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BENEFICIAL EFFECTS OF SILICON IN WHEAT (*TRITICUM AESTIVUM* L.) UNDER SALINITY STRESS

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Abstract

We evaluated growth performance of two wheat genotypes (Auqab-2000 & SARC-5) differing in salinity tolerance to applied silicon under saline conditions. Plants were grown in pots filled with normal (EC=1.16 dSm^{-1}) and saline soil (developed EC=10 dSm^{-1}). Silicon was applied @ 0, 50 and 130 µg Si/g soil using calcium silicate. Plants were harvested at maturity and different physical and chemical parameters were recorded. Salinity stress significantly ($p<0.01$) reduced dry matter production and grain yield of both wheat genotypes; however reduction was lower in SARC-5 than in Auqab-2000. Silicon application in growth medium significantly ($p<0.01$) improved dry matter and grain yield of both genotypes grown either in normal and/or in saline conditions. Potassium concentration was significantly increased in plants grown with Si in saline soil. Potassium concentration was lower in plants grown with salinity than those grown in normal soil only in –Si plants. Sodium uptake was higher in plants grown under salinity, however Si application significantly reduced Na uptake, resulting in a significant increase in K:Na ratio in shoots. Sodium concentration in shoots had a significant negative correlation ($r>0.81$, $p<0.01$) with shoot dry matter in both genotypes, however, reduction in SDM was more in Auqab-2000. Percent increase in Na concentration due to salinity was significantly reduced in plants receiving Si in root environment. Shoot Si concentration significantly correlated with shoot K concentration ($r=0.83$, $p<0.01$) and negatively with shoot Na concentration ($r=0.57$, $p<0.05$). Increased K concentration and reduced Na uptake or translocation may be one of the possible mechanisms of increased salinity tolerance by Si application in wheat.

Key words: Wheat, salinity, silicon, K:Na selectivity ratio

Introduction

Excess amount of soluble salts in root medium is an important constraint to crop production in soils of semi arid and arid environments around the globe. Approximately 6.3 million hectares of agricultural land in Pakistan is affected by varying degrees of salinity/sodicity (Rafiq, 1990; Ghassemi *et al*., 1995) that adversely affect plant growth and yield in a number of species including wheat (Munns, *et al*., 2006; Raza *et al*., 2006). Qureshi & Barrett-Lennard, (1998) reported that > 65% yield losses in wheat occurs due to salinity. To ensure food security and sustainable economy, there is dire need to find ways to improve salinity tolerance of wheat. Various chemical, physical and biological strategies are adapted for economic crop production on such soils (Ashraf, 1994; Flowers, 2004; Caurtero *et al*., 2006; Ashraf & Foolad, 2007). Of all these strategies, exogenous application of nutrients has gained a considerable ground as a shotgun approach to ameliorate the adverse effects of salt stress (Grattan & Grieve, 1999). For example, exogenous application of K ameliorated adverse effects of salt stress in wheat (Akram *et*

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al., 2007), Ca in bean (Awada *et al*., 1995), and N in *Phaseolus vulgaris* (Wagenet *et al*., 1983). Furthermore, some non-essential mineral nutrient may also counteract adverse effects of salt stress. For example, silicon is non-essential element for plant growth, however, various studies have demonstrated that Si application significantly increased plant growth under normal (Agurie *et al*.,1992) and stresse condition including biotic and abiotic stresses as salt stress (Ma *et al*., 2001; Rodrigues *et al*.,2003; Ma, 2004).

A number of possible mechanisms are proposed through which Si may increase salinity tolerance in plants, e.g., improving water status (Romero *et al*., 2006), increased photosynthetic activity and ultra structure of leaf organelles (Shu and Shi., 2001), stimulation of antioxidant system (Zhu *et al*., 2004), and alleviation of specific ion effect (Rafiq *et al*.,1992) by reducing Na uptake (Epstein, 2001; Gong *et al*., 2003; Liang *et al*., 2003) or by H-ATPase dependent enhancement in K in shoots (Liang *et al*., 2005). Gong *et al*. (2003) also observed improved water economy and dry matter yield of plants by Si application. Silicon application is reported to enhance leaf water potential in wheat under drought stress (Liang *et al*., 1999). They suggested that silica-cuticle double layer formed on leaf epidermal tissue is responsible for this higher water potential.

Keeping all beneficial mechanisms of Si in salinity tolerance of plants, the present pot culture study was conducted to evaluate growth, K and Na uptake by two wheat genotypes, grown under saline and normal soil conditions with different levels of Si in root medium.

Materials and Methods

Soil and growth conditions: A surface soil (0-15 cm), hyperthermic Ustalfic Haplargids, sandy clay loam soil (Gee & Bauder, 1986) was collected from research area of Institute of Soil & Environmental Sciences, University of Agriculture, Faisalabad. The soil contains 11.6 meq/kg of total dissolved salts, 0.85% organic matter (Nelson and Sommers, 1996), 2.1% calcium carbonate (Leoppert & Suarez, 1996), 5.6 mg/kg Olsen P, 185 mg/kg NH_4oAc-K, 240 mg/kg of total Si extracted by sodium acetate buffer, and 35 mg/kg calcium chloride extractable Si. The pH of soil in 1:10 calcium chloride suspension was 7.7.

Six kg of prepared soil was filled in each of 36 plastic pots lined with polyethylene bags. In half of pots, sodium chloride salt was added to develop salinity (10 dSm^{-1}) and rest of the pots were kept as control having original EC of 1.16 dSm^{-1}. The EC of 10 dS m^{-1} was selected because various earlier workers have reported a 50% yield reduction in wheat at this EC. A basal dose of N @ 100 mg/kg as urea, P @ 90 mg/kg as single super phosphate and K @ 120 mg/kg as potassium sulphate were added prior to seed sowing. Silicon was applied @ 0, 50 and 130 µg Si/g soil using calcium silicate. The soil was mixed thoroughly and irrigated with distilled water to field capacity (30%).

Average temperature in the green house varied from 17 to 25 ºC during night and day, respectively. Relative humidity in greenhouse ranged from 45% to 85% at day and night, respectively. Light intensity varied between 300 and 1400 µmol photon m^2S^{-1} depending upon day and cloud conditions during the growth period.

Plant growth: At field capacity, six pre-soaked seeds of two wheat genotypes, SARC-5 (salt tolerant) and Auqab2000 (salt sensitive) were sown in each pot, which were thinned to four plants after the establishment of seedling. Plants were grown till maturity and distilled water was used for irrigation during the growth period. Plants were harvested at maturity and grains were separated from shoots. The samples were oven-dried at 65 °C for 48 hours. The dried samples were ground in a mechanical mill fitted with stainless steel blades to pass through a 1 mm sieve. For Si estimation, a 0.2 g of ground plant samples was digested in 2 ml of 50% hydrogen peroxide and 6 ml of 50% NaOH for 4 hrs at 150 °C. Silicon was measured from the digest by amino-molybdate blue method using UV visible spectrophotometer (Shimdzu,Spectronic 100, Japan) at 650 nm wavelength (Elliot and Snyder, 1991). For the determination of Na and K, fine ground shoot samples were digested in di-acid mixture of nitric and per-chloric acids (3:1) at 60 °C for 2 hrs and K and Na was determined using a flame photometer (Jenway PFP-7).

Statistical analysis: The salinity and silicon treatments were factorially arranged in a 3X2 randomized complete block design with three replicates. The data was analyzed statistically using PC based program MStat-C (Michigan State University, 1996). Comparison among different means of genotypes, salinity and silicon were made by DMR test at 5% probability (Steel *et al*., 1996).

Results

Growth parameters: Shoot dry matter of plants of both genotypes was significantly lower ($p < 0.05$) when grown in saline soil (EC=10 dSm^{-1}) than those grown in normal soil (EC=1.16 dSm^{-1}) (Table 1). However, reduction in SDM was much lower in SARC-5 than in Auqab-2000. Addition of Si in soil significantly ($p<0.01$) increased SDM (up to 3.5 folds) of both genotypes grown either in saline or normal soil conditions. Increase in SDM due to Si application was more in Auqab-2000 when grown in normal soil, but the reverse was true plants grown in saline soil.

Number of tillers (NT) was significantly lower in plants grown with salinity in root environment of both genotypes (Table 1). However, reduction in NT due to root zone salinity was much lower in SARC-5 than in Auqab 2000. Application of Si in both normal and saline soil, significantly ($p<0.01$) increased NT in both genotypes. Salinity also reduced grain yield (more than 50%) in both genotypes. However, addition of Si improved grain yield from 50% to 225%. Grain yield increase due to Si was more pronounced in SARC-5 under saline environment.

Harvest index of both genotypes increased significantly under saline conditions (Table 1). Harvest index of plants grown with salinity was not affected when Si was added in the root medium.

Physiological parameters: Potassium concentration in shoot was similar in both genotypes. Salinity stress significantly reduced K concentration in shoot in both genotypes when grown without Si. Silicon application significantly ($p<0.01$) increased K concentration in leaves of wheat genotypes under normal and in saline environments. Increase in shoot K concentration varied from 1.25 folds to 1.56 folds in normal soil. Under saline conditions, increase in K concentration ranged from 2 folds to 2.6 folds due to Si application in root environment. Maximum K concentration (16.8 mg/g) was observed in SARC-5 when grown under saline conditions.

Sodium concentration was significantly more in plants of both genotypes grown either in saline or in normal soil (Table 2). Concentration of Na was higher in Auqab-

Table 1. Growth parameters of two wheat genotypes grown in saline and normal soil as affected by silicon application.

Parameters	Genotypes	Silicon Application Rate					
		0 µg Si/g		50 µg Si/g		130 µg Si/g	
		Normal	Saline	Normal	Saline	Normal	Saline
Shoot dry matter (g/plant)	Auqub-2000	3.78±2.19	1. 36±0.72	5.0±1.31	3.16±2.06	6.42±3.65	5.42±3.6
	SARC-5	3.51±2.1	1.71±0.89	4.33± 2.90	3.20± 2.0	6.35± 3.6	5.86± 2.5
Grain yield (g/plant	Auqub-2000	1.40±0.75	0.67±0.39	1.65±0.82	1.01±0.61	2.82±1.36	1.86±0.90
	SARC-5	0.67±0.39	0.61±0.3	1.60±0.79	1.12±0.67	2.57±1.2	2.17±1.01
Harvest index (%)	Auqub-2000	0.37±0.07	0.49±0.1	0.33±0.06	0.32±0.04	0.44±0.09	0.34±0.06
	SARC-5	0.19±0.01	0.36±0.03	0.37±0.07	0.35±0.05	0.40±0.08	0.37±0.06

Note: Normal soil : EC 1.18 dSm^{-1} and Saline soil EC: 10 dSm^{-1}.

Table 2. Concentration of potassium and sodium and their interaction in two wheat genotypes grown in saline and normal soil as affected by silicon application.

Parameters	Genotypes	Silicon Application Rate					
		0 µg Si/g		50 µg Si/g		130 µg Si/g	
		Normal	Saline	Normal	Saline	Normal	Saline
K concentration (mg/g)	Auqub-2000	7.00±3.71	5.0±2.20	8.60±4.01	11.7±4.85	9.20±4.42	16.6±6.6
	SARC-5	6.90±3.36	4.7±1.83	8.00±3.89	11.9±4.96	9.00±4.01	16.8±5.63
Na concentration (mg/g)	Auqub-2000	6.57±3.23	11.85±4.90	6.01±3.10	7.10±3.3	5.63±2.73	6.72±2.8
	SARC-5	5.78±2.23	9.01±4.01	5.02±1.94	6.98±3.42	4.90±1.85	5.50±2.63
K:Na ratio	Auqub-2000	1.1±0.22	0.40±0.13	1.40±0.78	1.60±0.91	1.60±0.89	2.50±1.68
	SARC-5	1.2± 0.85	0.50±0.16	1.60±0.91	1.70± 0.95	1.80± 0.97	3.0±1.23
Si concentration (mg/g)	Auqub-2000	4.99± 1.69	5.88±2.02	10.42±3.85	13.64±5.93	19.21±7.23	22.63±8.16
	SARC-5	4.60±1.23	6.18±2.19	9.63±3.12	12.12±5.22	17.01±6.95	19.73± 7.56

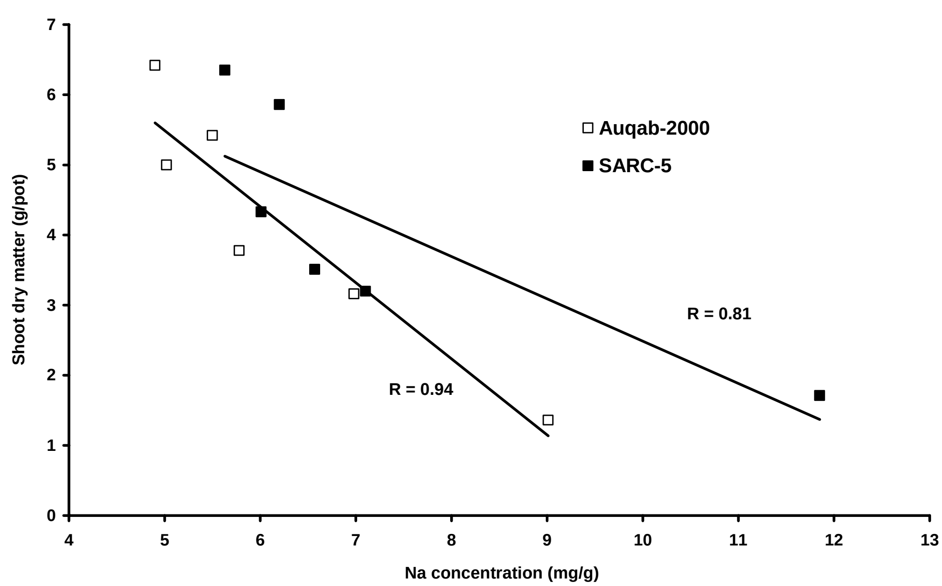

Fig. 1 Correlation between sodium concentration and biomass production of two wheat genotypes grown with different levels of Si

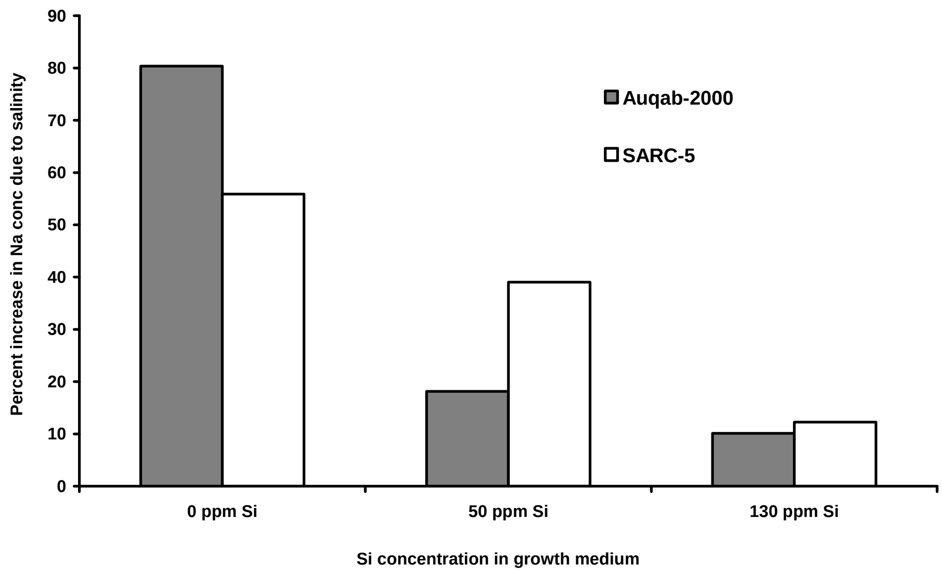

Fig 2. Percent increase in shoot Na concentration under salinity in two wheat genotypes grown at differnt levels of Si

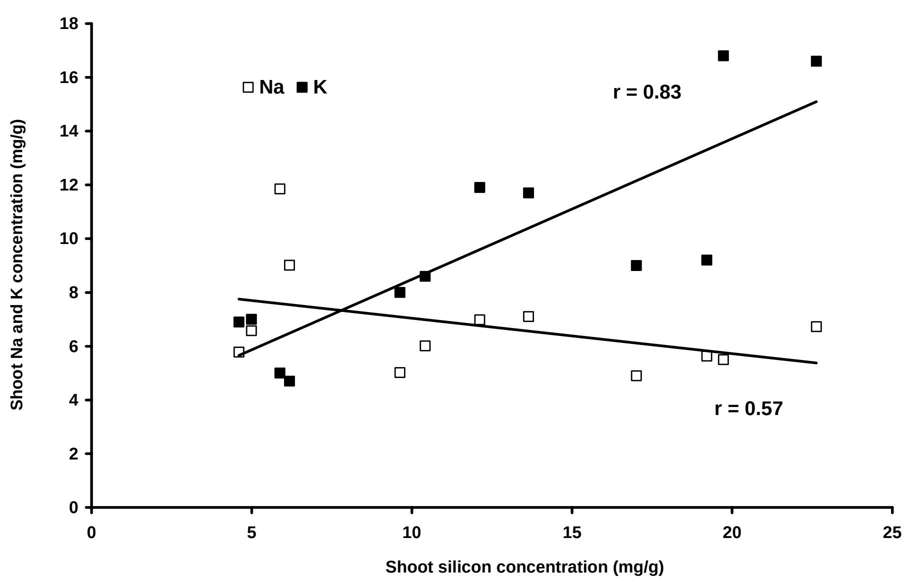

Fig. 3 Correlation between Si, Na and K concentration in wheat grown with different levels of Si

2000 than in SARC-5 at all levels of Si and salinity. Application of Si in root medium significantly decreased Na concentration in shoots of both genotypes compared to control. Maximum reduction in Na concentration due to Si application was observed when Si was added @ 130µg Si/g of soil. Cultivars differed non-significantly in K:Na ratio in all treatments except when grown with highest dose of Si. In –Si plants, salinity reduced K:Na ratio (2 folds) in both genotypes. When Si was added @ 50 µg Si/g of soil, K:Na ratio in saline and non saline plants was statistically similar in both genotypes. It increased significantly in plants receiving 130mM Si from 1.8 to 3.0 in SARC-5 and from 1.6 to 2.5 in Auqab-2000.

Discussion

Silicon is reported to enhance growth of many of higher plants particularly under biotic and abiotic stresses (Epstein, 1999). A number of possible mechanisms are proposed by which Si can increase resistance of plants against salinity stress which is a major yield limiting factor in arid and semiarid areas. The present experiment was an attempt to monitor the beneficial effects of Si application on growth and salinity tolerance of two wheat genotypes. Application of Si to growth medium significantly increased dry matter production and grain yield in both cultivars when grown under normal as well as in saline environments. Increase in dry matter was more pronounced in saline environments indicating beneficial effects of Si application in alleviating salinity stress (Al-aghabary *et al*., 2004). Bradbury & Ahmad (1990) also observed in *Prosopis Juliflora* significantly more dry matter production due to Si application in saline Si induced salinity tolerance is increased K uptake (Liang *et al*., 1999). Present results also revealed a significant increase in K uptake in both genotypes under saline conditions when Si was added (Table 2). However, salinity caused a significant decrease in K concentration when Si was not applied to root environment.

Sodium concentration in plants is also a good indicator of salinity tolerance, lower Na concentration in plants indicates lower Na uptake as in SARC-5, which is salinity tolerant genotype (Saqib *et al*., 2004). Sodium in higher amounts in plants caused a reduction in SDM which is evident from significant negative correlation between Na concentration and SDM in both wheat genotypes (Fig. 1). Silicon is known also to reduce Na uptake (Matichenkov & Kosobrukhov, 2004). Silicon when deposited in exodermis and endodermis of roots reduces Na uptake in plants (Gong *et al*., 2003). Present results also clearly exhibited reduced Na uptake by plants when grown with Si application in soil. Percent increase in Na uptake by salinity treatment was significantly reduced in plants grown with Si application (Fig. 2).

Auqab-2000 performed better for growth and grain yield under normal conditions, however, under saline conditions SARC-5 performed better for both growth and K concentration. Sodium concentration in SARC-5 was significantly lower than Auqab-2000 indicating some Na exclusion mechanism in this genotype (Saqib *et al*., 2004).

Low K uptake under saline and sodic conditions hampers crop production on these soils. Potassium has a significant role in improving plant water status and mitigating the toxic effects of Na. Silicon concentration was positively correlated with K concentration in shoots (Fig. 3) data indicating enhanced K uptake in plants by Si application. Liang *et al*., (2003) also reported a significant increase in K uptake and decrease in Na uptake under salt stress when Si was included because of increased activity of plasma membrane H-ATPase. Potassium:sodium ratio was significantly lower under salinity stress when Si was not applied. It was significantly increased when Si was applied in root environment indicating enhanced K/Na selectivity ratio in wheat genotypes thus enhancing dry matter and grain yield of both genotypes. Increased K uptake and decreased Na uptake by addition of Si in both genotypes was the major mechanisms responsible for better growth of plants under salinity. These along with other physiological mechanisms needs to be explored under control and field conditions.

Silicon application significantly increased dry matter and grain yield of both wheat genotypes under normal as well as under saline conditions indicating its importance in mineral nutrition of wheat. Major mechanism inducing tolerance against salinity in both genotypes was increased K uptake and decreased Na uptake, thus enhancing K/Na selectivity ratio in leaves. The present results warrant further studies to explore different mechanisms in plants working at cell level by which Si alleviates salinity stress.

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