CHAPTER EIGHT

Growth and Gas Exchange Response of Sugar Beet (Beta vulgaris L.) Cultivars Grown Under Salt Stress

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Abstract This study investigated intra-specific variation in the growth parameters and photosynthetic rates of individual attached leaves of sugar beet (Beta vulgaris L.) plants during salinisation. Sugar beet plants grown in sand culture were gradually exposed to different levels of salinity. Although growth parameters such as leaf area and dry matter accumulation were stimulated or unaffected at low level of salinity higher salt concentrations significantly decreased all growth traits. Net photosynthesis ($A_{\text{CO}_2}$) was plotted against computed leaf internal CO$_2$ concentration ($C_i$), and the initial slope of this $A_{\text{CO}_2}$-$C_i$ curve was used as a measure of photosynthetic ability. Leaves from plants exposed to 50 mM salinity showed little change in photosynthesis, whereas those treated to high level of salinity had up to 91.5% inhibition, with increase in CO$_2$ compensation point. Leaves appeared healthy and leaf chlorophyll content increased with increasing salinity. Although partial stomatal closure occurred with salinisation, reductions in photosynthesis were partly non-stomatal at high levels of salt treatment. Photosynthetic ability was inversely related to the concentration of either Na$^+$ and Cl$^-$ in the leaf lamina sampled at the end of experimental period.

Keywords Gas exchange, growth, salt stress, sugar beet

Introduction

The basis of decline in growth under saline conditions is poorly understood. Salinity may reduce expansion of young leaves followed by premature desiccation and senescence of the old leaves. The reduction in growth is consequence of several physiological responses including modification of ion balance, water status, mineral nutrition, stomatal behaviour and photosynthetic efficiency (Massimiliano et al. 2002; Dadkhah and Griffiths 2004).

The photosynthetic capacity of plants grown under saline conditions is depressed depending on type of salinity, duration of treatment, species and plant age. This could be due to a failure in osmotic adjustment and improper functioning of stomata thus affecting CO$_2$ diffusion into the mesophyll or due to the non-stomatal factors (Chartzoulakis et al. 2002).
Materials and methods

A pot experiment was designed to investigate the effect of salt stress on growth and gas exchange of four sugar beet (Beta vulgaris) cvs, three of Iranian origin (7233-P13, 7233-P21, and 7233-P29) plus a British cultivar (Madison).

Seeds of sugar beet plants were sown 5 mm deep in 15 cm diameter plastic pots containing washed sand. The growth conditions were 26 ± 1°C/16 ± 1°C (day/night), relative humidity was between 45–55%. PFD was about 250 μmol photon m⁻² s⁻¹ at canopy height with 16-h photoperiod. Five levels of salinity (0, 50, 150, 250, 350 mM NaCl + CaCl₂ in 5:1 molar ratio) were imposed through irrigation from the time most plants were at the four-leaf stage and continued for 8 weeks. Salts were added to the modified Hoagland nutrient solution. Plants were harvested at 8 weeks of salt treatment and were dried for 48 h at 70°C in a conventional oven and weight.

Net photosynthesis (Aₚₑₑ) of the attached youngest fully expanded leaves were measured by a Combined Infra Red Gas Analysis System (CIRAS-1 Portable photosynthesis system) at week 8th. In order to study photosynthetic ability, photosynthetic rates of individual attached leaves were measured at ambient CO₂ concentration and different levels of external CO₂ concentrations ranging from approximately 70–1,500 μmol CO₂ mol⁻¹ air and saturated light intensity (1,500 μmol photon m⁻² s⁻¹).

Extraction of chlorophyll pigments from the finely ground leaf samples was carried out using 80% acetone. The absorbance of optically clear filtrates were measured by using a Beckman spectrophotometer.

Leaf chlorophyll fluorescence measurements were done on youngest fully expanded leaves at week 8th by using the Plant Efficiency Analyser (PEA) (Hansatech, Norfolk, England).

For Na⁺ and K⁺ analysis, the leaves blade that were used for gas-exchange measurement were removed from the plants and were ashed in furnace for 24 h at 500°C. The ashes were dissolved in 50% Hydrochloric acid, diluted in distilled water and filtered through a sheet of Whatman paper. Na⁺ and K⁺ contents were determined by flame photometer (JENWAY, PEP-7).

Chloride (Cl⁻) determinations were made on a distilled water extract of the dried sample, shaken for 24 h and then filtered through a 90 mm Whatman No. 2 filter paper. The amount of Cl⁻ was measured by ion-exchange chromatography using DIONEX Model DX 500, fitted with a CD20 conductivity Detector, IP 25 pump and AS 14 Ion Exchange Column.

This experiment was carried out base on randomized complete block design. The data for all characters were analysed 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 and discussion

All growth characters were significantly decreased by increasing salinity in the nutrient solution. However, the sensitivity of the different characters varied. Total leaf area was reduced by 58.7% (average of four cvs) in plants grown at high level of salinity (350 mM) compared to leaf area of non-stressed plants after 8 weeks of salination. Leaf number per plant significantly decreased as salinity increased in all cvs. However, low level of salt treatment (50 mM) slightly increased the leaf number per plant in all cvs. This increase was not, however statistically significant. The results show that the leaf number was less affected than leaf area by salinity. It suggested that the most of reduction in plant leaf area was caused by the inhibition of leaf expansion. This is consistent with the result of previous research, which showed that high levels of salinity decreased leaf area due to a combination of a decrease in cell number and in cell size (De-Herrald et al. 1998).

Salt stress significantly reduced dry matter production. Shoot dry weight was significantly reduced by salinity. Shoot dry weight at highest salinity (350 mM) was decreased 38% (mean of all cvs) compared to non-stressed plants. Salt stress also had a significant reducing effect on root dry weight. The effect of salinity on root dry weight is greater than shoot dry weight because root dry
weight of all cvs decreased even at lowest level of salt concentration. Root dry weight at low level of salinity was decreased 33.6% compared to root dry weight of non-stressed plants. This might be due to the type of sugar beet root (storage root). Abdollahian-Noghabi (1999) found that shoot/root ratio of Beta vulgaris increased under drought stress condition. A possible reason for dry matter reduction could be the greater reduction in uptake and utilization of mineral nutrients by plants under salt stress (Pessarakli and Tucker 1988).

Figure 1a shows the results for youngest fully expanded leaves of four sugar beet cvs at five levels of salinity. Photosynthesis (A) significantly (P ≤ 0.001) decreased with increasing salt concentration. Plants grown at low and high levels of salinity had rates of 80% and 8.3%, respectively compared with controls.

The adverse effect of salinity on photosynthesis (A) was associated with a significant (P ≤ 0.001) decrease in the stomatal conductance (gₛ) up to 250 mM salinity but no significant differences in gₛ or A were observed between 250 and 350 mM salinity (Fig. 1b).

The ratio of intercellular to ambient CO₂ concentration (Cᵢ/Cᵣ) decreased up to 150 mM salinity compared to controls (data not shown). In spite of decreasing A and gₛ with increasing levels of salinity (Fig. 1a), Cᵢ/Cᵣ ratio not only showed no significant reduction at 250 mM but also increased at 350 mM. Leaf chlorophyll a, chlorophyll b, total chlorophyll content generally increased with increasing salinity (data not shown).

Reduction in A which may be a consequence of non-stomatal inhibition of A by salt has also been observed (Delfine et al. 1998). These alterations in capacity must be the result of either a change in the leaf content of photosynthetic machinery and/or alteration in the efficiency with which this machinery operates.

Total chlorophyll pigment contents in all cvs under saline conditions increased. This increasing in chlorophyll can be due to inverse effect of salinity on specific leaf area (SLA). As SLA is considered a measure of leaf density or thickness (Cramer et al. 1994), leaves of stressed plants became thicker than un-stressed plants, and thicker leaves contain more cells in a certain leaf area. Therefore, as both photosynthesis and chlorophyll concentration are expressed per leaf area, chlorophyll content could not be a limiting factor on photosynthesis in the presence of salinity.

The initial slope of A-Cᵢ curve is a convenient measure of efficiency often defined as the carboxylation efficiency (CE), and greater decreases in CE were observed with increased salinity level (Fig. 2). Changes in carboxylation efficiency with salinisation have been reported previously and may indicate a lower activity of Rubisco, because the initial slope of the A-Cᵢ curve is thought to be controlled mainly by ability of the enzyme to fix CO₂ (von Caemmerer and Farquhar 1986). Another limiting factor could be RuBP regeneration which could limit electron capture and transport for quinone reduction (Long and Hällgren 1993).
The fluorescence data suggested that the rate of energy translocation or light capture might be limited by salinity (Long and Hallgren 1993). In this study although there were significant differences in $F_{m}/F_{n}$ in different salt treatments, values of $F_{v}/F_{m}$ were relatively high for both control and salt stress treatments (0.80–0.91). Similar values of $F_{v}/F_{m}$ were found by Kafi (1996) for wheat grown in the presence of salinity.

In this experiment $C_{i}/C_{a}$ ratio decreased up to 150mM salinity. However, at 250 and 350mM despite reduction in $A$ and $g_{s}$ the $C_{i}/C_{a}$ ratio actually increased. It is likely that the increased intercellular CO$_2$ concentration ($C_{i}$) was mainly associated with the decreased CO$_2$ fixation of mesophyll cells due to the decreased CO$_2$ assimilation capacity or because of increasing CO$_2$ concentration from increasing respiration relative to photosynthesis (Lu and Zhang 1998).

References


