Beneficial effects of foliar application of silicon compounds and potassium sulfate on cell membrane stability, biochemical traits, and tuber yield of potato under salinity stress

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Abstract

Since potato plants are susceptible to salinity, it is essential to use strategies such as the application of potent anti-stress compounds such as potassium and silicon. Salinity levels of 0.3 (non-stress), 5, 8 and 12 $dS.m^{-1}$ were assigned to main plots, and foliar application of anti-stress compounds including potassium sulfate, sodium silicate nanoparticles, and silicon were assigned to subplots. Salinity stress increased ionic leakage and leaf malondialdehyde (MDA) content. The lowest leaf MDA content was observed at 5 and 12 $dS.m^{-1}$ salinity levels in silicon and sodium nano-silicate applications, which showed a 56% and 43% decrease, respectively, compared to non-stress conditions. Application of silicon compounds under saline conditions increased leaf soluble carbohydrates and proline content compared to the control plants. Salinity increased the Na to K ratio, but the application of silicon reduced this ratio more than twice compared to non-stress conditions. The results showed a positive effect of sodium silicate nanoparticles on tuber yield at salinity stress of 5 $dS.m^{-1}$. It seems that the use of silicon compounds, especially its nanoparticles, under salinity stress would be an effective way to reduce the effects of salinity.

Keywords: Ionic Leakage, Malondialdehyde, Sodium Nanosilicate, Na:K ratio.

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Introduction

Potato (*Solanum tuberosum*) is the fourth most important crop and is of particular importance in human and animal nutrition. In semi-arid regions, where potatoes are widely planted, salinity is a serious problem and drastically reduces productivity [1]. One of the strategies to increase crop tolerance to salt stress is the use of anti-stress compounds [2]. For example, potassium [2] and silicon [3] are among the compounds with anti-stressed effects under salinity stress conditions. Potassium has a synergistic effect on the uptake of other macro-nutrients such as nitrogen, phosphorus, and calcium, positive effects on osmotic adjustment process of root and shoot of plants under adverse conditions and helps to absorb more water and nutrients required by the plant [4]. The beneficial effects of silicon on plants have been reported especially in environmental stress conditions [5]. Silicon increases chlorophyll concentration per unit leaf area, increases the ability of plant to light absorption and improves photosynthesis [3], deposition on leaf cuticular layers and prevent water loss and enhances leaf physical resistance under stress conditions, and contributes to plant water balance [6].

Despite the importance of salinity stress studies on plants and crops, relatively few studies have been conducted on the exogenous use of materials to improve potato tolerance to salinity. Due to the necessity of investigating the effect of anti-stress compounds on potato cultivation under saline conditions, the effects of foliar application of conventional silicon and potassium compounds and the efficiency of sodium silicate nanoparticles on physiological relationships and tuber yield of potato plants were investigated.

Materials and methods

This study was conducted during the spring to autumn of 2016 at the research farm of Ferdowsi University of Mashhad, Iran. Experimental treatments consisted of salinity levels of 0.3 (control), 5, 8 and 12 $dS.m^{-1}$ as the main plots, and foliar application of potassium sulfate (1000 $mg.l^{-1}$), sodium silicate nanoparticles (400 $mg.l^{-1}$), and silicon (1000 $mg.l^{-1}$) as the sub-plots. The uniform tubers were planted in the second half of May, and irrigation was done from the early stages of growth and establishment to three to four leaves stage (up to one month after cultivation) with tap water. Then, salinity was applied through dissolution of sodium chloride salt based on its ionization coefficient in the water supply. Foliar application of the anti-stress compounds was performed two weeks after salinity stress in two stages; 10 days (40 days after planting) and 20 days after salinity stress (50 days after planting) at the end of the day. One week after the second foliar application of the anti-stress compounds, leaf samples were taken from the fully developed young leaves (third), and the physiological and biochemical traits were evaluated. Leaf MDA [7], electrolytes leakage (EL), relative water content (RWC) [8], total soluble carbohydrates (SC) [9], proline [10], sodium (Na), potassium (K) [11], and the ratio of sodium to potassium (Na: K) were measured. At the end of the growing season, taking into account the marginal effect, two square meters of each experimental plot were harvested to determine the tuber yield.

The experiment was conducted as a split-plot in a randomized complete block design with three replications. Analysis of variance and means comparison were performed by SAS 9.1 statistical software. Means were compared with LSD at 5% probability level.

Results and discussion

Salinity stress increased the EL rate of potato leaf, so that salinity stress levels of 5, 8, and 12 $dS.m^{-1}$ increased this parameter by 30, 58, and 57%, respectively (Fig. 1a). The RWC of leaves was also affected by salinity stress. The lowest RWC was observed at 12 $dS.m^{-1}$ salinity stress, which was significantly lower than that under non-stress conditions (Fig. 1a).

The effect of salinity and interaction of salinity and foliar application on leaf MAD content was significant. Under non-stress conditions, the lowest MDA was observed when potassium sulfate was applied, but at the stress level of 5 and 12 $dS.m^{-1}$, the lowest MDA was observed in silicon and sodium nano-silicate treatments by 56 and 43% decrease compared to non-stress conditions, respectively (Table 1). Researchers have linked the loss of cell membrane stability under stress conditions to increase membrane lipid peroxidation [4]. Increasing the range of effectiveness of nanoparticles compared to the conventional forms has been attributed to their unique properties and reactivity and transportability in the plant tissues [3, 5]. Also, one of the reasons for the decrease of ion leakage and MDA content in leaves treated with nanoparticles at salinity level of 12 $dS.m^{-1}$ and its relative difference with silicon and potassium sulfate treatments was due to the higher biological activity of nanoparticles and their high permeability in the plant tissues.

Salinity and foliar application interacted to affect leaf SC content. Overall, salinity decreased leaf SC content 61% of under salinity stress of 8 $dS.m^{-1}$ compared to non-stressed plants, but spraying with sodium nano-silicate increased leaf SC content 20% compared to the control (Table 1). Although there were no salinity effects of 5 and 8 $dS.m^{-1}$ and non-stress conditions in leaf SC treatments, the highest leaf SC content was observed at the salinity level of 12 $dS.m^{-1}$ (Table 1). Sodium nano-silicate application increased leaf proline content by 34% compared to the control under non-stress conditions (Table 1). Non-significantly, however, potassium sulfate application increased leaf proline content under salinity at 12 $dS.m^{-1}$ compared to the control (Table 1). Silicon application increased leaf proline content 45% under salinity stress of 12 $dS.m^{-1}$ compared to the control (20%). One of the strategies of plants facing environmental stresses is to increase the production of proteins and other compatible compounds to protect the cell and to help regulate the plant water relationships that the most important of which are proline, carbohydrates, glycine betaine, and polyols [12]. In the present study, the proline content of potato leaf increased with increasing salt stress levels. In general, the SC content decreased with increasing salinity stress. Application of anti-stress compounds had various effects on the SC content of the plant, so that silicon relatively increased and potassium sulfate relatively decreased SC content to control plants at 12 dSm^{-1} salinity level.

The effects of silicon under salinity conditions on different plant species and environmental conditions can be varied. Application of silicon reduced leaf proline content of different plants; including barley (*Hordeum vulgare*), wheat (*Triticum aestivum*), soybean (*Glycine max*), and sorghum (*Sorghum bicolor*) under salinity conditions, but short-term application of silicon under salinity stress can also increase compatible solutes, indicating their role in regulating cell osmotic potential [13]. In this study, it was also observed that the application of silicon compounds at 12 $dS.m^{-1}$ of salinity increased leaf proline compared to control, possibly indicating the plant effort to conserve leaf water and protect the cell against water desiccation.

Table 1 Effect of irrigation water salinity and foliar application of anti-stress compounds on biochemical traits of potato leaf in tuber stage

Salinity level ($dS.m^{-1}$)	Anti-stress compounds	Parameters					
		MDA ($nm.g^{-1}$ Fw)	Soluble carbohydrates ($mg.g^{-1}$ Fw)	Proline ($mg.g^{-1}$ Fw)	Na ($mg.g^{-1}$ Dw)	K ($mg.g^{-1}$ Dw)	Na:K
0.3	C	27.8^{a}	7.27^{a}	2.04^{ab}	4.16^{bc}	55.6^{a}	0.07^{b}
	SNS	17.6^{b}	5.14^{a}	3.12^{a}	5.76^{ab}	50.5^{a}	0.11^{ab}
	KS	11.8^{b}	7.88^{a}	1.20^{b}	2.11^{c}	44.7^{a}	0.04^{b}
	Si	13.3^{b}	8.01^{a}	2.06^{ab}	8.29^{a}	42.3^{a}	0.20^{a}
5	C	14.4^{a}	8.65^{a}	2.29^{a}	3.48^{b}	35.4^{a}	0.10^{b}
	SNS	12.6^{a}	5.07^{a}	5.75^{a}	2.11^{b}	40.5^{a}	0.05^{c}
	KS	12.4^{a}	6.23^{a}	2.83^{a}	7.17^{a}	38.7^{a}	0.18^{a}
	Si	6.3^{b}	5.64^{a}	2.60^{a}	3.25^{b}	54.6^{a}	0.06^{bc}
8	C	28.4^{a}	2.80^{a}	3.32^{a}	2.57^{b}	46.7^{a}	0.05^{b}
	SNS	14.6^{b}	6.22^{a}	2.57^{a}	0.98^{b}	42.9^{a}	0.02^{b}
	KS	15.3^{b}	4.26^{a}	2.89^{a}	11.5^{a}	42.9^{a}	0.27^{a}
	Si	14.7^{b}	4.66^{a}	2.97^{a}	10.8^{a}	44.3^{a}	0.25^{a}
12	C	15.7^{a}	5.08^{ab}	2.56^{a}	3.93^{b}	28.2^{a}	0.14^{ab}
	SNS	5.4^{b}	4.11^{ab}	3.66^{a}	2.79^{b}	43.7^{a}	0.11^{ab}
	KS	9.0^{ab}	2.62^{b}	4.10^{a}	9.24^{a}	42.5^{a}	0.23^{a}
	Si	9.1^{ab}	6.30^{a}	3.75^{a}	4.58^{b}	44.7^{a}	0.06^{b}

* MDA: Malondialdehyde; C: Control; SNS: Sodium nano silicon; KS: Potasium sulfate; Si:

Leaf Na content and Na: K ratio were affected by their salinity, foliar application, and their interaction. Interaction of salinity levels and the foliar application was also significant on leaf K content. The highest leaf Na was obtained by application of potassium sulfate in salinity of 8 $dS.m^{-1}$. Under non-stress conditions, potassium sulfate reduced leaf Na content by 49%, while, at the salinity levels of 5 and 8 $dS.m^{-1}$, the application of sodium Nano-silicate reduced leaf Na content by 64 and 160% compared to the non-stress conditions (Table 1). Although there was no significant difference in leaf K content between the levels of salinity, leaf K content decreased by increasing salinity levels (for instance, 20% at 12 $dS.m^{-1}$ under non-stress conditions) (Table 1). Salinity at 12 $dS.m^{-1}$ decreased leaf K content by 97% compared to the non-stress conditions, but the application of silicon increased leaf potassium content by 37% compared to the control

(Table 1). Salt stress significantly increased the Na: K ratio, which increased 50% in control plants at 12 $dS.m^{-1}$ salinity level under non-stress conditions (Table 1). Application of silicon at the salinity level of 12 $dS.m^{-1}$ reduced the Na: K ratio by more than twice under non-stress conditions.

High levels of sodium damage plant cells, such as cell metabolism, which slows down the growth and hasten the production of the reactive oxygen species. Under salt stress conditions, plant has to spend more energy to maintain a higher concentration of cytosolic potassium and a lower sodium concentration, which can reduce plant growth and productivity [14]. Silicon can reduce sodium accumulation in root or shoot. It has been observed in barley and oat application of silicon reduced sodium and chloride ions and increased potassium under salinity under stress conditions, resulting in a more equitable distribution of sodium and potassium in the root sections [15].

In the present study, salinity stress increased sodium and reduced potassium concentration in potato leaves. Shahzad, Zörb [16] also observed that sodium concentration of bean leaf (*Vicia faba*) significantly increased under salinity, but improved with application of silicon. In the present study, it was also observed that sodium Nano-silicate application reduced the concentration of leaf sodium of potato. Furthermore, the application of anti-stress compounds, especially silicon, increased leaf potassium content compared to the control plants under salinity stress. The Na^+/H^+ antiporters play an essential role in maintaining low sodium concentrations by removing sodium from the cytosol or placing it in the vacuole, which is supplied by ATP from H^+ -ATPase membrane proteins. It has been observed that the activity of the ATPase pump is increased by the application of silicon, which facilitates the expulsion of sodium from the cell [14].

Sometimes the mitigating effects of silicon under salinity conditions are not by preventing the entry of sodium and chlorine. For instance, it has been observed in tomatoes that silicon did not reduce the amount of sodium and chlorine in the leaves, but increased leaf water storage. This water content further dilutes salt and reduces salt toxicity and improves plant growth [17]. In our study, it was observed that increasing salinity up to 5 $dS.m^{-1}$ resulted in a relative improvement of leaf RWC compared to the control plants, but with increasing salinity, the RWC decreased. Silicon has been found to improve the RWC of wheat leaf under salinity stress but has no effect on the control plants [14]. There was no significant effect on the RWC of potato leaves in the present study, but the application of sodium Nano-silicate increased the osmotic potential of the leaf (data not shown). This indicates that in the case of potato, silicon may have improved plant growth and tuber yield by preventing the entry and accumulation of Na ions, and the role of salt dilution and water uptake was slight in this plant.

With increasing salinity stress, the yield of tubers larger than 30 mm drastically decreased, so that tuber yield of 36 $ton.ha^{-1}$ under non-stress condition was decreased to 1.4 $ton.ha^{-1}$ at 12 $dS.m^{-1}$ salinity level (Fig. 1b). Application of anti-stress compounds improved the tuber yield. Under non-stress conditions, the application of potassium sulfate and silicon increased tuber yield by 12 and 10%, respectively, whereas tuber yield was increased 56% at 12 $dS.m^{-1}$ of salinity level by the application of sodium Nano-silicate, compared to control plants (Fig. 1B). Due to the higher salinity levels of the potato tolerance threshold were applied in this experiment, the loss of tuber yield was not unexpected. Accordingly, the results of other studies on potatoes in a stressful environment have shown the detrimental effects of stress on tuber yield [2, 5]. It seems that the positive effects of the application of nanoparticles during the growing season coupled with a period of determination of the number and size of photosynthetic sinks in the soil, ultimately improved tuber yield per unit ground area. Kafi, Nabati [5] reported that photosynthesis and quantum yield was increased using Nano-containing compounds of silicon and potassium sulfate under salinity stress compared to the control plants. Supplying more photosynthetic materials is likely to obviation the reduced production of photoassimilates to fill tubers under salinity stress.

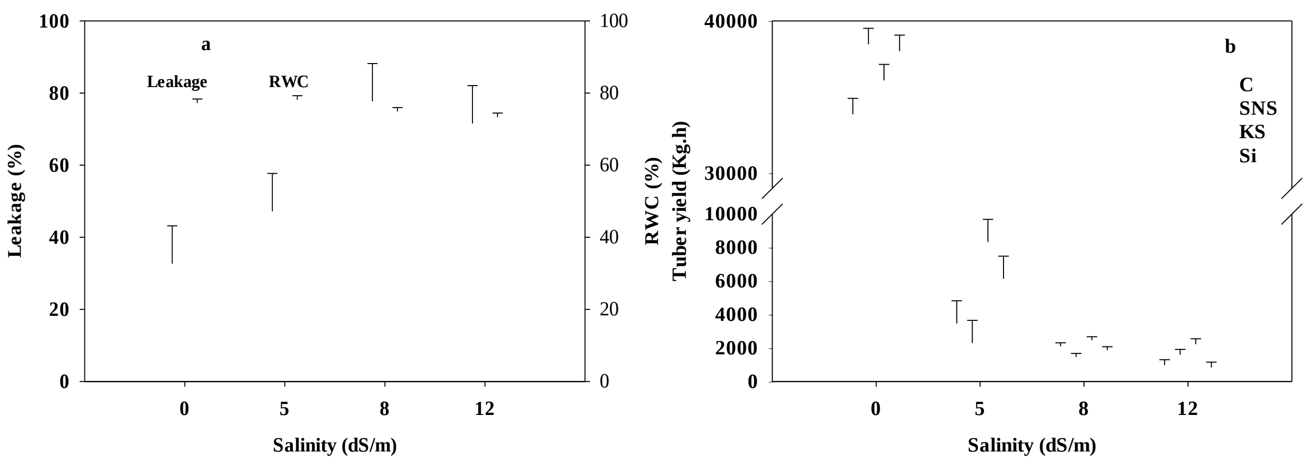

Figure 1 Effect of salinity levels of irrigation water on electrolytes leakage percentage and relative leaf water content (a), and interactive effect of salinity and foliar application of anti-stress compounds on the yield of tubers greater than 30 mm (b) in potato plants at tuber stage. C: Control; SNS: Sodium Nano-silicate; KS: Potassium sulfate; Si: Silicon. Vertical lines represent standard error.

Conclusion

Overall, the results showed that salinity had a significant effect on cell membrane damage and ion leakage. Also, stress conditions increased the content of soluble carbohydrates, proline, Na: K ratio, and decreased the yield of tubers greater than 30 mm. Foliar application by compounds of nanoparticles of sodium silicon, potassium sulfate, and silicon reduced the effects of salinity on traits such as electrolytes leakage, MDA content, and Na: K ratios, although the effects varied between treatments. The tuber yield was improved especially by the application of sodium nano-silicate at 12 $dS.m^{-1}$ of salinity compared to the control plants. According to the results, it can be concluded that silicon application will be an effective strategy to reduce the effects of salinity under stress conditions, and the use of nanoparticles will increase efficiency.

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