si contents in maize plants as compared to control.

Antioxidants enzymes

Application of Si and Chi considerably increased antioxidants to remove the active oxygen and improve the degree of damage (Fig. 3). Higher doses of Si and Chi were more effective to increase the antioxidants. Superoxide dismutase (SOD) was improved (36%) in the combined application of Si2 + Chi2 as compared to the control (Fig. 4).

Similarly, peroxidase (POD) activities were improved by 38% and catalase (CAT) activities were increased by 65% in Si2 + Chi2 treatment (Fig. 3).

CaCl$_2$ extractable Si concentration in soil

Application of Si and Chi significantly ($p \leq 0.05$) increased Si content in the soil (Fig. 4). However, the higher doses of Si and Chi were effective to increase soil Si. The maximum soil Si content was found in Si2 + Chi2 treatment (9%) compared to the control.

Discussion

Previous studies have shown that soil salinity is devastating for plant's growth as it adversely affects physiological and metabolic processes in the plant (Shaaban et al. 2013; Gowayed et al. 2017). Higher levels of salt stress (up to 80 and 160 mM) have been documented to decrease growth of wheat shoot more strictly as compared to growth of root (El-Hendawy et al. 2011). In the present study, the soil salinity stress substantially decreased plant growth, which is in line with the several earlier studies. Akram et al. (2010) revealed that the decline of biomass and yield of maize plants occurred under salinity stress condition. This might be because of the inhibition of expansion of cell due to low turgor pressure in greater salinity stress causing a reduction in growth of shoot. Higher salt stress could enhance the production of inhibitors such as abscisic acid
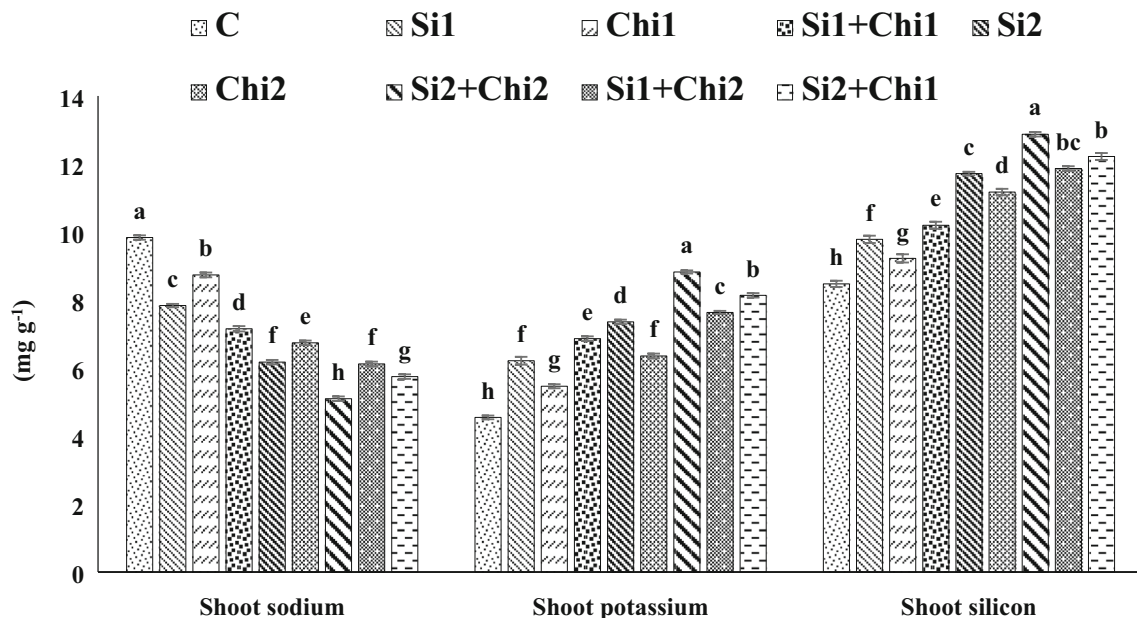
Fig. 2 Effect of various doses of Si and Chi on concentration of sodium, potassium, and silicon in maize shoot. Control (C), Si1 = 40 kg ha^{-1}, Si2 = 80 kg ha^{-1}, Chi1 = 15 kg ha^{-1} and Chi2 = 30 kg ha^{-1}. Letters belong to each treatment separately and data are shown as means ± SE of three replicates using Turkey-HSD test
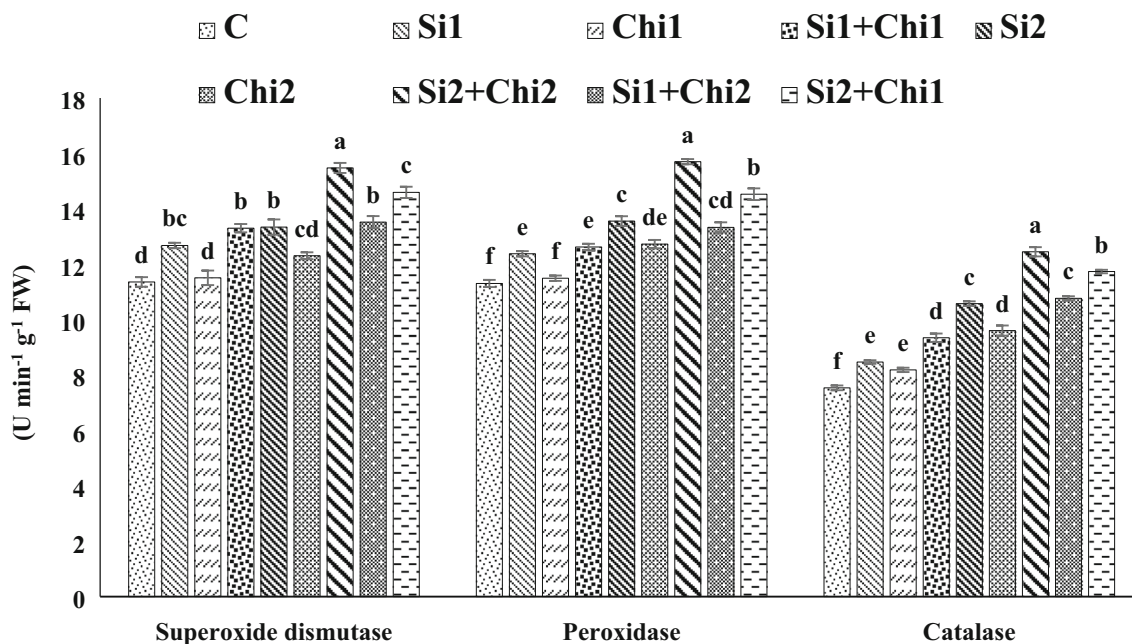
Fig. 3 Effect of various doses of Si and Chi on superoxide dismutase, peroxidase and catalase activity of maize. Control (C), Si1 = 40 kg ha^{-1}, Si2 = 80 kg ha^{-1}, Chi1 = 15 kg ha^{-1} and Chi2 = 30 kg ha^{-1}. Letters belong to each treatment separately and data are shown as means ± SE of three replicates using Turkey-HSD test

Fig. 4 Effect of various doses of Si and Chi on silicon in soil. Control, Si1 = 40 kg ha^{-1}, Si2 = 80 kg ha^{-1}, Chi1 = 15 kg ha^{-1} and Chi2 = 30 kg ha^{-1}. Letters belong to each treatment separately and data are shown as means ± SE of three replicates using Turkey-HSD test
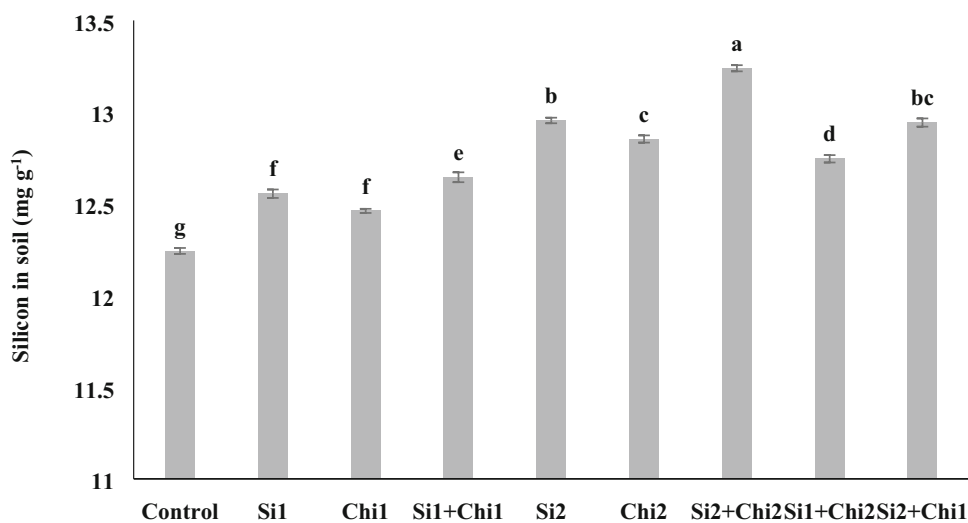
and hindered the production of plant growth promoters such as cytokinins (Munns and Tester 2008; Liu et al. 2020). However, the application of Si and Chi to soil considerably increased maize plant growth in the present study.

The combined application of Si and Chi to the salt stress during maize cultivation improved the growth as well as biomass in the present study. It has been documented that Si + Chi significantly ($p < 0.05$) improves plant biomass under saline stress condition (Parveen and Ashraf 2010). The reason of increase in biomass was greater concentration of mineral nutrient such as Fe, P, Ca and Mg up-take

by plants (Mateos-Naranjo et al. 2013). Researcher have revealed that high uptake of mineral nutrients is a potent approach to increase resistance against salinity (Chatzigianni et al. 2019). In our present study, soil salinity highly increased Na$^+$ concentration in shoot of plant with an obvious decline in K$^+$ contents in shoot, which might be due to specific toxicity of ion. Higher requirement of K has been identified for osmoregulation, enlargement of cell, stomatal opening and supply of CO$_2$ for photosynthesis (Munns and Tester 2008). In the current study, Si and Chi application not only reduced the concentration of Na$^+$ but also improved concentration of the K$^+$ in shoots of maize

plants. Maize plants survived at high levels of soil salinity by the combined application of Si2 + Chi2.

In the present study, results of maize plants indicated by length of shoot and root, fresh and dry biomass, RWC and MSI reduced in response to soil salinity stress. The decline in all growth indices of salt stressed maize plants found in the current study was supported by the previous finding of Ashraf et al. (2003). Decreased relative water content (RWC) might be attributed to reduction of the uptake of water due to low substrate water potential, or due to damaged root system under salinity stress (Garg and Singla 2009). Application of Si and Chi influenced the growth parameters and physiological and biochemical parameters of maize plants. Similar results were found by Ma et al. (2012) as they reported that priming with Chi of wheat seeds showed maximum growth of plants than untreated plants during salinity stress. Farouk and EL-Metwally (2019) conducted field experiment with the foliar application of Si (125 mg mL^{-1}), Chi (250 mg mL^{-1}) and Si + Chi (Si 125 mg mL^{-1} + Chi 250 mg mL^{-1}) under 100%, 70% and 40% moisture levels, and found that the combined application of Si and Chi under different moisture levels was more effective to improve morphological, chlorophyll, carotenoid, anatomical character and organic solutes compared with separate application.

Photosynthetic pigments such as chlorophyll a and b contents were also reduced in the plants grown under soil salinity stress, i.e. without application of Si and Chi. The decreased chlorophyll contents were due to the degradation of photosynthetic pigments such that chlorophyllase production started because of salinity stress (Jiang et al. 2017). Another possible reason is inefficient photosynthetic apparatus activity (Mateos-Naranjo et al. 2013).

Reactive oxygen species (ROS) in plants are poisonous which damage the subcellular organelles such as DNA, proteins, lipids and carbohydrates which eventually leads to the death of cell (Hoffmann et al. 2020). Under saline environmental conditions there are various strategies modified by plants to survive against high level of ROS and keep their healthy growth like making of different antioxidant enzymes. Salinity influenced the activity of CAT, POD and SOD in maize plants in the current study. Application of Si and Chi improved antioxidants activities in the stress environment. The SOD has vital role in plants because superoxide radical O_2- is dismutased by SOD which is abridged to O_2 and H_2O_2 (Wang et al. 2010). The H_2O_2 is changed into H_2O by CAT enzyme (Abdelaziz et al. 2018). Researchers have also stated rise in CAT and SOD production by the combined application of Si and Chi under stress conditions of salinity in different crops such as wheat, barley and maize (Gong et al. 2005; Moussa 2006). In the current study, SOD, POD and CAT were increased in Si and Chi (alone and combined) treated plants under saline

condition. Protective antioxidants like SOD, CAT and POD could reduces the concentration of ROS and retain homeostasis between formation and elimination of ROS and decrease the free radicals, and thus damage to plant cells could be reduced (Joseph and Jini 2011).

Application of Si and Chi also increased the yield traits. This was possible because the salinity stress was reduced which increased the biochemical processes including chlorophyll contents for increased grains, number of grain rows, and cobs per plant (Hoffmann et al. 2020).

Conclusion

The data reported herein revealed that Si and Chi play an important role to enhance photosynthesis of maize plants under salinity stress. The combined application of Si and Chi was the most effective to increase plant growth, biochemical traits and yield of the maize plant. In short, soil salinity can be alleviated by Si and Chi application. Further research is required to gain a full understanding of how Si and Chi amend the salinity stress responses in plants.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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