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SILICON ENHANCES THE SALT TOLERANCE OF TWO WHEAT CULTIVARS THROUGH DECREASING OXIDATIVE DAMAGE

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Abstract: *Using two wheat (Triticum durum) cultivars (cvs. Vitron and Simeto) hydroponic solution experiments were conducted in order to study the genotypic variation in tolerance to NaCl toxicity and to investigate effect of silicon supplied to the nutrient solution on wheat plants grown at salt stress. The experiment was a 2×2 factorial arrangement with two levels of NaCl in nutrient solution, 0 and 100 mM, and two levels of silicon (Si) in nutrient solution, 1 and 2 mM, as $Na_2SiO_3.9H_2O$. Silicon supplementation has an important role in alleviating salinity injury, however, the definite mechanisms stay scantily understood, and must be examined. The role of silicon application in improving growth, maintaining water status and alleviating oxidative injury of salt affected wheat plants were studied. Indeed, our results indicate salinity induced in wheat plants a notable increase in oxidative biomarkers, reduced plant growth and produced less dry matter content than those without NaCl. However, the reductions of seedling height, dry biomass, and soluble content were greatly alleviated due to Si addition to the culture solution. Thus, the beneficial effects of Si on oxidative biomarkers contents under NaCl stress were genotype-dependent. The beneficial effect of Si on alleviating oxidative stress was much more pronounced in Vitron (salt tolerant cultivar) than in Simeto (salt sensitive cultivar).*

Keywords: *alleviation, silicon, salinity, wheat cultivars, membrane permeability, tolerance, oxidative stress.*

1. Introduction

In arid and semi-arid ecosystems, marked by severe and frequent droughts, soil salinization is one of the main factors limiting plant development. Salinity is a major abiotic stress reducing the yield of a wide variety of crops all over the world [1]. Projections for 2050 show a further increase in the scale and impact of this environmental threat [2-3]. The drastic impacts of salinity stress on plant development are attributable to a hyperosmotic and ionic imbalance with excessive-production of reactive oxygen species (ROS) that severely hamper several physiological and biochemical pathways and molecular changes including chlorophyll depletion, lipid peroxidation, nucleic acid mutilation, and reduction in cell membrane fluidity and selectivity [4-6].

Salinity can be minimized through methods cultivating saline soils is selecting salt-tolerant species; however, profit to costs of cultures has been extremely restricted, since salt-tolerant genes are governed by several features, and their

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simultaneous selection is not a simple task [7]. Additionally, enhancing stress tolerance through substances application such as silicon may prove a promising approach for sustainable farming in an area under salinity stress conditions [8-9]. Silicon has been appraised for its beneficial properties in alleviating abiotic stresses such as drought and salinity [10], and it increases the yields of a diverse range of crops under stress conditions, including: rice, wheat, sugarcane, soybean, apples [11-19]. Silicon considerably functions in improving photosynthesis and ion homeostasis, activation of antioxidant capacity, regulation of genes required in diverse physiological processes, production of secondary metabolites, and the outcomes of Si foliar spraying, such as enhanced plant development, and biomass production have been previously reported [18-19]. Improving plant stress tolerance through Si supplementation is associated with enhanced antioxidant capacity [17, 19, 9]. Additionally, Si application can attenuate salt injury by decreasing sodium uptake via the formation of Na–Si complexes in roots or by partially blocking the transpiration bypass flow, thereby increasing the potassium/sodium ratio [20, 18, 9].

A short-term experiment with two wheat cultivars (Vitron and Simeto) was conducted to study the effectiveness of silicon in mitigating the adverse effects of salinity and to investigate possible mechanisms of silicon enhancement of salt tolerance in wheat. One of these cultivars (Vitron) was chosen because it is considered to be relatively salt tolerant, the other on account of its sensitivity to salinity.

2. Matherials and methods

Plant growth conditions and treatments

Seeds of two wheat (*Triticum durum* Desf.) cultivars, Vitron (salt-tolerant) and Simeto (salt-sensitive), were surface sterilized with $HgCl_2$ (1.0 g/L) for 5 min, rinsed thoroughly with distilled water. The seeds were submerged indeionized water in the dark overnight and germinated in sterilized moist quartz sand in a controlled chamber at 22°C/18°C (light/dark temperatures) respectively, with photoperiod of 16h light/8h dark and light. Twelve-day-old uniform seedlings (second leaf stage) were transplanted on to 3L pots. The pots were covered with polystyrol-plate with seven evenly spaced holes and placed in a greenhouse, in each hole two seedlings were located. The composition of the basic nutrient solution was (mg L^{-1}): $(NH_4)_2SO_4$ 48.2, $MgSO_4$ 65.9, K_2SO_4 15.9, KNO_3 18.5, Ca $(NO_3)_2$ 59.9, KH_2PO_4 24.8, Fe citrate 6.8, $MnCl_2.4H_2O$ 0.9, $ZnSO_4.7H_2O$ 0.11, $CuSO_4.5H_2O$ 0.04, H_3BO_3 2.9, H_2MoO_4 0.01. The solution was continuously aerated with air pumps and renewed every four days. Half strength nutrient solution was applied for the first four days and then changed to complete nutrient solution for two weeks. Thereafter, sodium chloride (NaCl) and silicon (as $Na_2SiO_3.9H_2O$) were added to the nutrient solutions to form six treatments with six replications for each treatment as following: (1) control (Basal nutrient), (2) 1 mM Si (Basal nutrient+ 1 mM Si), (3) 2 mM Si (Basal nutrient + 2 mM Si), (4) NaCl (100 mM), (5) NaCl + 1 mM Si (100 mM NaCl +1mM Si) and (6) NaCl + 2 mM Si (100 mM NaCl +2 mM Si). The pH of culture solution in each pot was adjusted to 5.7 every other day with 1M HCl or NaOH as required.

Determination of plant growth

Growth traits were measured in terms of plant height, shoot and root dry weight after 30 days of treatment. Ten plants from each replication of all treatments were sampled and measured by a centimeter scale, and then the plants were separated into shoots and roots, before fresh weights were recorded.

Relative water content (RWC)

Between four to six samples (replications) are taken from a single treatment. Each sample is placed in a pre-weighed airtight vial. In the laboratory vials were weighed to obtain fresh leaf sample weight (FW), after which the sample was immediately hydrated to full turgidity for 4 h under normal room light and temperature. Samples were rehydrated by floating on deionized water in a closed petri dish. After 4 h the samples were taken out of water and were well dried of any surface moisture quickly and lightly with filter paper and immediately weighed to obtain fully turgid weight (TW). Samples were then oven dried at 80°C for 24 h and weighed to determine dry weight (DW). All weighing were done to the nearest mg. [21].

Calculation: $RWC\ (\%) = \frac{FW-DW}{TW-DW}\ x100$

Membrane permeability, lipid peroxidation and hydrogen peroxide determinations

Electrolyte leakage was used to assess membrane permeability. This procedure was based on Lutts *et al.* 1996 [22]. Electrolyte leakage was measured using an electrical conductivity meter. Leaf samples of one randomly chosen plant per replicate were taken from the youngest fully expanded leaf and cut into 1 cm segments. Leaf samples were then placed in individual stoppered vials containing 10mL of distilled water after three washes with distilled water to remove surface contamination. These samples were incubated at room temperature (ca. 25 °C) on a shaker (100 rpm) for 24 h. Electrical conductivity (EC) of bathing solution (EC1) was read after incubation. The same samples were then placed in an autoclave at 120 °C for 20 min and the second reading (EC2) was determined after cooling solution to room temperature. The electrolyte leakage was calculated as EC1/EC2 and expressed as percent.

Lipid peroxidation and hydrogen peroxide determinations: The level of lipid peroxidation in plant tissues was expressed as 2-Thiobarbituric Acid (TBA) reactive metabolites, mainly Malondialdehyde (MDA) and was determined according to Hodges et al. (1999) [23]. Fresh samples (leaves) of around 0.5 g were homogenized in 4.0 mL of 1% Trichloroacetic Acid (TCA) solution and centrifuged at 10,000×g for 10 min. The supernatant was added to 1 mL 0.5% (w/v) TBA made in 20% TCA. The mixture was heated in boiling water for 30 min and the reaction was stopped by placing the tubes in an ice bath. The samples were centrifuged at 10,000×g for 10 min and the absorbance of the supernatant was recorded at 532 nm. Correction of non-specific turbidity was made by subtracting the absorbance value read at 600 nm. The level of lipid peroxidation was expressed as nmol/g fresh weight, with a molar extinction coefficient of 0.155/mM/cm.

The Hydrogen peroxide (H_2O_2) contents in the leaves were assayed according to the method of Velikova et al. (2000) [24]. Leaves were homogenized in ice bath with 0.1% (w/v) TCA. The extract was centrifuged at 12,000×g for 15 min, after which to 0.5 mL of the supernatant was added 0.5 mL of 10 mM potassium phosphate buffer (pH 7.0) and 1 mL of 1 M KI and the absorbance was read at 390 nm. The content of H_2O_2 was given on a standard curve.

Statistical analysis

All values reported in this study are the mean of at least three replicates. For each parameter, data were subjected to a one-way ANOVA analysis. Differences between means were evaluated for significance by using Tukey's (HSD) test (Minitab software version 16.0).

3. Results

Growth parameters

Effect of exogenous silicon treatment on the plant growth under NaCl stress is presented in table 1. Reductions in length roots in the NaCl treatment were 30% and 36% compared to control with no salt added and in the absence of supplementary Si, for salt-tolerant (Vitron) and sensitive (Simeto) cultivars, respectively. Moreover, salinity stress considerably decreased length leaves showed 19% and 21 % in both cultivars grown at high salinity compared to control values. When NaCl was absent from the nutrient solution, Si significantly increased plant height at 2 mM level and 1 mM level relative to the control. Indeed, higher Si level (2mM) had greater alleviating effect of NaCl toxicity than lower Si level (1 mM).

Table 1:

Effects of silicon (Si) application methods on length roots and leaves of two wheat cultivars under salinity stress conditions

Treatments	Root length (cm)	Leaves length (cm)
Vitron		
Control(C)	9.66 c	17.98 c
C + Si 1	10.59 b	18.1 b
C+ Si 2	11.65 a	18.48 a
Salinity (S)	6.73 f	14.5 f
S+ Si 1	7.38 e	16.24 e
S + Si 2	8.3 d	16.70 d
Simeto		
Control (C)	8.25 c	16.78 c
C + Si 1	9.42 b	17.25 b
C+ Si 2	10.21a	17.76 a
Salinity (S)	5.26f	13.12 f
S+ Si 1	6.85e	14.05 e
S+ Si 2	7.16d	14.98 d

The same letters after the data within a column indicates there was no significant difference at a 95% probability level (Tukey's test) between treatments (p < 0.01).

Relative water content (RWC) and Electrolyte leakage (EL)

Relative water contents (RWC) were lower in both cultivars grown at high salinity compared to control values; lowest values were in Simeto (Table 2). On another note, under saline conditions Si application mitigated the decreased relative water content levels in the salinity treatments. The effects of NaCl and Si application on the electrolyte leakage content of wheat plants are presented in table 2. The results showed that wheat plants under salinity displayed a noteworthy increase in electrolyte leakage content relative to the control group. The salinity treatment impaired membrane permeability by increasing electrolyte leakage. However, silicon application to the NaCl treated plants partially maintained membrane permeability but only fully restored in to control levels in the salt tolerant cultivar (Vitron) with high concentration Si2+ salinity (100 mM NaCl).

Lipid peroxidation (MDA) and hydrogen peroxide (H_2O_2) contents

Oxidative damages to cell membrane lipids were evaluated by estimating the malondialdehyde (MDA) production. The stress induced by salinity accelerated MDA production that increased by 57% and 69% compared to the control with salt tolerant (Vitron) and sensitive (Simeto) cultivars, respectively (Table 3). In contrast, Si addition decreased MDA production. This mitigating effect was observed in the salinized wheat plants receiving Si application, as evidenced by 56% and 34% decline in MDA production respectively, relative to salt affected plants.

Table 2:
Electrolyte leakage (EL) and relative water content (RWC) in two wheat cultivars grown in nutrient solution with or without NaCl and supplementary Si

Treatments	Cultivars			
	Vitron		Simeto	
	Relative water content (%)	Electrolyte leakage (%)	Relative water content (%)	Electrolyte leakage (%)
Control (C)	92.60 c	22.67 d	91.45 c	23.56 d
C + Si 1	93.22 b	20.78 e	92.87 b	21.74 e
C+ Si 2	94.01 a	18.89 f	93.05 a	20.05 f
Salinity (S)	87.06 f	46.08 a	85.67 f	51.35 a
S+ Si 1	90.0 e	37.14 b	87.65 e	45.33 b
S+ Si 2	91.44 d	29.06 c	89.78 d	38.64 c

The same letters after the data within a column indicates there was no significant difference at a 95% probability level (Tukey's test) between treatments ($p < 0.01$).

The H_2O_2 contents in both the two cultivars of wheat plants are shown in table 3. The results show that salinity increased hydrogen peroxide production in the wheat plants of two genotypes relative untreated plants. However, Si application methods reduced NaCl induced H_2O_2 accumulation in the shoots relative to salt affected plants. This outcome was notable with treatment S+ Si 2 that attenuated the impact of salinity, causing a 43% and 38% decline in H_2O_2 production in the salt tolerant cv. and the salt sensitive cv. respectively relative to plants grown under salinity only. Simeto (salt sensitive cultivar) had consistently and significantly higher MDA and H_2O_2 contents regardless of the stress treatment or stress duration.

Table 3:
Effects of silicon (Si) application methods on the Malondialdehyde (MDA) and hydrogen peroxide (H_2O_2) concentrations of two wheat cultivars under salinity stress conditions

Treatments	Cultivars			
	Vitron		Simeto	
	Malondialdehyde *(nM/gFW)*	Hydrogen peroxide *(µM/gFW)*	Malondialdehyde *(nM/gFW)*	Hydrogen peroxide *(µM/gFW)*
Control (C)	5.61 d	15.69 d	4.79 d	18.97 d
C + Si 1	3.59 e	14.21 e	3.83 e	16.24 e
C+ Si 2	3.01 f	12.99 f	3.26 f	13.05 f
Salinity (S)	12.94 a	48.13 a	15.71 a	55.78 a
S+ Si 1	9.51 b	35.73 b	12.33 b	45.01 b
S+ Si 2	8.25 c	27.45 c	10.23 c	34.33 c

The same letters after the data within a column indicates there was no significant difference at a 95% probability level (Tukey's test) between treatments ($p < 0.01$).

4. Discussion

In this experiment, it has been shown that salt stress in wheat causes significant reductions in length root and shoots growth. Plant development was drastically suppressed in stress conditions. Comparable results were observed in salinity affected plants [6, 7, 25, 26]. Inhibition of plant growth under saline conditions may either be due osmotic reduction in water availability or to excessive ion Na and Cl, accumulation in plant tissues [27]. Indeed, the reduction in growth related attributes may be due to impaired cell development resulting from growth hormone effectively, leading to a reduction in cell turgor, cell volume, and ultimately cell growth, and it may also be due to the blocking up of conductive tissue vessels; hence, blocking every translocation that passes through these tissues [28]. Moreover, the present results showed that plant growth parameters of wheat plants were increased by Si addition under non-NaCl stress condition, proving the beneficial effect of Si. Similarly, many researchers reported beneficial effects of silicon in many crops [29-32]. The positive impacts of Si on plant growth may be due to the increased antioxidant capacity [19], and K^+ absorption, which increase the number of chloroplasts per cell, and leaf area [33].

Salinity stress significantly reduced relative water content, thereby significantly increasing water saturation deficiency. Indeed, salinity leads to a reduction in the capacity of plants to absorb water, a drop in leaf water and osmotic potentials [34-35]. Salinity tolerance levels vary greatly between plants [36]. The study revealed that the relative water content of durum wheat plants decreases significantly in sodium chloride-treated plants, compared to control plants. Thus, according to various authors, salt stress results from the disruption of the water, mineral and carbon nutrition functions of plants [37-38]. The relative water content is often considered as an excellent indicator of the water status of the plant. It is linked to the plants capacity to maintain a level of hydration of the tissues in order to guarantee the continuity of its metabolism or metabolic activity [6].

On another note, under saline conditions, Si application mitigated the decreased relative water content. Also, this induced that the osmolyte accumulation was associated with the increasing osmotic adjustment capacity relative to that of the control plants [7-39]. This may be related to limiting water loss and optimising the hydromineral nutrition of plants by decreasing excessive transpiration, as excess transpiration leads to stomatal closure and decreased photosynthesis [11-40].

Electrolyte leakage is one of the majorly used indicators in detecting the severity of salinity-induced injuries [17]. In the current study, electrolyte leakage increased significantly with salinity. The significant increase in electrolyte leakage observed could indicate that salt stress affected the membrane integrity and stability of the stressed plants. Similar results were obtained by Lutts et al. (1996); Kaya et al. (2002); Tuna et al. (2007) and Farouk et al., 2020 [22, 41, 42, 7]; who reported that high salt concentration can affect the membrane permeability of rice, strawberry and wheat varieties, respectively. The dysfunction of cell membrane permeability can be expressed by the increased rate of electrolyte leakage. The cellular membrane dysfunction due to stress is well expressed in its increased permeability for ions and electrolytes, which can be readily measured by the efflux of electrolytes [22].

In addition, in our work, we also found that the application of silicon decreased the rate of electrolyte leakage in both salt-stressed and unsalted plants. Several similar works have been reported [43-46]; suggesting that silicon could restore membrane permeability and maintain membrane integrity [32].

The cell membrane can be the target of reactive oxygen species. ROS primarily target the lipids present in cell and subcellular membranes. Lipid peroxidation induces a change in membrane fluidity and permeability [47]. Malondialdehyde, the oxidation product of lipid membranes, accumulates when plants are exposed to oxidative stress. MDA concentrations are considered as an indicator of lipid peroxidation after abiotic stress [48]. The determination of its concentrations is used as a reliable tool to detect lipid peroxidation [49-51]. Thus, our results showed that sodium chloride induced a very highly significant increase in MDA concentrations in the leaves of stressed durum wheat plants. Daud et al. (2015) [52], also recorded that MDA level increases in Cotton (*Gossypium hirsutum* L.) subjected to salt stress. This may be due to lipid peroxidation; and thus membrane destabilization due to the high production of ROS causing oxidative damage. Indeed, the overproduction of ROS causes lipid peroxidation which leads to the formation of degradation products such as alkanes and aldehydes (Malondialdehyde) [53]. The most detrimental effect of ROS in plants is lipid peroxidation, which can lead to membrane disruption [54-55]. In contrast, the addition of both concentrations of silicon to salt-stressed wheat plants decreased MDA concentrations in the leaves of durum wheat plants. This indicates that silicon reduces lipid peroxidation by improving membrane permeability in salt-stressed plant cells. Similar results have been reported [56-58].

As for hydrogen peroxide (H_2O_2), we noted a clear increase in the leaves of durum wheat plants treated with sodium chloride. This may be related to oxidative damage to the membrane. Our results also show that the accumulation of H_2O_2 is more noted in the leaves of treated plants compared to controls. Salinity induced-phytotoxicity is strongly associated with ROS accumulation [7]. Similarly, salt stress drastically induced H_2O_2 accumulation, leading to increased MDA production that destroys cellular membranes and upsets regular cellular processes [16, 17, 59]. Hydrogen peroxide can be derived from the dismutation reaction of superoxide anion by SOD [60-61]. It can also be caused by the alteration of electron transport in the photosynthetic and respiratory chains [62-63]. This increase could be explained by the important role that H_2O_2 plays in oxidative stress signaling [64]. H_2O_2 can be diffused over relatively long distances causing changes in the redox status of surrounding tissues and cells or at relatively low concentrations where it triggers an antioxidant response. Thus, H_2O_2 acts as a signal molecule that alerts the cell to the presence of environmental stress [65]. Hydrogen peroxide (H_2O_2) can function as a secondary messenger at low concentrations but becomes toxic at high concentrations [66].

Furthermore, in our work we noticed that pretreatment with silicon significantly decreased the production of hydrogen peroxide (H_2O_2) in leaves of NaCl-treated durum wheat plants. The decrease of H_2O_2 synthesis after silicon application has been shown by many authors [27, 67, 68, 69, 17, 19]. Indeed, it has been suggested that pretreatment of plants with silicon could significantly improve the defense capacity against oxidative damage induced by salt stress toxicity. These findings are parallel to previous reports, wherein Si treatment effectively attenuated the undesirable effects of oxidative stress on the cell membrane by acting as a ROS scavenger [18-59].

5. Conclusion

These results showed existence of a variation in tolerance to salinity between the durum wheat cultivars Vitron and Simeto. Higher NaCl sensitivity of Simeto was associated with increased levels of oxidative biomarkers MDA and H_2O_2. In conclusion, suitable application of silicon concentration in the plant-growing medium with NaCl could alleviate salinity induced toxicity in wheat plants by relieved oxidative damages through biological processes, including, improving growth of shoots and roots, maintaining balance water status, reducing electrolyte leakage and alleviating oxidative injury, thereby resulting in a considerable reduction in ROS-induced oxidative biomarkers in both salt-sensitive and tolerant cultivars.

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