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SILICON APPLICATION IMPROVES GERMINATION AND VEGETATIVE GROWTH IN MAIZE GROWN UNDER SALT STRESS

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Salinity stress is a major abiotic factor limiting growth and yield of agronomic crops including maize. The present study was conducted to categorize the latest maize cultivars according to their tolerance against salinity stress and to screen out the salt tolerant and sensitive maize cultivars at different growth stages. Initially 15 maize cultivars were categorized into three classes viz sensitive, medium and tolerant to salinity on the basis of germination parameters under control and 90 mM NaCl salinity. Eight selected cultivars were germinated in petri plates with 90 mM NaCl and 2 mM K_2SiO_3 in a second experiment. Application of Si increased all germination parameters under salinity stress irrespective of cultivars. Two cultivars contrasting in their salinity tolerance at germination (Syngenta 8441 and EV1089) were selected to evaluate role of Si at vegetative growth stage. Plants were grown in pots with 60 mM NaCl and 2 mM H_2SiO_3. Significant variation existed in both cultivars for growth and ionic concentration. Cultivar EV1089 performed better in non-saline conditions than Syngenta 8441; however, it could not tolerate salinity in root zone and significant reduction in biomass observed. Silicon application improved growth in both cultivars under salinity stress by reducing Na uptake and improving K uptake. Silicon nutrition management and selection of salinity tolerant cultivars can improve productivity of salt affected lands and more area can be taken under cultivation to feed ever increasing population.

Keywords: Abiotic stress, salinity tolerance, germination, cereals.

INTRODUCTION

To feed ever-increasing population, there is dire need to improve crop yields per unit area or to increase area under crop production. The problem is increasing in arid to semi-arid climates and good quality arable soils are being converted to marginal and/or poor quality soils not fit for agricultural purposes.

Osmotic stress can be simulated by NaCl in petri dishes (*in vitro*) for plants to maintain uniform osmotic potential throughout the experimental period (Kulkarni and Deshpande, 2007). Poor germination is the first symptom of salinity stress (Mohammed *et al.,* 2002) mainly because of physiological drought (Munns *et al.*, 2006). Salinity delays the onset, reduces the rate and increases the dispersion of germination events (Mohammed *et al.*, 2002), resulting in a reduced plant growth and crop yield (Ashraf and Foolad, 2005; Kulkarni and Deshpande, 2007). This low germination is also related to salinity induced disturbance of metabolic processes in plants leading to increase in phenolic compounds (Ayaz *et al.,* 2000). Significant reduction in germination ranging from 24 to 53% has been reported in barley cultivars grown with irrigation water of EC ranging from 9.2 to 16.28 dS m^{-1} (Hussain *et al.*, 1997). An obvious reduction was reported in radicle, plumule and seedling length in different maize varieties when they were subjected to salt stress (Farsiani and Ghobadi, 2009; Gholamin and Khayatnezhad, 2010; Khayatnezhad *et al.,* 2010; Khodarahmpour, 2012; Ziaf *et al.*, 2014).

Silicon is known to improve plant growth particularly under abiotic stresses (Ma and Yamaji, 2008). It improves plant water status in context of relative water content and transpiration rate (Romero-Aranda *et al.,* 2006; Tahir *et al.,* 2011), ameliorates the harmful effects of salinity on chlorophyll content and plant biomass (Tuna *et al.,* 2008), lowers Na^+ concentrations in both leaves and roots (Liang *et al.,* 2003; Kafi and Rahimi, 2011; Tahir *et al.,* 2012).

Salinity-silicon interactions have been investigated in a number of plant species (Al-Aghabary *et al.,* 2004; Zhu *et al.,* 2004; Liang *et al.,* 2005; Tahir *et al.,* 2012). Increasing the availability of Si in the growth medium can reduce salinity stress in plants by altering soil and plant factors (Kafi and Rahimi, 2011), but specific mechanisms are still debatable. Liang *et al.* (2007) reported that Si uptake in a salt stressed plant increases root activity for nutrient uptake inhibits transpiration which reduces osmotic stress. Silicon also increases the activity of ATPase & PPase in plasma membrane (Tuna *et al.,* 2008) which ultimately increases K and decrease Na uptake. Furthermore, crop species and cultivars within species significantly differ in their response to soil salinity (Nasim *et al.,* 2008; Tahir *et al.,* 2011). These variations can be exploited to increase crop growth and yield and to improve salinity tolerance.

Numerous studies have reported the beneficial effects of Si on growth of crop plants at vegetative growth and at maturity (Tuna *et al.,* 2008; Liang *et al.,* 2003). As germination and early vegetative growth is very important for good crop stand and growth, hence it is very important to study the beneficial effects of Si at germination stage and to screen maize germplasm for salinity tolerance at germination. The primary objective of the present study was to compare latest fifteen maize cultivars towards salinity stress and to select the salt tolerant and sensitive cultivars of maize; afterwards, comparing those cultivars against salinity and silicon treatments to study the role of Si in improving maize germination parameters and selected cultivars were tested for different growth and ionic parameters at early vegetative growth.

MATERIALS AND METHODS

Experiment I*: *Exogenous salt application on germinated maize seeds: The study was conducted under controlled conditions in Petri plates to screen out the maize cultivars on the basis of salinity stress and later on to characterize them as tolerant and sensitive. Seeds of fifteen maize cultivars (Table 1) were thoroughly washed with distilled water and dipped in sodium hypochlorite solution (10%) for 5 minutes. Petri plates were also washed with distilled water and then autoclaved. Temperature of the growth room was maintained at 25±2°C. Filter paper was placed in each petri plate and 10 seeds per petri plate were placed and covered by filter paper. Sodium chloride solution 90 mM was applied as a salinity stress to the recommended petri plates and distilled water was given to control. Then, petri plates

Table 1. Categorization of maize cultivars on the basis of their index scores of various parameters into low, medium and high scoring cultivars.

Parameter	Low (Score 1)	Medium (Score 2)	High(Score 3)
Radicle length (cm)	<0.40 EV1089<Golden Cross <Monsento919	0.40-1.54 Pioneer30R50<monsento6789<Supraseed4444 <Neelum<Agaiti2000<EV6089<Agaiti85<EV 77< 32B33	>1.54 Dekalb< Syngenta8441< ICI hybrid
Plumule length (cm)	<0.18 GoldenCross<Monsento919 <32B33<EV1089<Monsento678 9	0.18-0.91 Dekalb<ICI hybrid<EV77<Agaiti2000<EV6089 <Pioneer30R50<Neelum<Supraseed4444	>0.91 Agaiti85< Syngenta 8441
Seedling length (cm)	<0.35 EV1089<Monsento919 <Golden Cross<32B33	0.35-1.20 Syngenta8441<Supraseed4444<Pioneer30R50 <Monsento6789<Agaiti2000<Neelum <EV6089<Agaiti85	> 1.20 Dekalb<ICI hybrid<EV77
Germination percentage	<0.71 32B33<Monsento919 <Golden Cross	0.71-1.10 Pioneer30R50< Supraseed 4444< EV6089=Agaiti85 <Agaiti 2000 <EV1089 <Monsento6789 < EV77< Neelum	> 1.10 Syngenta8441<ICI hybrid<Dekalb
Vitality index	<0.24 Monsento919<Golden Cross <EV1089< 32B33	0.24-1.12 Supraseed 4444< Pioneer30R50< EV6089<Agaiti85 < Agaiti 2000< Monsento6789<Neelum	>1.12 Syngenta8441<ICI hybrid=Dekalb <EV77
Seed vigour index	<0.26 Monsento919<Golden Cross <32B33<EV1089	0.26-1.23 EV77< Supraseed 4444< Pioneer30R50 <Monsento6789<Agaiti 2000<EV6089 <Agaiti85<Neelum	>1.23 Dekalb< Syngenta8441< ICI hybrid
Mean germination Time	<0.97 Dekalb< Syngenta8441< ICI hybrid	0.97-1.07 Monsento6789=Monsento919< Pioneer30R50=Golden Cross<Neelum<Agaiti2000 <Agaiti85=Supraseed4444<EV77	>1.07 32B33<EV1089=EV6089

Seeds were grown with 90mM NaCl solution in petri plates for 8 days. Classification of each cultivar is based on performance of saline treatment relative to its control with the population mean (μ) and standard deviation (SD) for each parameter. The cultivars are assigned as low if their mean is $< \mu-SD$, medium if their mean is between $\mu-SD$ to $\mu+SD$ and high if mean $>\mu+SD$. ($LSD_{0.01}$ for three way interaction = 11.6) were randomized and each treatment was replicated three times. Daily germination count was recorded. Seeds were considered germinated when the emergent radicle reached 2 mm length. After 7 days, germination percentage was measured by ISTA (International Seed Testing Association) standard method. At end of the 7^{th} day, the length of radicle and plumule of seeds, seedling length, the germination percentage, germination index, and seed vigor (Ellis and Roberts, 1981) were also measured.

Germination percentage (GP) = SNG/SN0 × 100

Where SNG is the number of germinated seeds, and SN0 is the total number of experimental seeds with viability (Scott *et al.,* 1984).

Vitality index (VI) = S × GI

Where S is the length of seedlings and GI is the germination index.

Mean Seed vigor index was calculated by the given formula given below:

Seed vigor = Germination percentage × Seedling length.

Maize cultivars were categorized for salinity tolerance on basis of above parameters following Aziz *et al.* (2011) into three classes viz susceptible/sensitive, moderately tolerant and tolerant. The categorization was based on the individual values for each parameter compared with mean value for all cultivars. The categorization of different maize cultivars was based on the performance of saline treatment relative to its control with the population mean (µ) and standard deviation (SD) for each parameter.

***Experiment II*: *Exogenous silicon application on maize seedling growth under salt stress*:** Four salt sensitive maize cultivars (Monsento-919, Golden cross, 32B33 and EV-1089) and four salt tolerant (Syngenta-8441, Pioneer-30R50, ICI hybrid and Dekalb) were selected on the basis of their index scores of various parameters into low, medium and high scoring cultivars from experiment 1 (Table 1) to study the response of added Si on germination. Seeds were thoroughly washed by distilled water and placed in sodium hypochlorite solution for 5 minutes. Petri plates were also washed by tap water and then autoclaved. Temperature of the growth room was maintained at 25±2°C. After wards, filter paper was placed in each petri plate (10 cm in diameter) and 10 seeds per petri plate were sown and then covered by filter paper. There were two salinity levels viz 0 and 90 mM NaCl and two Si levels viz 0 and 2 mM added through spray. Silicon was added as potassium silicate (K_2SiO_3).

The petri plates were randomized and each treatment replicated three times. Daily germination count was recorded. After 8 days, following parameters were recorded.

a) Germination percentage (%)
b) Germination index
c) Vitality index
d) Seedling length
e) Seedling vigor

***Experiment III*: *Exogenous silicon application on maize shoot biomass and its ionic concentration under salt stress*:** Two maize cultivars (salt tolerant ‘Syngenta-8441’ and salt sensitive ‘EV-1089’) were selected from Experiment II to study the response of added Si on early vegetative growth under salt stressed condition. A pot study was carried out in wire-house, Institute of Soil and Environmental Sciences (ISES), University of Agriculture, Faisalabad. There were two salinity levels viz 0 and 60 mM NaCl and two Si levels viz 0 and 2 mM H_2SiO_3 added. Then, ten seeds of each cultivar were sown in each pot. After four days of germination, four plants per pot were maintained. Each treatment was replicated three times and pots were randomized accordingly. Distilled water was used to maintain moisture contents of soil at field capacity in all the pots during the experimental period. Plants were harvested after 25 days of growth. Plant Samples were washed with distilled water and blotted dry with tissue paper. The plant samples were air-dried and then oven dried at 65˚C in a forced air driven oven to a constant weight. Fresh and dry matter yield was taken. Plant samples were tested for the Na^+ and K^+ concentration. Finely ground plant samples (0.1 g) were digested in a di-acid (HNO_3:$HClO_4$) mixture (Jones and Case, 1990). The Na and K concentration in the digest was estimated by flame photometer (Jenway, PFP-7). For Si determination, the ground samples (0.2 g) were digested in 2 mL 50% hydrogen peroxide (H_2O_2) and 4.5 mL 50% NaOH in open vessels (Teflon beakers) on a hot plate at 150°C for 4 hours. Silicon concentration was measured using calorimetric amino molybdate blue color method (Elliot and Synder, 1991) on UV-visible spectrophotometer (Shimadzu UV-1201). To 1 mL of supernatant filtrate liquid, 10 mL of ammonium moblybdate (54g L^{-1}) solution and 25 mL of 20% acetic acid was added in 50 mL of polypropylene volumetric flask.

After five minutes, 5 mL of 20% tartaric acid and 1 mL of reducing solution was added in flask and volume was made with 20% citric acid. After 5 but not more than 30 minutes, the absorbance was measured at 650 nm wave length with a UV visible spectrophotometer (Shimdzu, Spectronic 100, Japan). The reducing solution was made by combining solution A (2 g of Na_2SO_3 in 25 mL of DM plus 0.5 g of l-amino-2-naphthol-4-sulfonaic acid) and solution B (25 g of $NaHSO_3$ dissolved in about 200 mL of DM) and diluting to 250 mL.

***Statistical analysis*:** The data obtained from Experiment I was statistically analyzed by *Microsoft Excel 2010*® (Microsoft Cooperation, USA) and characterization made on the basis of (mean-standard deviation) and (mean + standard deviation). All the data from Experiment II and III was statistically analyzed by *Microsoft Excel 2010*® (Microsoft Cooperation, USA) and *Statistix 8.1*®. Different treatment means were separated using least significant difference (LSD) test (Steel *et al.,* 1997).

RESULTS

Experiment I. Effect of salt stress on seed germination and its characterization: There was significant ($P \leq 0.01$) genotypic variation among maize cultivars in response to salinity stress (Table 1). Salinity stress significantly ($P \leq 0.01$) reduced all germination parameters irrespective of the cultivars. Categorization of maize cultivars was done on the basis of their index scores of various parameters into low, medium and high scoring cultivars. Classification is based on the relative values of each cultivar with the population mean (μ) and standard deviation (SD) for each parameter as in Aziz *et al.* (2011). The cultivars are assigned as low if their mean is < μ−SD, medium if their mean is between μ−SD to μ+SD and high if cultivar mean is >μ+SD.

Cultivars 'EV1089', 'Golden Cross' and 'Monsento 919' produced radical length having relative values < 0.40 cm plant^{-1} and gained lowest index score (1) when grown with applied salinity (Table 1). Cultivars 'Dekalb', 'Syngenta 8441', and 'ICI hybrid' gained maximum index score (3) as they produced radical length >1.54 cm plant^{-1}. Other ten cultivars were categorized as medium for radical length. Their radical length ranged from 0.43 cm plant^{-1} to 1.44 cm plant^{-1}.

Plumule length was significantly decreased by salt stress. Five cultivars 'EV1089', 'Golden Cross', '32B33', 'Monsento 6789', and 'Monsento 919' gained minimum index score (1) and plumule length was <0.18 cm plant^{-1}. Only 2 cultivars "Agaiti 85" and "Syngenta 8441" produced plumule length >0.91 cm plant^{-1}. Remaining eight cultivars were ranged from 0.57-0.79 cm plant^{-1}.

Cultivars, 'EV1089', '32B33', 'Golden Cross' and 'Monsento 919' were categorized as salt sensitive as they gained lowest index score (1) and produced seedling length <0.35 cm plant^{-1}, vitality index <0.24 plant^{-1} and seed vigor index <0.26 plant^{-1}, respectively. Cultivars, 'Dekalb', 'Syngenta 8441', 'ICI hybrid' and Pioneer 30R50 were categorized as salt tolerant as they gained maximum index score (3) and germination % age >1.10. 'Dekalb', 'Syngenta 8441' and 'ICI hybrid' also shown maximum vitality index >1.12, seed vigor >1.23 and mean germination time >1.07, respectively.

On the basis of above mentioned results, eight maize cultivars (four salt sensitive and four salt tolerant) were selected on the basis of their index scores of various parameters into low and high scoring cultivars and response of added silicon on germination of salt stressed cultivars were interpreted.

Experiment II. Effects of exogenous silicon application on seedling growth and germination parameters: There were significant ($P \leq 0.01$) main and interactive effects of salinity and Si applications on seedling growth (Fig. 1). Salinity stress significantly ($P \leq 0.01$) decreased the seedling length in all cultivars. However, cultivars differed significantly ($P \leq 0.01$) in their response to the salinity and Si application.

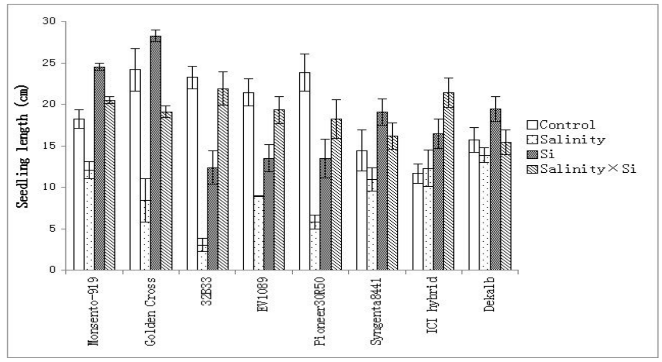


Figure 1. Seedling length (cm) of eight maize cultivars supplied with different rates of salinity (0 and 90 mM) and Si (0 and 2 mM). There were six seeds per petri plate in experiment II and values are mean± S.E. n=3

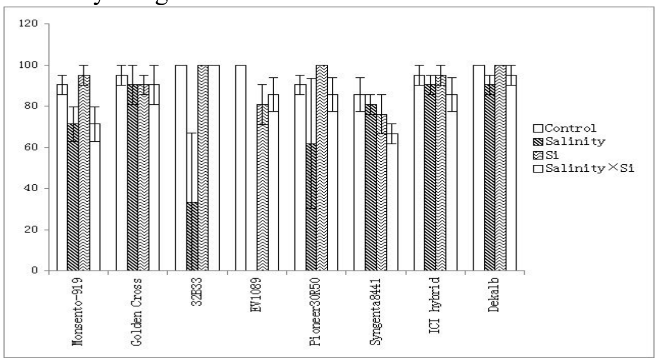
Germination percentage of the maize cultivars was significantly ($P \leq 0.01$) affected by main effects of cultivar and Si application (Fig. 2). Silicon application under salt stress increased germination percentage in cultivars '32B33' and 'EV1089' as compared to saline treatment only. However, interaction among all cultivars remained non-significant for germination %age.

Vitality index of maize cultivars was significantly ($P \leq 0.01$) influenced by interactive effects of cultivar, salinity and Si application (Fig. 3). On average, vitality index was decreased about 6 folds because of salinity. Silicon application significantly increased vitality index in all maize cultivars; while '32B33' and 'ICI hybrid' showed maximum vitality index of 211 and 179, respectively.

Seed vigor index of maize cultivars was significantly ($P \leq 0.01$) influenced by main and interactive effects of cultivars, salinity and Si application (Fig. 4). In general, application of Si increased while salinity decreased the seed vigor index in salt sensitive cultivars. The application of Si did not affect the seed vigor index in two cultivars, 'Syngenta 8441' and 'Dekalb' under salinity, while it improved seed vigor in rest of 6 cultivars.

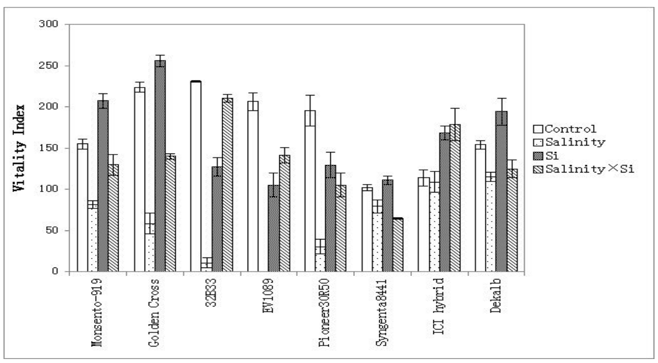
Shoot dry weight was significantly ($P \leq 0.01$) reduced by salt stress in both cultivars; however the reduction was variable among cultivars (Fig. 5). Reduction in shoot dry weight was more in cultivar EV-1089 (64%); than in

Syngenta-8441 (21%). Silicon application increased shoot dry weight in both cultivars.



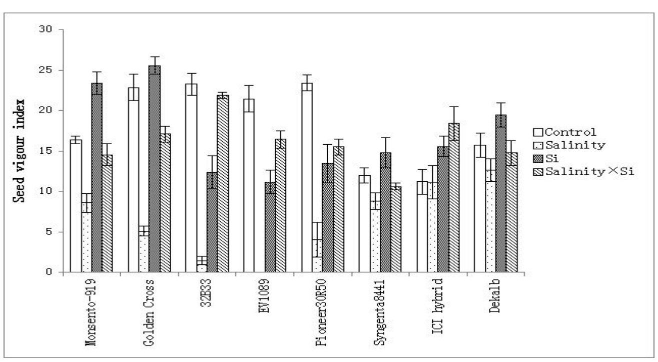
($LSD_{0.01}$ for three way interaction = 36.26)

Figure 2. Germination percentage of eight maize cultivars supplied with different rates of salinity (0 and 90 mM) and Si (0 and 2 mM). There were six seeds per petri plate in experiment II and values are mean± S.E. n=3



($LSD_{0.01}$ for three way interaction = 48.4)

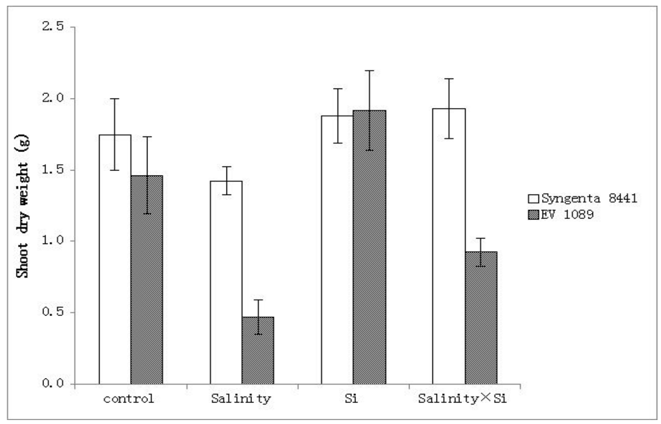
Figure 3. Vitality index of eight maize cultivars supplied with different rates of of salinity (0 and 90 mM) and Si (0 and 2 mM). There were six seeds per petri plate in experiment II and values are mean± S.E. n=3



($LSD_{0.01}$ for three way interaction = 8.2)

Figure 4. Seed vigor index of eight maize cultivars supplied with different rates of salinity (0 and 90 mM) and Si (0 and 2 mM). There were six seeds per petri plate in experiment II and values are mean± S.E. n=3

***Experiment III. Effects of silicon on shoot biomass and ionic concentration*:** Salinity stress significantly (*$p<0.01$*) decreased plant fresh weight of both cultivars, however reduction was variable among both cultivars (Fig. 5). Maximum decrease in shoot fresh weight was observed in cultivar EV-1089 (29%); while cultivar syngenta-8441 showed minimum reduction (9%) relative to control. There was 32% increase in shoot fresh weight of EV1089 with Si application under salt stress as compared to saline treatment.



($LSD_{0.01}$: interaction effect for dry weight, 0.78)

Figure 5. Shoot dry weight (g plant^{-1}) of two maize cultivars supplied with different rates of salinity (0 and 60 mM) and Si (0 and 2 mM). There were four seeds per pot in experiment III and values are mean ± S.E. n=3

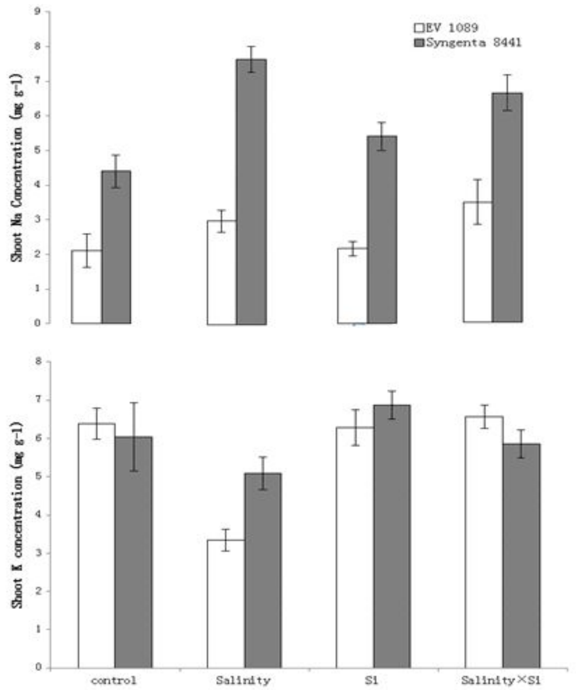
Salinity stress significantly (*$p<0.01$*) increased shoot Na concentration of both cultivars, however reduction was variable among both cultivars (Fig. 6) (A). Shoot Na concentration decreased with Si application in cultivar Syngenta-8441(18%) relative to saline treatment only.

Salinity stress significantly (*$p<0.01$*) decreased shoot K concentration of both cultivars; however reduction was variable among both cultivars (Fig. 6) (B). The decrease in shoot K concentration was more prominent in cultivar EV-1089 (49%) than cultivar syngenta-8441 (15%) relative to control. Silicon application enhanced the shoot K concentration in both cultivars relative to saline treatment only. The reduction in shoot K concentration of cultivar EV1089 was decreased from 49 to 1% in treatment where plants were grown with silicon under salinity stress.

Shoot Si concentration decreased significantly *($P\leq0.01$)* with salinity stress in both cultivars, however reduction was variable among both cultivars (Fig. 7). Silicon application enhanced the shoot Si concentration in both cultivars relative to saline treatment.

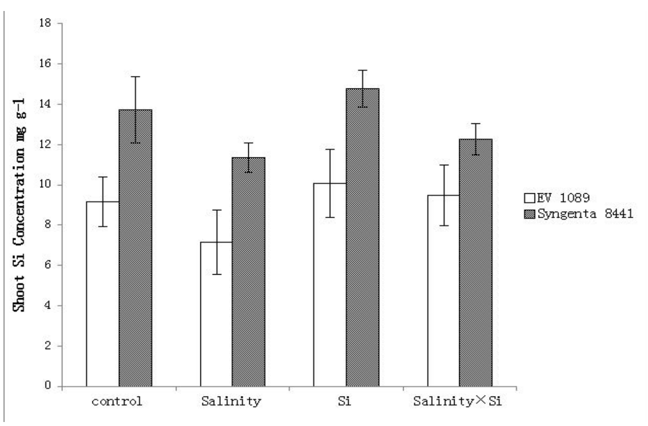
(A)

(B)



($LSD_{0.01}$: interaction effect for Na, 2.61; for K, 1.98)

Figure 6. Shoot Na and K concentration (mg g^{-1}) of two maize cultivars supplied with different rates of salinity (0 and 60 mM) and Si (0 and 2 mM). There were four seeds per petri plate in experiment III and values are mean± S.E. n=3



($LSD_{0.01}$: interaction effect for Si, 1.81)

Figure 7. Shoot Si concentration (mg g^{-1}) of two maize cultivars supplied with different rates of salinity (0 and 60 mM) and Si (0 and 2 mM). There were four seeds per petri plate in experiment III and values are mean± S.E. n=3

DISCUSSION

Soil salinity significantly affects seed germination and early growth (Misra and Dwivedi, 2004) by decreasing germination rate and initiation of the seedling growth (Almansouri *et al.,* 2001). Significant reduction in seedling length under salinity has been reported in maize and it has been categorized as salt sensitive crop particularly at germination stage (Farsiani and Ghobadi, 2009; Gholamin and Khayatnezhad, 2010; Khayatnezhad *et al.,* 2010). In present experiment, germination in all cultivars was reduced significantly because of salinity stress (Table 1); however the effect was variable among different cultivars.

The absolute values of seedling length, vitality index, seed vigor of salt sensitive cultivars such as EV1089 and 32B33, were more or less similar or even higher than salt tolerant cultivars, but their performance at saline treatments was very poor (Table 1). Hence cultivars were categorized for their performance under salinity stress relative to their potential yield/growth at normal conditions. The categorization of different maize cultivars was based on the performance of saline treatment relative to its control with the population mean (μ) and standard deviation (SD) for each parameter following Aziz *et al.* (2011) who categorized the brassica cultivars against phosphorus deficiency stress. In both experiments, Cultivars 'Syngenta 8441', 'Dekalb', and 'ICI hybrid' were efficient against salt stress (Table 1) in all parameters studied, while cultivars '32B33', 'EV 1089', and 'Golden Cross' were sensitive to NaCl stress.

Salinity stress generally delays seed germination (Mohammed *et al.,* 2002), which was observed by increased mean germination time of all cultivars under salinity stress, however cultivars varied for mean germination time (Table 1). Decreased osmotic potential in saline treatment is one of the reasons for increased mean germination time in corn (Alebrahim *et al.,* 2008). Osmotic stress is the first deleterious effect of salinity as Munns *et al.* (2006) has proposed a dual phase model of salinity stress response. Salinity stress caused a decrease in seed vigor with a significant inter-genotype variation (Table 1).

Mineral nutrition is an effective strategy to increase salt resistance in plants and to sustain crop productivity in low input and environmental friendly agriculture systems (Tuna *et al.,* 2008). Chemical treatments can stimulate seeds germination in many plant species (Meot-Duros and Magne, 2008). As reactive oxygen species production and lipid peroxidation are the major consequences of salt stress which further deteriorates the seed (Lehner *et al.,* 2008), so exogenous application of ethanol and ascorbic acid can protect the seed against reactive oxygen species and lipid peroxidation, thus enhancing seed germination. In our experiment, the exogenous Si application in growth medium increased the germination rate, germination percentage, vitality index and the seedling length in maize under salt stress (Fig. 2, 3). These findings suggested that Si is involved directly or indirectly in both morphological changes and physiological processes in plants (Moussa, 2006). The response of maize cultivars varied significantly in terms of different germination parameters. The absolute values of seedling length, vitality index, seed vigor of salt sensitive cultivars were more or less similar or even higher, but their performance at saline treatments was very poor (Fig. 4). In experiment II, germination % and vitality index could not be calculated for cultivar EV 1089 under salinity stress (Fig. 2, 3) because there was no plumule growth in EV 1089.

Silicon provision to a salt stressed maize plant increased the shoot growth at early vegetative growth (Fig. 5). It is also reported that Si application enhances root fresh and dry weights in maize under saline regimes (Moussa, 2006; Parveen and Ashraf, 2010).

Salt stress increased the shoot Na concentration while shoot K concentration was decreased (Fig. 6); as already reported in a number of plants (Moussa, 2006; Kafi and Rahimi, 2011; Nasim *et al.*, 2008; Tahir *et al.*, 2012). Key to salt tolerance is the ability of crop to reduce Na^+ uptake while maintaining cytoplasmic K^+ concentrations at levels required for stomatal conductance, net photosynthesis, hormonal balances and the energy requirements of either ion transport or the synthesis of compatible solutes (or both) could contribute to increase crop growth (Bose *et al.,* 2015). Silicon application improved shoot K concentration and decreased Na concentration, (Fig. 6) thereby maintaining K: Na ratio necessary for metabolic functions (Marschner, 1995).

The genetic variation among cultivars for salinity tolerance and their variable response to Si application demands further investigation for identification of Si induced mechanism of salinity tolerance in maize. Cultivar EV1089 showed excellent growth in normal conditions so it must be preferred in normal soils; while Cultivar Syngenta 8441 should be grown in salt affected conditions.

***Conclusion*:** Significant genetic variation existed among maize cultivars which should be exploited improving production on salt affected soils. Proper selection of cultivars for normal as well as saline soils would enhance maize yield. Silicon application enhanced germination, growth and improved ionic parameters.

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