Research article

The Impart and Effect of Silicon and Potassium Nitrate in Dealing with Environmental Stress on Wheat Resistance in Saline Soil

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Abstract | This study deals with the biotechnological study of the role of silicon and potassium nitrate in dealing with environmental stresses on the resistance of wheat in saline soil. In the *in vitro* condition, three varieties of wheat were grown on sterile filter paper moistened with 20, 40, 60, 80 and 100 mmol/l NaCl solution. The results showed that the wheat cultivars had significant differences in terms of growth response to different concentrations of sodium chloride, and it was the most tolerant to sodium salt stress and was used in the second part of the study. In the greenhouse experiment, it was cultivated in the hydroponic system under different levels of NaCl (20, 60 and 100 mmol/L) and silicon treatment (0, 2 and 4 mmol/L, final concentration in nutrient solution using potassium). Findings show that environmental stress significantly increased the accumulation of proline and sodium content in plant tissues and decreased the absorption and accumulation of potassium by plants. In addition, plant weight, 100 seed weight, relative water content, chlorophyll content and photosynthesis were also affected by different levels of NaCl. However, the external application of silicon and potassium nitrate decreased sodium absorption, increased potassium, and as a result improved plant weight, 100-seed weight, seed yield, cob length, and photosynthesis rate. This study showed that the use of a salt-tolerant cultivar with appropriate foliar application of potassium nitrate (2 mmol/L) and silicon (4 mmol/L) at the wheat booting stage may be a promising approach to obtain it.

Keywords: Environmental stress, Silicon, Potassium nitrate, Saline soil, Wheat.

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INTRODUCTION

Silicon is the second most common element in soil, which has beneficial effects in increasing tolerance to biotic and abiotic stresses in plants. Salinity is the major stress factor, and is one of the most serious environmental problems influencing crop growth and production. Excessive soil salinity, resulting from natural processes or from crop irrigation with saline water, occurs in many semi-arid to arid regions of the world where it affects plant growth and yield through osmotic effects, nutritional imbalances, oxidative damage, and/or specific ion toxicities to sustain food security and the well-being of humankind, a priority should be given to minimize the detrimental effects of salt stress. Attempts to improve tolerance to salinity through physiological selection criteria has increased substantially to improve the probability of success by making empirical selection more efficient. Researches have shown that physiological activities such as photosynthesis and respiration, water balance, turgor pressure, degeneration of cell membranes, efficiency of enzymes, mineral nutrients uptake, synthesis, storage of assimilates, and metabolites such as proline are directly affected by salt stress (Amirinejad, 2013).

Plants have developed complex mechanisms that contribute to acclimate to salinity induced osmotic and ionic stresses (Meloni et al., 2004). Among different techniques, proper management of mineral nutrients plays a crucial role in increasing plant tolerance to salinity. A number of studies have shown that silicon may increase salinity tolerance in wide variety of plants through different mechanisms including reduced Na+ uptake and translocation, improved plant water status, increased photosynthetic activity and ultra structure of leaf organelles, stimulation of antioxidant system (Zhu et al., 2004), and alleviation of specific ion effect by H-ATPase dependent enhancement of potassium in shoots. In addition, silicon is reported to reduce the effect of salinity on wheat and other crops. Saqib et al (2008), have reported that silicon decreased plant sodium uptake and shoot root sodium distribution of a salt-resistant as well as a salt-sensitive wheat genotype. They found that silicon increased cell-wall sodium binding, concentration of glutathione and antioxidants under saline conditions (Romero-Aranda et al., 2006).

Silicon existing in the Earth's crust is classified as the most abundant element following oxygen. It is most commonly found in soils in different forms including silicon in soil solution as silicic acid (Si (OH)), and its absorption occurs directly in this form (Chen et al., 2010). This element is also one of the most abundant mineral elements in plant tissues (Zhu et al., 2004). Although, silicon is not considered as an essential element for plant growth, it is designated as an element with a beneficial influence on plant growth and development as well as crop yield and required in large amounts for Gramineae crops, in particular. Ample evidence indicated that silicon, when readily available to plants, had positive effects on plant growth, particularly under biotin abiotic stresses. In addition, studies have shown that supplementing the soil with silicon can improve salt tolerance of barley, maize, rice and wheat. Trenholm et al. (2004) have suggested that silicate crystals deposited in epidermal cells form a barrier that reduced water loss through the cuticles (Ferrón-Carrillo & Urrestarazu, 2021). Romero-Aranda et al. (2006) have suggested that silicate crystals deposited in the epidermal cells form a barrier that reduces water loss through cuticle, which in turn, contributes to salt dilution, mitigating salt toxicity effects in tomato. More recently, Si benefits on salt tolerance of barley and cucumber have been related to antioxidant enzyme activity (Zhu et al., 2004).

Among the mineral nutrients, potassium is known to be very dynamic and a major contributor to the organic structure and metabolic functions of the plant. Potassium contents in plant tissues progressively decrease with increasing salinity. Therefore, maintenance of adequate level of K+ is essential for plant survival under salt stress. Potassium has substantial effect on enzyme activation, protein synthesis, photosynthesis, stomatal movement, and water relation in plants. Increased application of potassium has been shown to enhance photosynthetic rate, plant growth and yield in different crops under salinity water stress conditions. For example, exogenous application of potassium ameliorated adverse effects of salt stress in wheat rice, tomato, cucumber, and pepper. The aim of this study was to evaluate the effect of different concentrations of NaCl on plant growth and yield and the contribution of silicon and potassium nitrate foliar application to salt tolerance of wheat (Zare et al., 2014).

MATERIALS AND METHODS

The laboratory and greenhouse of the Agricultural and Natural Resources Research Center of Razavi Khorasan Province of Iran was used to investigate the effect of using silicon and potassium on salinity tolerance in wheat during 2024. At first, a factorial experiment based on a completely randomized design with three replications was used to investigate the tolerance to salinity of three wheat cultivars in the laboratory. The seeds of the same size from each of the cultivars were treated with hydrogen peroxide for ten minutes and They were surface sterilized with 95% ethanol for 10 seconds. Then the seeds were washed with sterile water several times in a row. 100 seeds from each of the cultivars were placed in a Petri dish for the germination of plants. Different concentrations of salt (20-40-60-80 and 100 mmol/L) were coated, placed, and allowed to grow in the dark at a temperature of 24 degrees. Seed germination was counted every day and the speed Germination was obtained at the end of a 10-day period with the following formula Germination rate Ni/Ti = where Ni is equal to the number of germinated seeds on day i and Ti is equal to the number of days after sowing. In the following, the number of healthy seeds was expressed as a percentage. In addition, the length and weight of the root and the size of the stem and their average was calculated for all the seeds. Based on the results of the laboratory (Tables 1 and 2), was chosen as the most tolerant cultivar to continue the experiment. For this purpose, a completely randomized block design was used. The selected seeds were the same as the method mentioned above. They were surface sterilized and cultivated in plastic pots (diameter = 25 cm, height = 30 cm) which were filled with perlite and vermiculite in a volume ratio of one to one. The pots were placed in a greenhouse under natural light. Every day, one liter of fresh Hoagland's solution and half strength (half concentration) was used to feed the seeds, and Hoagland's strong solution (pH=5.6) was used when the plants were in the three-leaf stage and the germination rate was reduced from 10 to 5 pots in the day had decreased. At this time, NaCl and silicon treatment was applied by adding salt and K2Sio3 to one liter of food solution. The final salt concentrations were 100-20-60 mmol/liter and the final silicon concentrations were 0-2 and 4 mmol/l. mol/liter was set. Potassium spray treatment was applied at the stage of elongation and tillering and in concentrations of 0-1.5-1 and 2 grams of potassium nitrate per liter. Potassium nitrate spray solution was diluted by diluting an appropriate amount of potassium nitrate in sterile water and adjusted pH was obtained at 5.5. One drop of Tween 20 surfactant was added to 50 ml of the spray solution and all the vegetative and reproductive parts of the plants were treated with potassium nitrate. 1 liter of the solution was sprayed on the plants at intervals of 20 minutes and continuously. For all control samples, water was used instead of potassium nitrate.

Data collecting

At seed filling stage, photosynthetic active radiation of flag leaf was recorded by a data logger. Data collecting was performed at 10 o'clock in the morning. Five plants in each plot were selected randomly, and flag leaves were removed to evaluate leaf relative water content, proline accumulation and chlorophyll concentration. Relative water content was determined for detached wheat leaves using the method cited by Omidbakhsh et al (2013). according to the formula below:

Relative water content (%) =(FW-DW)/(TW-DW) ×100

Where, FW, fresh weight; DW, dry weight (obtained after drying the samples at 80°C for at least 48 h); TW, turgor weight which was determined by subjecting leaves to rehydration for 2 h. Proline content of leaves was determined according to a modification of the method of Akram et al (2007), Samples of leaves (0.5 g) were homogenized in a mortar and pestle with 10 mL Sul Pho salicylic acid (3% w/v), and then centrifuged at 18000 ×g for 15 min. Two milliliters of the supernatant was then added to a test tube, to which 2 mL glacial acetic acid and 2 mL freshly prepared acid ninhydrin solution (1.25 g ninhydrin dissolved in 30 mL glacial acetic acid and 20 mL 6 mol L-1 orthophosphoric acid) were added. The test tubes were incubated in a water bath for 1 h at 100°C and then allowed to cool to room temperature. Four milliliters of toluene were then added to the tubes and mixed on a vortex mixer for 20 s. The test tubes were allowed to stand for at least 10 min to allow separation of the toluene and aqueous phases. The toluene phase was carefully pipetted out into a glass test tube and its absorbance was measured at 520 nm in a spectrophotometer. The content of proline was expressed as mg g-1 FW. Chlorophyll was extracted in 80% acetone from the leaf samples, according to the method of Bybordi (2012). Extracts were filtrated and then absorbance of chlorophyll a and b were determined by a spectrophotometer (UV-S, Sinco 2100) at 645 and 663 nm. The content of chlorophyll was expressed as mg g-1 FW. At the end of growing period, when wheat plants turned yellow, all plants were harvested and single plant weight, single plant yield, 100-seed weight, and ear length were determined. Moreover, sodium, potassium and silicium contents were assayed in whole part of the plants. Potassium and sodium were measured using a flame-photometer (Jen Way PFP7, Burlington, NJ, respectively). The total silicium content was measured using an atomic absorption method (Model GBC 932).

Statistical analysis

The first and second experiments were structured in a completely randomized design arranged in 3×5 factorial and randomized complete block design arranged in 4×3×3 factorial with three replications, respectively. For all variables, analysis of variance (ANOVA) was performed to test for differences between NaCl, silicon and potassium treatments and their interactions using the GLM procedure in SAS ver. 9.1. Main and interaction effects of experimental factors were determined. Where interactions between two factors were significant, we presented the results in the form of a combination of treatments and not separately or individually. The significance of differences among treatment means was compared by Duncan's multiple range teat at the 5% probability level.

RESULTS

Germination test

The results of analysis of variance on germination indexes are given in Table 1. There are significant differences between cultivars and NaCl stress levels. Comparisons of means showed that, irrespective of cultivar, increase in NaCl concentrations had deleterious effect on germination pace, germination percentage, radicle and shoot length as well as radicle and shoot weight (Table 2). Among cultivars, cultivar showed the highest germination pace and percentage at all levels of NaCl. The results also indicated that cultivar produced the highest radicle and shoot length and radicle and shoot weight. Therefore, cultivar was selected as the most salt tolerant cultivar for further studies in the second part of the experiment. Potassium nitrate, silicon and NaCl stress treatments had a significant effect on all studied traits.

Proline accumulation

Comparison of means revealed that interaction between potassium nitrate, silicon and NaCl stress was significant on proline accumulation. Experimental treatments caused a significant increase in proline accumulation and the highest proline accumulation was observed when 4 mmol L-1 silicon and 2 mmol L-1 potassium nitrate was applied under mild and severe stress conditions (Table 4). On the other hand, the lowest proline accumulation was found in plants which were not treated with silicon. Proline is an important osmolyte which synthesized in many microorganisms and plants which protect them against salinity and drought stress. Proline accumulation in plants exposed to salinity stress is due to low activity of oxidant enzymes. Increasing potassium nitrate concentration also increased proline content under NaCl stress (Table 4). Potassium nitrate induced proline accumulation under NaCl stress might due to an increase of ornithine amino transferase activity in ornithine pathway (Cao and Wei 2010).

Table 1: Analysis of variance on wheat germination indexes affected by cultivar and salinity.

Source of variation	df	Germination pace	Germination percentage	Radicle length	Shoot length	Radicle weight	Shoot weight
Cultivar	2	**	**	**	**	**	**
Salinity	4	**	**	**	**	**	**
Cultivar×Salinity	8	**	**	**	**	*	**
Error	30	2.46	0.35	8.84	10.69	0.00002	0.0009
Coefficient of variation (%)		2.97	0.87	10.44	6.86	8.20	15.57

Table 2: Interaction between salinity and cultivar on wheat germination indexes.

Cultivar	Salinity (mmol L^{-1})	Germination pace	Germination percentage (%)	Radicle length (mm)	Shoot length (mm)	Radicle weight (g)	Shoot weight (g)
Pishgam	20	90.83 a	99.16 a	84.21 a	84.93 a	0.17 a	0.92 a
	40	79.50 bc	96.50 b	30.5 d	71.16 b	0.08 c	0.12 c
	60	59.50 e	62.50 e	20.48 e	40.38 d	0.04 e	0.08 cdef
	80	41.50 g	50.50 h	14.45 fg	31.50 ef	0.02 g	0.04 efg
	100	25.16 i	39.50 k	8.33 h	53.41 c	0.01 hi	0.02 fg
Afagh	20	81.83 b	98.83 a	78.16 b	80.50 a	0.16 b	0.70 b
	40	71.50 d	95.50 c	29.21 d	38.16 d	0.07 d	0.10 cd
	60	49.50 f	61.50 f	18.58 ef	30.50 f	0.03 ef	0.08 cdef
	80	39.50 g	49.50 i	12.50 gh	52.50 c	0.02 g	0.03 fg
	100	23.50 i	37.50 l	7.28 h	36.45 de	0.006 i	0.02 g
Alvand	20	78.16 c	98.16 a	68.98 c	54.60 c	0.16	0.67 b
	40	59.50 e	93.50 d	20.65 e	26.16 f	0.06 d	0.09 cde
	60	39.50 g	59.50 g	14.51 fg	51.48 c	0.03 f	0.06 defg
	80	30.50 h	47.50 j	11.41 gh	37.50 d	0.01 gh	0.02 g
	100	20.16 j	22.50 m	7.50 h	25.68 f	0.01 hi	0.006 g

Table 3: Analysis of variance on some traits of salt tolerant wheat cultivar affected by salinity, silicon and potassium nitrate.

Sources of variation[1)]	df	Plant weight	Proline	Sodium	Potassium	Silicium	100-seed weight	Seed yield	Ear length	Relative water content	Chlorophyll	Photosynthesis
B	2	**	*	**	**	**	**	**	**	**	**	**
K	3	**	**	**	**	**	**	*	**	**	**	**
S	2	**	**	**	**	**	**	**	**	**	**	**
N	2	**	**	**	**	**	**	**	**	**	**	**
K×S	6	ns	*	**	**	**	*	**	ns	**	**	ns
K×N	6	ns	**	**	**	**	ns	*	ns	**	**	ns
S×N	4	ns	**	**	**	**	*	**	**	**	**	ns
K×S×N	12	*	**	**	**	**	ns	**	ns	**	**	ns
Error	70	0.39	4.95	0.76	0.45	0.0005	1.07	0.05	0.16	3.79	0.40	5.27
Coefficient of variation (%)		5.14	7.47	2.28	4.66	4.22	3.31	6.16	6.72	3.90	1.50	13.28

Table 4: Interaction between potassium nitrate, silicon and salinity on some traits of salt tolerant wheat cultivars.

Potassium (mmol L^{-1})	Silicon (mmol L^{-1})	Salinity (mmol L^{-1})	Proline (mg g^{-1} FW)	Sodium (mmol g^{-1} DW)	Potassium (mmol g^{-1} DW)	Silicium (mmol g^{-1} DW)	Plant weight per plant (g)	100-seed weight (g)	Relative water content (%)	Chlorophyll (mg g^{-1} FW)
0	0	20	8.20 q	0.24 k	0.30 lm	0.04 k	0.83 ef	4.20 efg	65.15 h	47.48 ij
		60	8.94 pq	0.45 f	0.26 n	0.06 j	0.55 lm	3.6 hijkl	35.14 op	37.51 o
		100	9.91 mnop	0.73 a	0.24 o	0.05 j	0.34 stu	2.89 op	20.18 v	17.85 v
	2	20	9.91 mnop	0.14 no	0.31 l	0.15 i	0.93 ab	4.60 bcde	75.1 1ef	55.48 ef
		60	10.51 lmn	0.29 j	0.28 mn	0.16 hi	0.64 j	3.83 ghij	44.1 1kl	44.51 l
		100	11.91 ijk	0.59 d	0.24 o	0.17 fgh	0.45 pq	3.29 lmno	25.18 st	24.33 t
	4	20	11.85 ijk	0.08 qrs	0.32 k	0.17 defg	0.74 h	4.80 bc	82.15 abc	57.51 cd
		60	13.21 fg	0.19 lm	0.20 p	0.18 bcdef	0.47 op	3.84 ghij	51.03 i	47.48 ij
		100	16.17 ab	0.39 gh	0.16 q	0.17 defg	0.26 wx	3.59 hijklm	3.11 w	27.51 r
0.5	0	20	9.14 opq	0.21 klm	0.38 hi	0.06 j	0.86 de	4.30 def	70.37 g	49.44 h
		60	9.21 opq	0.40 g	0.29 mn	0.06 j	0.56 lm	3.79 ghijk	38.11 no	39.48 n
		100	11.27 jkl	0.69 b	0.34 k	0.07 j	0.35 st	2.99 nop	21.11 uv	22.46 u
	2	20	11.27 jkl	0.11 opqr	0.54 c	0.16 hi	0.96 a	4.70 bcd	77.25 de	56.48 de
		60	12.01 hijk	0.241 k	0.39 gh	0.17 defgh	0.46 op	3.99 fgh	47.18 jk	45.48 kl
		100	13.11 fgh	0.53 e	0.37 ij	0.18 cdefg	0.68 i	3.39 jklmn	27.51 rs	25.51 s
	4	20	13.22 fg	0.07 rst	0.54 c	0.18 cdefg	0.76 gh	5.54 a	84.11 ab	58.48 bc
		60	13.52 ef	0.13 op	0.36 j	0.19 bcd	0.47 op	3.77 ghijk	52.14 i	48.48 hi
		100	16.48 ab	0.33 i	0.24 o	0.19 bc	0.29 vw	3.56 hijklm	34.14 p	28.41 r
1	0	20	9.01 pq	0.19 lm	0.49 d	0.06 j	0.88 cd	4.46 cde	72.14 fg	52.44 g
		60	10.23 lmno	0.36 hi	0.34 k	0.06 j	0.58 kl	3.77 ghijk	40.46 mn	42.53 m
		100	11.72 ijk	0.63 c	0.44 f	0.06 j	0.38 rs	3.30 lmno	22.13 tuv	24.50 st
	2	20	12.20 ghij	0.09 pqrs	0.53 c	0.17 gh	0.69 i	4.67 bcd	79.16 cd	57.50 cd
		60	12.20 ghij	0.22 kl	0.40 g	0.18 cdefg	0.42 qr	3.89 fghi	49.22 ij	46.51 jk
		100	13.50 ef	0.52 e	0.37 ij	0.18 cdefg	0.21 y	3.38 jklmn	30.11 qr	25.16 st
	4	20	13.64 def	0.05 st	0.66 b	0.18 cdefg	0.79 fg	4.98 b	85.18 a	59.44 b
		60	14.67 cd	0.12 opq	0.39 gh	0.18 bcde	0.50 no	3.98 fgh	52.14 i	49.16 h
		100	15.54 bc	0.21 klm	0.29 mn	0.19 b	0.31 uv	2.08 q	34.18 p	30.46 q
2	0	20	9.60 nop	0.17 mn	0.54 c	0.06 j	0.91 bc	4.48 cde	73.16 fg	54.46 f
		60	10.86 klm	0.36 hi	0.36 j	0.06 j	0.61 jk	3.98 fgh	42.14 lm	44.51 l
		100	12.27 ghij	0.68 b	0.46 e	0.06 j	0.41 qr	3.18 mno	24.14 tu	25.50 s
	2	20	11.40 jkl	0.09 pqrs	0.65 b	0.17 efgh	0.70 i	4.78 bc	81.11 bc	58.48 bc
		60	12.88 fghi	0.21 klm	0.47 e	0.18 cdefg	0.46 op	3.84 ghij	51.66 i	47.25 j
		100	14.81 c	0.50 e	0.30 lm	0.18 bcdef	0.24 xy	3.49 ijklm	37.81 no	24.51 st
	4	20	14.56 cde	0.03 t	0.70 a	0.18 bcdef	0.81 f	4.88 bc	83.11 ab	62.44 a
		60	16.05 ab	0.011 opqr	0.34 k	0.19 b	0.53 mn	3.35 klmn	51.14 i	51.50 g
		100	16.81 a	0.191 m	0.20 p	0.26 a	0.32 uv	2.58 p	33.11 pq	32.10 p

SODIUM, POTASSIUM AND SILICIUM CONTENTS

Sodium, potassium and silicium contents were affected by all experimental treatments. The highest sodium cone- tent was observed when severe NaCl stress was applied without any potassium or silicon treatment (Table 4). Silicon application especially at 4 mmol L-1 Concentra- Tion significantly decreased sodium content in the plants. The effect of potassium nitrate varied from treatment to treatment. Regarding potassium content, the highest potassium content was observed in non-stressed plants, receiving 2 mmol L-1 potassium nitrate and 4 mmol L-1 silicon (Table 4). Silicium content increased due to high level of silicon and potassium nitrate application (Table 4). The lowest silicium content was obtained under weak stress conditions without using silicon or potassium nitrate (Table 4). In an experiment with wheat, the addition of silicon to the solution cultures decreased the sodium content. In this study, added silicon was also found to significantly decreased sodium content under salt stress (Table 4). However, the mechanism by which silicon stimulated potassium uptake but inhibited sodium uptake remains poorly understood. As has been known, sodium is passively taken up by the plants and the uptake process is affected mainly by the transpiration rate. The reduced uptake of sodium by plants in this study can be explained at least partly by the inhibitory effect of silicon on the transpiration rate. While, potassium uptake and transport are an active process associated with ATP-driven hydrogen pump in the plasma membranes. One possible mechanism for stimulating effect of silicon on potassium uptake by plants under salt stress is the activation of HC-ATPase in the membranes (Gong et al. 2005).

PLANT WEIGHT

The highest plant weight was obtained when 2 mmol L-1 silicon and 0.5 mmol L-1 potassium nitrate were applied on plants subjected to weak NaCl stress (Table 4). While, the lowest plant weight values were observed under severe NaCl stress along with 4 mmol L-1 silicon and 0 or 0.5 mmol L-1 potassium nitrate and also 2 mmol L-1 silicon and 1 or 2 mmol L-1 potassium nitrate (Table 4). The oxidative stress caused by salt stress can lead to a decrease in dry weight of plant. It has been reported that wheat dry matter weight was significantly increased by the addition of a small amount of soluble silicon. Silicon supplementation resulted in improved plant growth and yield due to significant reduction in sodium content in the rice and barley shoots. Kaya et al. (2006) showed that application of silicon increased corn fresh and dry weight and improved grain yield. Potassium nitrate at 0.5 mmol L-1 increased plant weight; increasing potassium nitrate concentration in nutrient solution with NaCl has improved the possibility of potassium absorbance, and therefore relieves the adverse saline effects.

SEED YIELD

Interaction between potassium nitrate and silicon application as to seed yield is given in Fig. 1. A glance sat this Fig. reflects this fact that increase in silicon concentration increases seed yield. Moreover, potassium nitrate has significant effect on seed yield improvement so that the highest seed yield was obtained when 4 mmol L-1 silicon and 2 mmol L-1 potassium nitrate were applied. Interaction between salt stress and silicon application is shown in Fig. 2. Although, salt stress decreased seed yield, silicon application improved seed production at each level of NaCl.

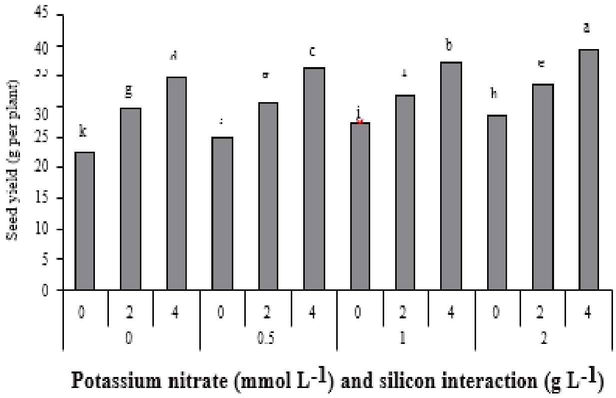

Figure 1: Interaction between potassium nitrate and silicon on seed yield. Values within each column and followed by the same letters are not different at $P<0.05$ by an ANOVA protected Duncan's multiple range test. The same as below.

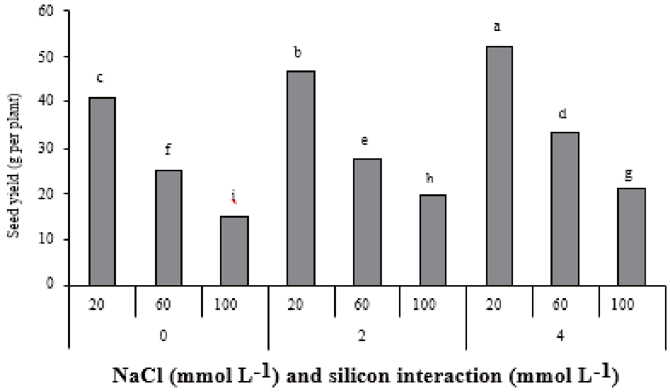

Figure 2: Interaction between salinity and silicon on seed yield.

SEED WEIGHT

Application of 4 mmol L-1 silicon and 0.5 mmol L-1 potassium nitrate significantly increased 100-seed weight. On the other side, the lowest seed weight was obtained when 4 mmol L-1 silicon and 1 mmol L-1 potassium nitrate were applied under severe NaCl stress conditions (Table 4). Kamkar et al. (2004) reported that salinity reduced the yield primarily by a sever reduction in grain number and weight Sharifnabi and Nili (2011), reported that increasing potassium application could be useful to overcome the adverse effect of salinity on the growth of wheat plant. It can be stated that the ability of plants to retain potassium at high sodium concentration, of the external solution, may be involved in reducing the damage associated with excessive sodium concentration in plant tissue. The results of

Table 5: Correlation coefficient between different traits of wheat affected by salinity, silicon and potassium nitrate.

Proline	1										
Sodium	-0.15 ns	1									
Potassium	-0.08 ns	-0.43^{**}	1								
Silicium	0.76^{**}	-0.43^{**}	0.01 ns	1							
Plant weight	-0.50^{**}	-0.53^{**}	0.53^{**}	-0.19^{*}	1						
Seed yield	0.004 ns	-0.83^{**}	0.65^{**}	0.26^{**}	0.74^{**}	1					
100-seed weight	-0.17 ns	-0.43^{**}	0.47^{**}	0.07 ns	0.70^{**}	0.68^{**}	1				
Ear length	-0.18 ns	-0.75^{**}	0.66^{**}	0.10 ns	0.83^{**}	0.96^{**}	0.77^{**}	1			
Relative water content	-0.19^{*}	-0.79^{**}	0.68^{**}	0.12 ns	0.79^{**}	0.94^{**}	0.66^{**}	0.93^{**}	1		
Chlorophyll	-0.14 ns	-0.86^{**}	0.60^{**}	0.15 ns	0.76^{**}	0.91^{**}	0.70^{**}	0.90^{**}	0.92^{**}	1	
Photosynthesis	0.01 ns	-0.82^{**}	0.62^{**}	0.21^{*}	0.60^{**}	0.86^{**}	0.46^{**}	0.81^{**}	0.85^{**}	0.82^{**}	1

researchers have shown that the silicon causes increase of seed weight in crops. In addition, Liang et al. (2003), found that increasing of yield by the use of silicon in plants is due to increased grain weight.

EAR LENGTH

Main effect of NaCl, silicon and potassium nitrate application were significant on ear length (Table 3). As can be seen from Fig. 3, potassium application increased ear length so that increase in potassium concentration was severe NaCl stress and minimum use of silicon (Table 4). Decrease in relative water content due to NaCl stress has been reported previously in lentil and corn. parallel with increase in ear length (Liang et al., 2005).

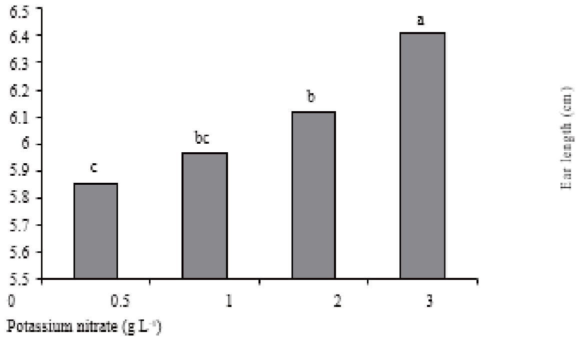

Figure 3: Main effect of potassium nitrate foliar application on ear length.

Increased leaf way interaction between NaCl and silicon on ear length: The highest ear length was related to 4 mmol L-1 silicon and 20 mmol L-1 NaCl. It is clear from the data that increase in silicon concatenation in increases ear length linearly while increase in NaCl decreases this parameter.

Leaf relative water content: Leaf relative water content significantly increased due to application of 4 mmol L-1 silicon and 1 or 2 mmol L-1 potassium nitrate in plants subjected to weak salt stress. The lowest relative water content was observed under relative water content by 26.5% in corn. Furthermore, according to Gunes et al. (2008), silicon applied to the soil increased sunflower leaf relative water content. Li (2006) revealed that potassium application increased relative water content from 92 to 94% in tobacco leaf. Such increase with potassium application may be ascribed to improve cell turgor through osmotic adjustment.

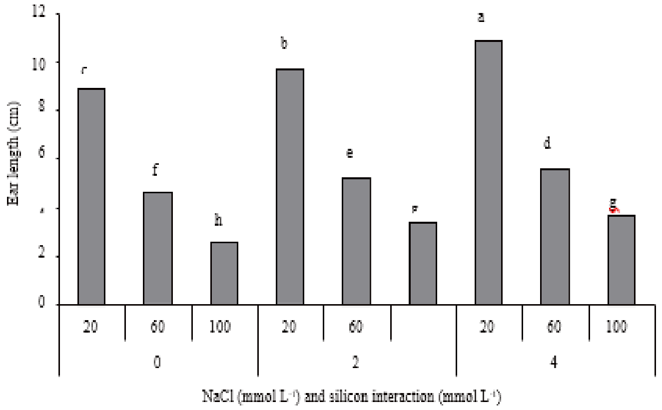

Figure 4: Interaction between salinity and silicon on ear length.

CHLOROPHYLL CONTENT

The highest chlorophyll content was observed when 4 mmol L-1 silicon and 2 mmol L-1 potassium nitrate were applied on wheat plants grown under weak salt stress conditions. On the other hand, severe salt stress and no application of silicon along with 0 or 0.5 mmol L^{-1} potassium nitrate showed the minimum amount of chlorophyll in the plants (Table 4). There have been reports of a significant decrease in the total chlorophyll content of corn grown under salt stress (Celik et al., 2010). The results of the current study were in agreement with the findings of the studies that reported an increase in the total chlorophyll content after treating rice and barley (Liang et al., 2003), with silicon following salt stress treatment. Potassium is reported to improve water relations as well as productivity of different crops under environmental stresses (Islam et al., 2004).

Photosynthesis rate

Photosynthesis rate improved on account of potassium application. Similarly, silicon application led to increase in photosynthesis rate in wheat plants so that the highest concentration of silicon showed the highest photosynthesis rate. The authors have reported that added silicon increased the leaf net photosynthetic activity and depressed the uptake of sodium but stimulated the uptake of potassium by barley grown hydroponically, thereby enhancing the selectivity ratio. That silicon increases the two synthesis of wheat plants might be associated with the increases in activities of photosynthetic enzymes, chlorophyll content and anthocyanin content. Mohsen et al. (2013), reported that the addition of silicon could increase the chlorophyll content and ribulose is phosphate carboxylase activity in cucumber plants grown in recirculating nutrient solution. According to Levent Tuna et al. (2008), an accumulation of silicon in the leaves of plants in Poaceous family causes the leaves to erect, which facilitates light penetration, and promotes photosynthesis by significantly lowering the production of ethylene, which destroys chlorophyll. On the contra wry, NaCl stress decreased photosynthesis dramatically. Significant and positive correlation coefficient was found between proline and silicium, while significant and negative correlation was observed between proline and plant weight and proline and relative water content (Table 5). Sodium accumulation in wheat plants had significant and negative correlation with all studied traits. Conversely, potassium content showed the positive correlations. Silicium and plant weight correlate to each other negatively, while this correlation is positive with seed yield and photopsinthesis. Plant weight indicates a significant and positive correlation with all studied traits. Similar results were obtained regarding seed yield, seed weight, ear length, relative water content, chlorophyll, and photosynthesis rate.

CONCLUSION

In general, our results indicated that silicon may act to wheat cultivars, were surface sterilized with hydrogen peroxide for 10 min and 95% ethanol for 10 s. After that, seeds were rinsed thoroughly with sterile water for several times. 100-seed of each cultivar were placed on sterile deep dish plant germination Petri plates containing two sheets of sterile filter paper moistened with five different concentrations of sodium chloride solution (20, 40, 60, 80, and 100 mmol L-1) and allowed to germinate in the dark at 24°C. The germinated seeds were counted every day to calculate germination pace at the end of the 10-d period could alleviate symptoms of the individual salt stress by improving water relations, nutrient uptake, chlorophyll content and photosynthesis.

radicle length and weight as well as shoot length and weight were also measured and average for all seeds was calculated. Based on the results of laboratory experiment (Tables 1 and 2), the most salt-tolerant cultivar, was chosen for investigating the interactive effects of silicon and potassium nitrate in salt tolerance of wheat. For this purpose, a randomized complete block design with three replicates was used. Candidate wheat seeds were surface sterilized as mentioned above and sown in plastic pots (25 cm in diameter and 30 cm in height) filled with perlite and vermiculite (1:1; v: v). The pots were placed in greenhouse subjected to natural light. 1 L of fresh half strength Hoagland nutrient solution (pH 5.6) was used every day and full-strength Hoagland nutrient solution was introduced at three-foliate stage when seedlings were reduced from ten to five plants per pot. At this time, NaCl and silicon treatments were started by adding sodium chloride (NaCl) and K2SiO3 to 1 L of nutrient solution. Final concentrations of sodium chloride were 20, 60 and 100 mmol L-1 while silicon 0, 2 and 4 mmol L-1 in nutrient solution. Potassium nitrate foliar treatments were applied at stem elongation and booting stage at 0, 0.5, 1, and 2 g potassium nitrate L-1. The potassium sprays were prepared by diluting the appropriate amount of potassium nitrate in distilled water and adjusting to pH 5.5. One drop of Tween 20 surfactant was added to 500 mL of spray solutions. All vegetative and generative parts of the plants were subjected to different treatments of potassium nitrate. 1 L of solution was sprayed onto the plants two times successively at 20 min intervals. For all control treatments water, instead of the K solution was sprayed.

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CONFLICT OF INTEREST

The author has declared no conflict of interest.

NOVELTY STATEMENT

This is a biotechnological study of the role of silicon and potassium nitrate in dealing with environmental stresses on the resistance of wheat in saline soil. It shows that the use of a salt-tolerant cultivar with foliar application of potassium nitrate and silicon at the wheat booting stage may be a promising approach to obtain it.

REFERENCES

Akram MS, Athar HR, Ashraf M (2007). Improving growth and yield of sunflower (*Helianthus annuus* L.) by foliar application of potassium hydroxide (KOH) under salt stress. Pak. J. Bot, 39(3): 769-776.

Amirinejad A (2013). the effect of silicon on the yield and production of wheat under low irrigation conditions, National Conference on Soil, Sustainable Agriculture, Melayere. https://civilica.com/doc/231122

Bybordi A (2012). Effect of ascorbic acid and silicium on photosynthesis, antioxidant enzyme activity, and fatty acid contents in canola exposure to salt stress. J. Integrat. Agricult. 11(10): 1610-1620 https://doi.org/10.1016/S2095-3119(12)60164-6.

Cao F, Wei Y (2010). Effect of potassium nitrate on proline metabolism in tobacco (Nicotiana tabacum l.) under osmotic stress. Acta Agricult. Boreali-occidentalis Sin., 9: 144-148.

Celik H., Asik BB, Gürel S., Katkat AV (2010). Potassium as an intensifying factor for iron chlorosis. Int. J. Agricult. Biol., 12(3): 359-364.

Chen W, Yao X, Cai K, Chen J (2011). Silicon alleviates drought stress of rice plants by improving plant water status, photosynthesis and mineral nutrient absorption. Biolog. Trace Element Res., 142: 67-76. https://doi.org/10.1007/s12011-010-8742-x

Gong H, Zhu X, Chen K, Wang S, Zhang C (2005). Silicon alleviates oxidative damage of wheat plants in pots under drought. Plant Sci., 169(2): 313-321 https://doi.org/10.1016/j.plantsci.2005.02.023.

Gunes A, Pilbeam DJ, Inal A, Coban S (2008). Influence of silicon on sunflower cultivars under drought stress, I: growth, antioxidant mechanisms, and lipid peroxidation. Commun. Soil Sci. Plant Analys., 39: 1885-1903. https://doi.org/10.1080/00103620802134651

Islam MS, Haque MM, Khan MM, Hidaka T, Karim M (2004). Effect of fertilizer potassium on growth, yield, water relations of bushbean (*Phaseolus vulgaris* L.) under water stress conditions. Japanese J. Trop. Agricult., 48: 1-9.

Jamil M, Rehman SU, Lee KJ, Kim JM, Rha HK (2007). Salinity induced growth PS2 photochemistry and chlorophyll content in radish. Scient. Agricola, 64: 570- 573. https://doi.org/10.1590/S0103-90162007000200002

Kamkar B, Kafi N, Mahallati MA (2004). Determination of the most sensitive developmental period of wheat (Triticum aestivum) to salt stress to optimize saline water utilization. In: Proceedings of the 4th International Crop Science Congress, Iran.

Kaya C, Tuna L, Higgs D (2006). Effect of silicon on plant growth and mineral nutrition of maize grown.under water-stress condition. J. Plant Nutrit., 29: 1469-1480. https://doi.org/10.1080/01904160600837238

Ferrón-Carrillo F., Urrestarazu M (2021). Effects of Si in nutrient solution on leaf cuticles. Scien. Horticult., 278: 109863. https://doi.org/10.1016/j.scienta.2020.109863

Levent Tuna A, Kaya C, Dikilitas M, Higgs D (2008). The combined effects of gibberellic acid and salinity on some antioxidant enzyme activities, plant growth parameters and nutritional status in maize plants. Environ. Exper. Botan, 62: 1-9 https://doi.org/10.1016/j.envexpbot.2007.06.007.

Li FS (2006). Potassium and water interaction. In: International Workshop on Soil Potassium and K Fertilizer Management. Agricultural College, Guangxi University. China. pp. 1-32. (in Chinese)

Liang YC, Chen Q, Zhang WH, Ding RX. (2003). Exogenous silicon (Si) increases antioxidant enzyme activity and reduces lipid peroxidation in roots of salt-stressed barley https://doi.org/10.1078/0176-1617-01065 (Hordeum vulgare L.). J. Plant Physiol., 160: 1157-1164.

Liang Y C, Zhang W H, Chen Q, Ding RX. (2005). Effect of silicon on H+-ATPase and H+-PPase activity, fatty acid composition and fluidity of tonoplast vesicles from roots of salt-stressed barley (Hordeum vulgare L.). J. Environ. Exper. Botan., 53: 29-37 https://doi.org/10.1016/j.envexpbot.2004.02.010.

Ma JF (2004). Role of silicon in enhancing the resistance of plants to biotic and abiotic stresses. Soil Sci. Plant Nutrit., 50: 11-18 https://doi.org/10.1080/00380768.2004.10408447.

Meloni D, Gulotta M, Martinez C, Oliva M. (2004). The effects of salt stress on growth, nitrate reduction and proline and glycinebetaine accumulation in Prosopis alba. Brazilian J. Plant Physiol., 16: 39-46 https://doi.org/10.1590/S1677-04202004000100006.

Mohsen AA, Ebrahim MKH, Ghoraba WFS (2013). Effect of salinity stress on Vicia faba productivity with respect to ascorbic acid treatment. Iranian J. Plant Physiol., 3: 725-736.

Omidbakhsh A, Abdulzadeh A, Bagherieh Najjar M (2013). The role of silicon in the absorption of potassium and calcium elements in wheat plants, the first national conference on sustainable agricultural development using cropping patterns, Hamedan, available on: https://civilica.com/ doc/278249

Romero-Arnada MR, Jourado O, Cuartero J (2006). Silicon alleviates the deleterious salt effects on tomato plant growth by improving plant water status. J. Plant Physiol., 163: 847-855 https://doi.org/10.1016/j.jplph.2005.05.010.

Sharifnabi B, Nili N (2011). Effect of silicon nutrition on oxidative stress induced by Phytophthora melonis infection in cucumber. American Phytopathol. Societ., 95: 455-460 https://doi.org/10.1094/PDIS-05-10-0379.

Saqib M, Zörb C, Schubert S (2008). Silicon-mediated improvement in salt resistance of wheat (*Triticum aestivum* L.) comes from increased sodium exclusion and cell wall sodium binding, and resistanceto oxidative stress. Function. Plant Biol., 35: 633-639 https://doi.org/10.1071/FP08100.

Trenholm LE, Datnoff LE, Nagara RT (2004). Influence of silicon on drougth and shade tolerance of St. Augustinegrass. HortTechnology, 14: 487-490 https://doi.org/10.21273/HORTTECH.14.4.0487.

Zhu Z G, Wei G Q, Li J, Qian Q Q, Yu J Q. (2004). Silicon alleviates salt stress and increases antioxidant enzymes activity in leaves of salt-stressed cucumber (*Cucumis sativus* L.). Plant Sci., 167: 527-533 https://doi.org/10.1016/j.plantsci.2004.04.020.

Zare HR, Ghanbarzadeh Z, Behdad A, Mohsenzadeh S (2015). Effect of silicon and nanosilicon on reduction of damage caused by salt stress in maize (Zea mays) seedlings. Iranian J. Plant Biol., 7(26): 59-74.