



Effect of short-term salinity on photosynthesis and ion relations in two sugar beet cultivars

Alireza Dadkhah* and Ghorbanali Rassam

Higher Education Complex of Shirvan, Ferdowsi University of Mashhad, Mashhad, Iran.

Abstract

A factorial pot experiment was conducted based on randomized complete blocks design in green house condition to investigate the effect of short-term salt stress on leaf photosynthesis and ion relations of two sugar beet cultivars (Madison and 7233-P₂₉). Plants were exposed to 0, 50, 150, 250, and 350 mM salinity (NaCl and CaCl₂ in 5:1 molar ratio) for 48 hours. Measurements were done on youngest fully expanded leaves. Salinity caused a significant reduction in stomatal conductance and consequently leaf net photosynthesis in both cultivars. Net photosynthesis of cv 7233-P₂₉ at low level of salinity (50 mM) at 12 h, 24 h and 48 hours after salinity application decreased by 7.4%, 15.1% and 20%, respectively, compared to control. However, reduction in photosynthesis at highest level of salinity (350 mM) at the same times were 62.4%, 73%, and 72.3%, respectively, compared to control. For Madison the percent of reduction was significantly higher than P₂₉. Cultivar P₂₉ at 12 and 24 hours after salinization had significantly higher Na⁺ content than Madison up to 250 mM. Potassium concentration tended to decrease with increase in salinity. Salinity led to increased Cl⁻ concentration in both cultivars. However, Madison had significantly higher Cl⁻ content than P₂₉ at the highest level of salinity at all three times of sampling. A strong correlation between photosynthesis and stomatal conductance ($R^2=0.98$) and weak correlation between photosynthesis and sodium concentration ($R^2=0.22$), and photosynthesis and chloride concentration ($R^2=0.55$) indicated that in short-term exposure to salinity, stomatal conductance was one of the main causes of photosynthesis.

Key words: *Beta vulgaris*; salt Stress; stomatal conductance; NaCl

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Introduction

Plants exposed to salinity show less CO₂ uptake by their leaves than the same plants not exposed to salinity (Hester et al., 2001; Dadkhah and Griffiths, 2004, Dadkhah, 2011). This decrease has been attributed to specific ion effects mainly from Na⁺ and Cl⁻ which may damage photosynthesizing tissues (Dadkhah and

Griffiths, 2004). However, the direction and magnitude of these changes varies according to the level and duration of salinization treatment as well as the plant species. Salinity exerts its undesirable effects through osmotic inhibition and ionic toxicity. Osmotic inhibition is the result of the salt presented in the soil solution which reduces the ability of the plant to take up water, and leads to slower growth (Dadkhah and Griffiths, 2006; Koyro, 2006). Ionic toxicity is caused by an excessive amount of salt entering the transpiration stream which eventually injures cells in the transpiring leaves and may further

*Corresponding author
E-mail address: dadkhah@um.ac.ir
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reduce growth (Koyro, 2006). Reduction in growth and photosynthesis are among the most conspicuous effects of salinity stress. In addition, stomatal closure in order to reduce transpiration appears to be the main cause of the decrease in photosynthetic rate. Moradi and Esmail (2007) reported that salinity could seriously change the photosynthetic carbon metabolism as well as photosynthetic efficiency. The ability of plants to cope with salinity stress is an important determinant of crop distribution and productivity in many areas, so it is important to understand the mechanisms that confer tolerance to saline environment. The main objectives of this study were to explore the changes in photosynthesis and ion concentration of sugar beet leaves under short-term salinity.

Materials and Methods

A factorial pot experiment in randomized complete block design was carried out under greenhouse condition with four replications. The experiment was conducted with two sugar beet cultivars (Madison and 7233-P₂₉) to investigate short-term effect of salinity on net photosynthesis (youngest leaf over 50% full size) and ion relations of two sugar beet cultivars. Plants were grown in 15 cm diameter pots filled with washed sand. Day length was 16 hours during the experiment and relative humidity was between 35-55%. Five levels of salinity 0, 50, 150, 250 and 350 mM (NaCl and CaCl₂ in 5:1 molar ratio) were added to a modified Hoagland nutrient solution (Mass and Poss, 1989). Forty-day-old sugar beet plants most being at 6-leaf stage were irrigated with saline water. Net photosynthesis (A) and stomatal conductance (g_s) were measured three times (12 h, 24 h, and 48 h after salinity application) at a photon flux density of 500 $\mu\text{mol m}^{-2} \text{s}^{-1}$ and the temperature of the growth condition using combined infrared gas analysis system (CIRAS-1 portable photosynthesis system, LTD, Hoddesdon, UK).

For Na⁺ and K⁺ analysis, samples of dried leaves were heated to ash in a furnace for 12 h at 550° C. The ash was dissolved in 20% sulfuric acid, diluted in distilled water, and filtered through a 90 mm Whatman No. 541 filter paper. Chloride (Cl⁻) determinations were made on a

distilled water extract of the dried sample (\cong 200 mg), shaken for 24h, and then filtered through a 90 mm Whatman No. 2 filter paper. Na⁺ and K⁺ contents were determined by flame emission photometry. The amounts of Cl⁻ were measured by ion-exchange chromatography using a DIONEX Model DX 500, fitted with a CD 20 conductivity detector, IP 25 Pump and AS 14 Ion Exchange Column.

The data for all characters were analyzed using the analysis of variance procedure of Statistical Analysis System (SAS) software, version 6.12. Means were compared by Duncan's multiple range tests at the 0.05 probability level for all comparisons.

Results

Photosynthesis significantly ($P \leq 0.001$) decreased with increasing salt concentration (Fig. 1). Leaf photosynthesis of cv P₂₉ treated with low and high levels of salinity had rates of 92.6% and 37.6% (12 h after salinity application), 84.9% and 27% (24 h after salinity application) and 80% and

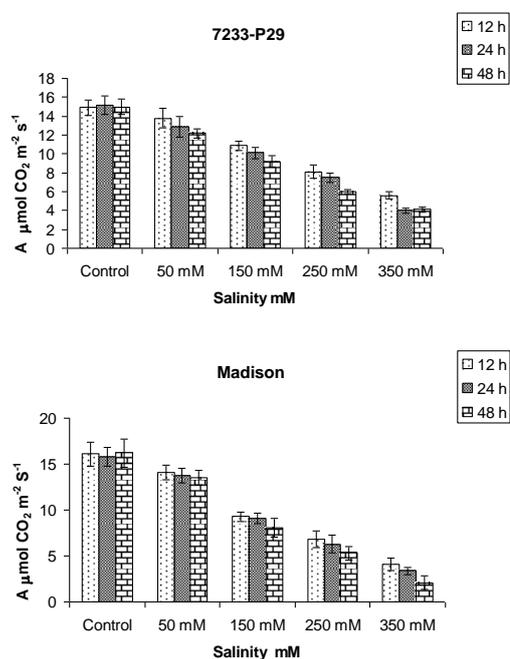


Fig. 1. Net leaf photosynthesis (A) after short-term exposure of different cultivars to different salt concentrations; each bar is the average of four replications. Vertical lines are standard error of the means.

26.3% (48 h after salinity application) respectively, compared to control. However, leaf

photosynthesis of cv Madison treated with low and high levels of salinity had rates of 87.6% and 25.5% (at 12 h after salinity application), 87.3% and 22.1% (at 24 h after salinity application), and 83.3% and 13% (at 48 h after salinity application), respectively, compared to control. Analysis of variance revealed that there were significant differences between cultivars in the amount of net photosynthesis. Cultivar 7233-P₂₉ had higher net photosynthesis than cv. Madison especially at high levels of salinity.

The adverse effect on photosynthesis was associated with a significant ($P \leq 0.001$) decrease in the stomatal conductance (g_s) (Fig. II). Stomatal conductance of cv P₂₉ treated with low and high levels of salinity had rates of 88.2% and 39.2% (12 h after salinity application), 87.5% and 32.4% (24 h after salinity application), and 80% and 30% (48 h after salinity application), respectively, compared to control. However, g_s of cv Madison treated with low and high levels of salinity had rates of 90% and 26.5% (12 h after salinity application), 81.3% and 19.1% (24 h after salinity application), and 82.3% and 15.2% (48 h after salinity application), respectively, compared to control.

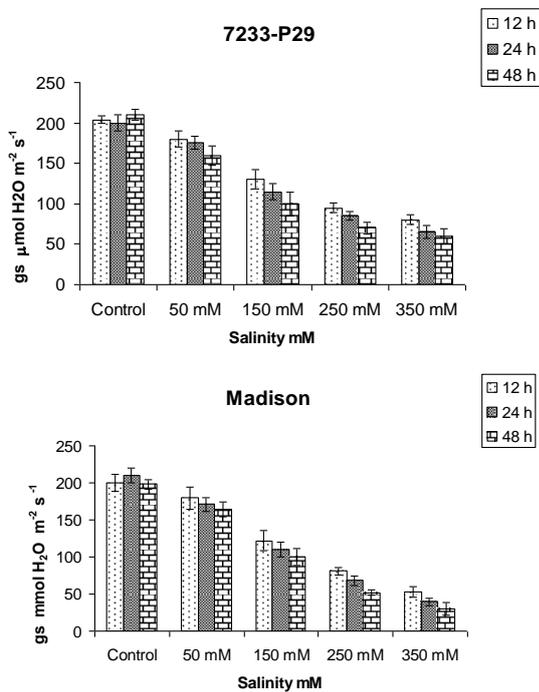


Fig. II. Stomatal conductance (g_s) after short-term exposure of different cultivars to different salt concentrations; each bar is the average of four replications. Vertical lines are standard error of the means.

after salinity application) respectively, compared to control (Fig. II).

The ratio of intercellular to ambient CO₂ concentrations (C_i/C_a) decreased at high levels of salinity compared to controls in both cultivars of sugar beet. However, cultivar 7233-P₂₉ had higher C_i/C_a than cultivar Madison especially at high levels of salinity (Fig. III).

When saline treatments were imposed on sugar beet plants, there was a significant increase in sodium concentration in both cultivars used (Madison and P₂₉) in the short-term experiment (Fig. IV). Sampling for short-term cation and anion measurement was started at 12 hours and continued to 24 hours, and 48 hours after salinization. Cultivar P₂₉ 12 hours and 24 hours after salinization had significantly higher Na⁺ content than Madison up to 250 mM. 48 hours after salinization differences between these two cultivars was only significant at 250 mM (Fig. IV). 12 hours after salinization plants of both cultivars grown in 150 mM had markedly the highest Na⁺ concentration (Fig. IV).

Potassium concentration tended to decrease with increasing salinity (Fig. 5). At 12

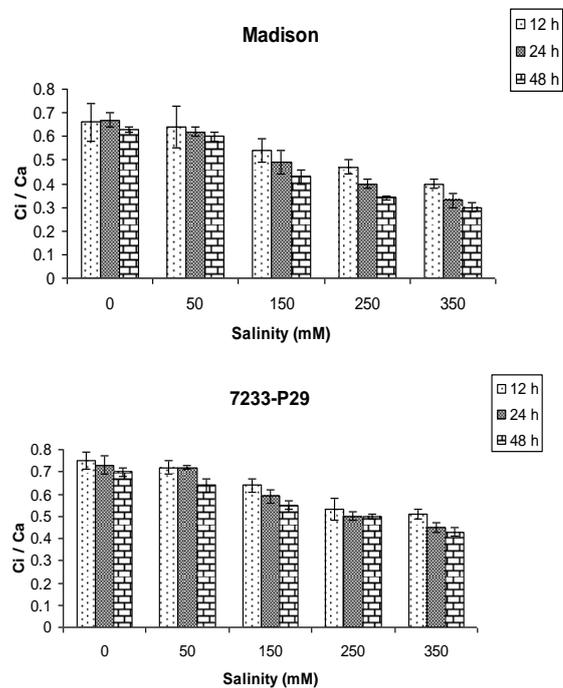


Fig. III. The ratio of intercellular to ambient CO₂ concentrations (C_i/C_a) after short-term exposure of different cultivars to different salt concentrations; each bar is the average of four replications. Vertical lines are standard error of the means.

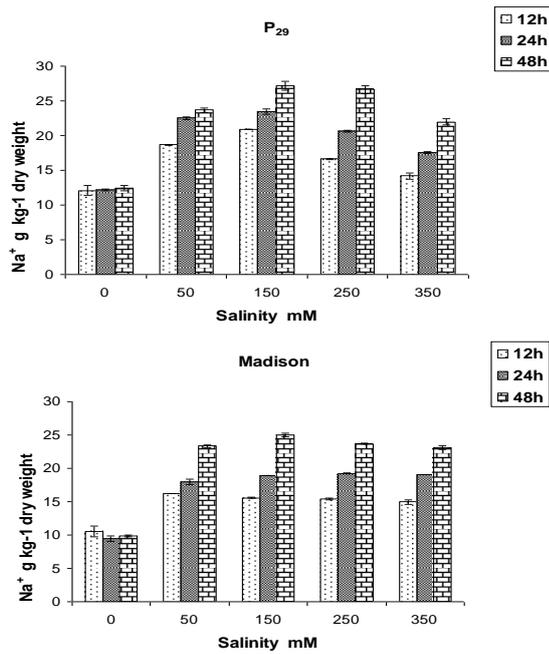


Fig. IV. Leaf sodium (Na⁺) concentration (g kg⁻¹ D.W) after short-term exposure of different cultivars to different salt concentrations. Each bar is the average of four replications. Vertical lines are standard error of the means.

There was not a high correlation between photosynthesis and Na⁺ concentration ($R^2 = 0.22$) and Cl⁻ concentration ($R^2 = 0.55$) (Figs. VII and VIII). However, a strong positive linear correlation was observed between photosynthesis and stomatal conductance ($R^2 = 0.98$) (Fig. IX).

Discussion

The present study indicated substantially lower net photosynthesis rates with increasing salinity concentrations. Similar results were obtained with other species by Guanghai et al. (1993), Everard et al. (1994) and Kafi (2009), but not by Flanagan and Jefferies (1988) who only found slight decreases in photosynthesis rates with increasing salinity concentrations. Decreased net photosynthesis rate at high external salinities are often more pronounced in non-halophytes than halophyte species (e.g. Rowson et al., 1988; Banuls and Primo-Millo, 1992; Walker et al., 1993; Chartzoulakis et al., 1995)

In the present study increased salinity treatments often led to significantly smaller stomatal conductance. This has been found in

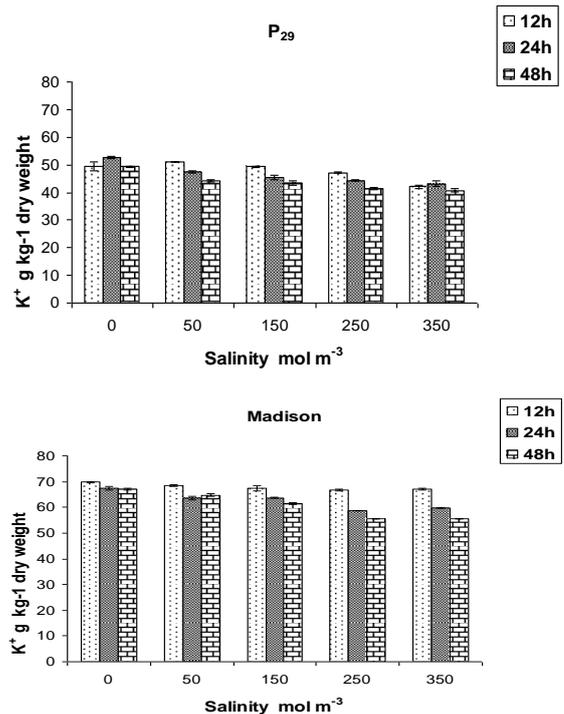


Fig. V. Leaf potassium (K⁺) concentration (g kg⁻¹ D.W) after short-term exposure of different cultivars to different salt concentrations; each bar is the average of four replications. Vertical lines are standard error of the means.

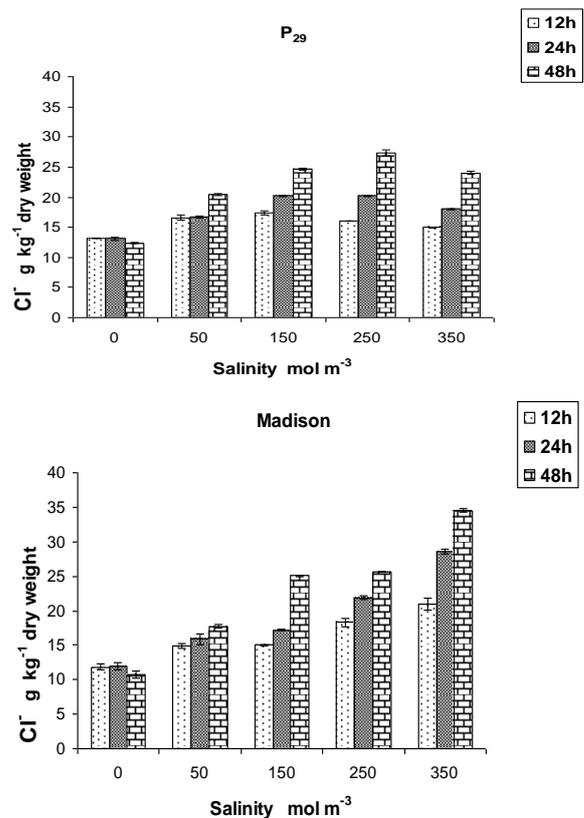


Fig. VI. Leaf chloride (Cl⁻) concentration (g kg⁻¹ D.W) after short-term exposure of different cultivars to different salt concentrations; each bar is the average of four replications. Vertical lines are standard error of the means.

most other studies (e.g. Downton et al., 1985; Seeman and Critchley, 1985; Walker et al., 1993; Chartzoulakis et al., 1995; Kafi, 2009; Dadkhah, 2011). It was reported that a part of growth reduction due salinity is a direct consequence of stomatal closure and a reduction in the C_i which led to decrease in photosynthesis rate (Querghi et al., 2000; Netondo et al., 2007). The reduction in g_s under salt stress is estimated to be substantial in spinach and *Phaseolous vulgaris* with the intercellular CO_2 concentration reduced up to 30% (Seemann and Critchly, 1985).

Accumulation of inorganic ions, predominantly Na^+ and Cl^- , has an important role in the process of osmotic adjustment. There is substantial evidence that plants of moderate to high salt tolerance may accumulate large amounts of salt under saline conditions, contributing to osmotic adjustment (Flowers, et al., 1977; Binzel et al., 1988; Ashraf, 2001; Ghoulam et al., 2002).

In short-term salinity, Na^+ concentrations were higher in tissues subjected to moderate salinity (150 mM) than high levels of salt treatments. There might be an excluding mechanism in the roots which prevents Na^+ and Cl^- loading to xylem from the growth medium at high levels of salinity. However, differences were observed between these two cultivars under low levels of salinity. Figs. (V) and (VI) show that Madison had significantly lower (or equal Na^+) and Cl^- content than P₂₉ over short-term exposure up to 250 mM salinity. One explanation for low absorption of Na^+ and Cl^- in short-term in this experiment could lie in the rate of water and nutrient absorption from the rooting medium in the first hours after the changes in osmotic potential resulting from application of saline treatments. It may take time for Madison plants to lower their potential to be able to absorb water from the external solution. The higher Na^+ and Cl^- concentration of salt-tolerant cultivar P₂₉, in the short-term under moderate salinity may indicate that it started water uptake sooner than the Madison cultivar.

Potassium concentration decreased significantly with increasing salinity (Fig. V). However, this reduction was not as much as increasing sodium concentration. There were significant differences in potassium accumulation

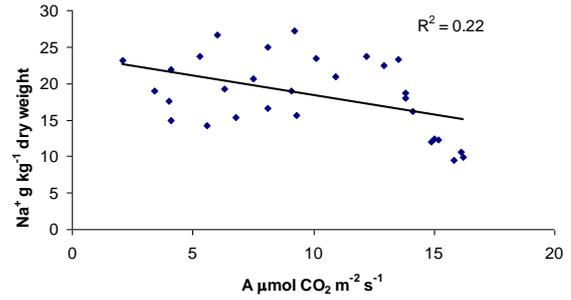


Fig. VII. Relationship between leaf sodium concentration and photosynthesis (A) in two sugar beet cultivars in the presence of short-term salinity; each point is the average of three replications.

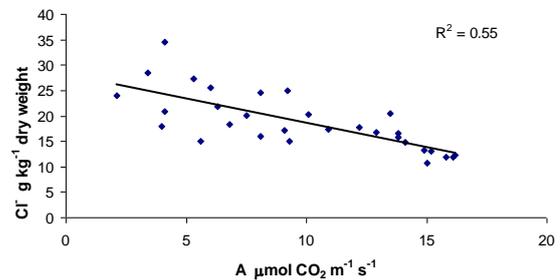


Fig. VIII. Relationship between leaf chlorid concentration and photosynthesis (A) in two sugar beet cultivars in the presence of short-term salinity; each point is the average of three replications.

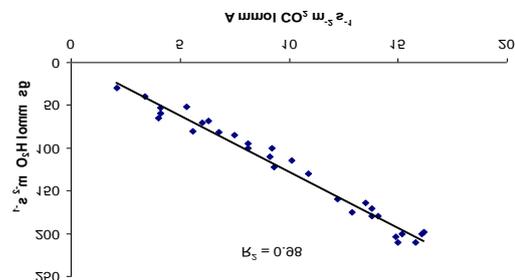


Fig. IX. Relationship between leaf stomatal conductance and photosynthesis (A) in two sugar beet cultivars in the presence of short-term salinity; each point is the average of three replications.

between cultivars in short-term exposure to salinity, cultivar P₂₉ having a lower shoot potassium concentration in all salt treatments. However, the percentage reduction in potassium concentration in Madison and P₂₉ under high salinity 48 h after salinization compared to their control were 20.5% and 17.9%, respectively. These results are in agreement with Heuer and Plaut (1989) and Ghoulam et al. (2002) in sugar beet, Lutts et al. (1996) in rice, and Colmer et al.

(1996) in *Sorghum bicolor*. Based on the opposing changes in leaf K^+ and Na^+ concentration with salinity, it was suggested that the K^+ mobilization was in part the result of exchange of vacuole K^+ for Na^+ .

Not a high correlation was found between photosynthesis and Na^+ concentration ($R^2 = 0.22$) and Cl^- concentration ($R^2 = 0.55$) (Figs. VII and VIII). However, a strong positive linear correlation between photosynthesis and stomatal conductance ($R^2 = 0.98$) indicated that stomatal conductance was the main causes of photosynthesis reduction in short-term salinity (Fig. IX). In other words, it indicates that non-stomatal parameters did not limit the gas exchanged rate. The reduction in stomatal conductance with increasing salinity can be attributed to reduction in water absorption by root due to lower water potential in soil. These observations are in agreement with those of Kafi (2009) who reported that decrease in stomatal conductance was the main factor for limited photosynthesis in wheat plants.

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