



Full Length Article

Effect of Salinity on Growth, Mineral Composition, Photosynthesis and Water Relations of Two Vegetable Crops; New Zealand Spinach (*Tetragonia tetragonioides*) and Water Spinach (*Ipomoea aquatica*)

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ABSTRACT

New Zealand spinach (*Tetragonia tetragonioides* L.) is widely cultivated throughout the world for use as a vegetable, ground cover and medicinal plant; however its salt tolerance has not been clarified. This study examined the difference in the salt tolerance mechanisms between New Zealand spinach and water spinach (*Ipomoea aquatica* L.). Both plants were exposed to salt stress by daily irrigation with 0, 50, 100 and 200 mM NaCl solution for 14 days. The growth of water spinach was markedly and gradually reduced with increasing salinity, whereas that of New Zealand spinach was increased with elevating salinity, indicating that New Zealand spinach is halophilic. The leaf water potential (LWP) and osmotic potential (OP) were also gradually decreased with increasing salinity; the reduction of the LWP and OP was higher in New Zealand spinach than water spinach. New Zealand spinach accumulated more Na⁺ ions in the leaves. The photosynthetic rate (Pn) and transpiration rates (Tr) of both species decreased with increasing salinity, but both the Pn and Tr in New Zealand spinach were maintained at a higher level than in water spinach. © 2010 Friends Science Publishers

Key Words: Ion accumulation; *Ipomoea aquatica*; Photosynthesis; Salinity; *Tetragonia tetragonioides*

Abbreviations: Leaf water potential=LWP; Intercellular CO₂ concentration=Ci; Osmotic potential=OP; Photosynthetic rate=Pn; Stomatal conductance=gs; Transpiration rates=Tr

INTRODUCTION

Salinity is one of the major environmental factors that leads to a deterioration of agricultural land and reduction in crop productivity worldwide (Munns, 2002; Viswanathan *et al.*, 2005). The ability of vegetation to survive under higher salinity conditions is important for the distribution of plants and agriculture around the world. Enhancing the salt tolerance of plants is an important breeding objective in areas, which are affected by soil salinity (Flowers & Flowers, 2005).

A plant's ability to acclimate to salt stress includes alterations at the leaf level, associated with morphological, physiological and biochemical characteristics whereby many plants adjust to high salinity and the consequent low soil water availability (Munns, 2002; Ashraf, 2004). One of the major effects of salt stress in plants is induced nutritional disorders; these disorders may result from the effect of salinity on nutrient availability, competitive uptake and transport or partitioning within the plant (Grattan & Grieve, 1999; Bartels & Sunkar, 2005; Munns & Tester, 2008).

Under saline conditions, halophytic plants tend to take up and accumulate Na⁺ in their vacuoles and use it as an osmoticum (Glenn & Brown, 1999); however non-halophytic monocotyledons tend to exclude Na⁺ to maintain a high K⁺/Na⁺ ratio, which seems to be crucial for salt tolerance (Greenway & Munns, 1980; Grattan & Grieve, 1999). Salt stress also induces a decrease in stomatal conductance and transpiration. Under saline conditions, stomatal closure helps to maintain a higher leaf water content; however this leads to a decrease in the leaf CO₂ assimilation rate (Maggio *et al.*, 2000; Parida *et al.*, 2004). On the other hand, Azooz *et al.* (2009) indicated that salinity tolerance in maize (*Zea mays* L.) plants is related to the lipid peroxidation and antioxidant enzyme activity in the leaves. Moreover salt stress induced chlorosis and necrosis of mung bean (*Vigna radiata* L.) leaves due to decreased chlorophyll and mineral nutrient deficiency by salinity (Wahid *et al.*, 2004).

Osmotic adjustment is recognized as an important adaptive mechanism for poor water availability as it helps maintain growth in many plants (Flower *et al.*, 1990;

Morgan, 1995). It involves the regulation of the intracellular levels of organic compounds, many of which are compartmentalized principally in the cytoplasm, whereas inorganic ions are sequestered in the vacuole (Matoh *et al.*, 1987). Under saline conditions, the osmotic adjustment, which occurs through the accumulation of inorganic compounds (mainly Na^+ & Cl^-) in plants is less energy- and carbon-demanding than adjustment by organic solutes (Greenway & Munns, 1983).

New Zealand spinach (*Tetragonia tetragonioides* (Pall.) O. Kuntze) is a member of Tetragoniaceae and is distributed widely from tropical and subtropical to temperate areas (Wilson *et al.*, 2000). This plant is used as a vegetable, ground-cover cum ornamental and medicinal sources (Kato *et al.*, 1985). Water spinach (*Ipomoea aquatica* L.) is a member of Convolvulaceae and is distributed in humid areas from subtropical to temperate zones and is used as a green vegetable, food for livestock and is useful for the sequestration of environmental pollutants (Harwood & Sytsma, 2003; Yao *et al.*, 2009). However, to the best of our knowledge, the physiological responses to salt tolerance of both vegetable crops have not been reported. The objectives of the present study were to assess the influence of salt stress on the absorbance of inorganic ions, photosynthesis and water relations in both plants and compare and discuss the physiological responses and adaptive strategies to salt stress.

MATERIALS AND METHODS

Plant material and culture conditions: This experiment was conducted at the Graduate School of Biosphere Science, Hiroshima University, Higashi-Hiroshima, Japan, from April to June, 2008. Seeds of New Zealand spinach (*Tetragonia tetragonioides* L.) and water spinach (*Ipomoea aquatica* L.) were germinated in seedbeds with a soil mixture containing granite regosol soil, perlite and peat moss (2:1:1 v/v/v). Pots were kept under greenhouse conditions. Plants were irrigated with nutrient solution at each watering using an irrigation system. The basal nutrient solution contained 8.3 mM $\text{NO}_3\text{-N}$, 0.8 mM $\text{NH}_4\text{-N}$, 0.5 mM P_2O_5 , 2.2 mM K_2O , 0.7 mM MgO , 2.1 mM CaO , 11 μM MnO , 5 μM B_2O_3 and 13 μM Fe . At six weeks after transplanting, the plants were subjected to three levels of salinity treatment through irrigation with a nutrient solution containing 0, 50, 100 and 200 mM NaCl twice (at 10:00 a.m. & 15:00 p.m.) every day until water drained from the bottom of the pot. Each treatment was applied to three replicates located randomly in the greenhouse in order to avoid positional effects. Three plants per treatment were collected for analysis at two weeks after salinity treatment.

Measurement of growth: At 2 weeks after treatments, three plants were harvested and each was separated into the leaves, stems and roots. Plant parts were washed gently with tap water for a few minutes, wiped with paper and their fresh weight was measured. The fresh samples were kept

frozen in liquid nitrogen, then freeze-dried and the dry weight was measured. Dry samples were ground into fine powder using a vibrating sample mill (Model T1-100, Heiko Co., Ltd., Japan) for chemical analysis.

Measurement of leaf water potential, osmotic potential and photosynthetic rate: The leaf water potential was measured according to the method described by Saneoka *et al.* (1995), using the uppermost fully expanded leaf employing a pressure chamber (Daiki-Rika Instruments, Tokyo, Japan) at 21 days after the initiation of the salt treatment. After the water potential was measured, the leaves were frozen in liquid nitrogen and thawed, centrifuged at 1,000 g for 10 min to extract cell sap and the osmotic potential of the sap was measured using a Wescor 5500 vapor pressure osmometer (Wescor Inc., Logan, UT). The photosynthetic rate was simultaneously measured for the attached and uppermost fully expanded leaves using a portable open gas exchange system (Li6400, Li-Cor, Lincoln, Nebraska). The photosynthetic photon flux density was maintained at 1,500 $\mu\text{mol m}^{-2} \text{s}^{-1}$ and the relative humidity was 60%. The temperature of the leaf was 25°C and the ambient CO_2 concentration was 370 $\mu\text{mol mol}^{-1}$, while measurements were taken.

Measurement of mineral concentrations: After the measurement of leaf water potential, the other half of the same leaf samples were frozen in liquid nitrogen, freeze dried and ground into a fine powder using a vibratory mill and passed through a 1 mm mesh. The Na^+ and K^+ concentrations were determined after digestion by nitric acid–hydrogen peroxide, using a flame photometer (ANA 135, Eiko Instruments Inc., Tokyo). The Ca^{2+} and Mg^{2+} concentrations were determined using an inductively coupled argon plasma method (ICAP-575, Nippon Jarrel Ash, Kyoto, Japan). The total N concentration was determined by the Kjeldahl method after digestion with sulfuric acid.

Statistical analysis: Data (n=3) were examined by one-way ANOVA analysis of variance. Multiple comparisons of means of data between different salinity treatments within the plants were performed using Duncan's test at the 0.05 significance level (all tests were performed with SPSS Version 16.0 for Windows).

RESULTS

The dry weight of roots of New Zealand spinach increased at low salt level (50 mM) and then decreased with increasing salinity; however the dry weights of leaves and roots of this plant were still higher on 100 and 200 mM treatment compared to the control (Fig. 1). The dry weight of stems of New Zealand spinach was not affected by the salinity. That of leaves, stems, and roots of water spinach was markedly decreased ($p < 0.05$) with increased salinity.

The LWP of both species was decreased ($p < 0.05$) with increasing salinity. However New Zealand spinach exhibited a lower LWP than water spinach under each

treatment (Table I). The OP also decreased with increasing salinity and the OP of New Zealand spinach was lower than that of water spinach.

Both species accumulated Na^+ ($P<0.05$) with increasing salinity in all plant tissues (leaves, stems & roots), except that the Na^+ concentration in the leaves of New Zealand spinach was reduced ($P<0.05$) on 200 mM NaCl treatment (Table II). The concentration of Na^+ in leaves of New Zealand spinach was higher than that of water spinach, but the concentration of Na^+ in the stems and roots of water spinach was higher than that of New Zealand spinach.

The uptake of Na^+ by both species rose with increasing salinity (Fig. 2). The uptake of Na^+ by New Zealand spinach was twice that of water spinach on 50 and 100 mM NaCl treatment and 1.5 fold at 200 mM NaCl. The percentage distribution of Na^+ in the leaves of New Zealand spinach was 81 and 90% of the control on 50 and 100 mM NaCl treatment, respectively and 70% on 200 mM NaCl treatment. In the leaves of water spinach it was 43 and 58% of control on 50 and 100 mM NaCl treatment, respectively.

The K^+ concentration in the leaves of both species was markedly decreased with increasing salinity ($P<0.05$) (Table III). The Na^+/K^+ ratios of leaves of both species rose with increasing salinity. The Na^+/K^+ ratio in the leaves of New Zealand spinach was slightly higher than that of water spinach. The Ca^{2+} and Mg^{2+} concentrations in the leaves of New Zealand spinach were markedly decreased with increasing salinity. These elements in the leaves of water spinach were slightly increased, but there was no difference between treatments (Table III).

The uptake of N by New Zealand spinach on 50 mM treatment was increased compared to the control and that on 100 and 200 mM NaCl treatment was not altered compared to the control (Fig. 3). The uptake of N by water spinach was markedly decreased on 50 mM NaCl treatment. The uptake of N by New Zealand spinach was higher than that of water spinach for all treatments.

Salinity levels strongly influenced leaf gas exchange (Table IV). The Pn, gs, Ci and Tr of both species decreased ($p<0.05$) with increasing salinity, but the reduction of these parameters was lower in New Zealand spinach compared to water spinach. The Tr of both species also decreased with increasing salinity; however the Tr of New Zealand spinach was higher than that of water spinach for all treatments.

DISCUSSION

In the present study, the two plant species, New Zealand spinach and water spinach, were exposed to salt stress by increasing the NaCl concentration (0, 50, 100 & 200 mM NaCl) of irrigation water. When the salinity increased, the plant dry weight of water spinach markedly decreased; however the growth of New Zealand spinach increased under salt conditions (Fig. 1). The dry weight of New Zealand spinach increased 1.7, 1.4 and 1.3 times on 50, 100 and 200 mM NaCl treatment, respectively compared

Table I: Effect of salt stress on the leaf water potential (LWP) and osmotic potential (OP) of New Zealand spinach and water spinach, the same letter on each line indicates no significantly difference ($p<0.05$)

Crops/ Characters	Treatment (NaCl mM)			
	0	50	100	200
MPa				
New Zealand spinach				
LWP	-0.65±0.01a	-1.35±0.06b	-2.20±0.15c	-2.50±0.06b
OP	-1.01±0.03d	-1.87±0.06c	-2.76±0.03a	-2.61±0.003b
Water spinach				
LWP	-0.23±0.02b	-0.30±0.03b	-1.60±0.06a	-1.70±0.06a
OP	-0.94±0.006c	-0.84±0.02c	-1.88±0.003b	-1.99±0.057a

Table II: Effect of salt treatment on the Na concentration of the leaves, stems, and roots of New Zealand spinach and water spinach, the same letter on each line indicates no significantly difference ($p<0.05$)

Crops/ Parts	Treatment (NaCl mM)			
	0	50	100	200
mg/g DW				
New Zealand spinach				
Roots	1.51±0.07d	4.2±0.19c	6.07±0.30b	12.96±0.78a
Stems	11.71±0.49b	28.72±1.65a	34.24±4.72a	33.61±1.03a
Leaves	29.69±1.62d	69.84±0.69c	94.95±2.24a	76.42±1.55b
Water spinach				
Roots	1.37±0.82d	15.78±1.30b	10.74±1.31c	24.99±1.49a
Stems	3.69±0.29c	3.61±0.01c	51.98±2.60b	63.5±0.17a2
Leaves	9.49±0.14c	22.5±0.07b	62.77±0.21a	64.31±2.23a

with the control. Generally the growth of glycophytes decreases with increasing salinity, while that of halophytes improves. In the present study, the growth of New Zealand spinach increased under salt stress, agreeing with previous data reported on the halophytes *Salicornia europaea* and *Suaeda maritima* (Moghaieb *et al.*, 2004) and *Alhagi pseudoalhagi* (Kurban *et al.*, 1999), in which salt treatment at low levels improved plant growth. These results indicated that New Zealand spinach is a halophyte and so the salt tolerance of this plant was higher than that of water spinach.

Table I shows that the leaf water potential and osmotic potentials of New Zealand spinach were lower than those of water spinach under salt stress. From the results of these parameters, New Zealand spinach could be absorbing more water from the saline soil compared to water spinach. In fact, in the present study, the water content of New Zealand spinach was 74, 73 and 64% of 50, 100 and 200 mM NaCl treatment, respectively however in water spinach, the water content was markedly decreased by salt treatment, being 63, 56 and 44% on 50, 100 and 200 mM NaCl treatment, respectively.

In the present study, the Na^+ concentration of leaves of New Zealand spinach was higher than that of water spinach at all salt treatments (Table II). In New Zealand spinach, 80% of Na^+ uptake up was distributed to the leaves (Fig. 2). The marked decline in the osmotic potential of New

Table III: Effect of salt treatment on K⁺, Ca²⁺, Mg²⁺ and the Na⁺/K⁺ ratio of the leaves in New Zealand spinach and water spinach, the same letter on each line indicates no significantly difference (p<0.05)

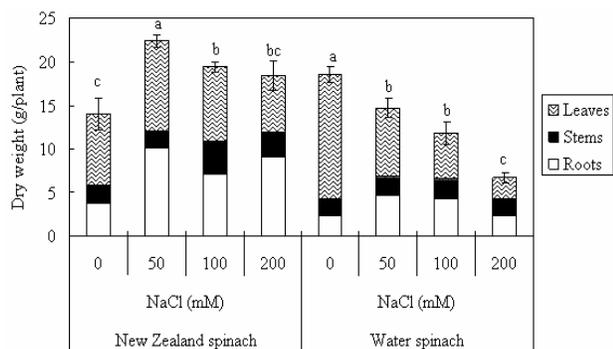
Contents (mg/g dry weight)		Treatment (NaCl mM)			
		0	50	100	200
K ⁺	New Zealand spinach	83.41±4.88a	44.55±1.68b	33.35±1.39c	26.90±0.67c
	Water spinach	66.54±6.21a	35.95±10.58b	31.18±7.66b	30.62±3.01b
Ca ²⁺	New Zealand spinach	10.91±1.40a	4.93±0.36b	4.39±0.51b	3.15±0.94b
	Water spinach	11.31±1.14a	14.9±2.31a	14.27±1.04a	16.87±1.69a
Mg ²⁺	New Zealand spinach	6.95±0.62a	2.48±0.18b	3.23±0.13b	2.90±0.28b
	Water spinach	2.72±0.09a	3.11±0.43a	2.77±0.27a	3.52±0.12a
Na ⁺ /K ⁺ ratio	New Zealand spinach	0.35	1.57	2.85	2.84
	Water spinach	0.14	1.63	2.01	2.10

Zealand spinach was mainly due to a large accumulation of

Table IV: Effect of salt treatment on the photosynthetic rate (Pn), stomatal conductance (gs), intercellular CO₂ concentration (Ci) and transpiration rate (Tr) on New Zealand spinach and water spinach., the same letter on each line indicates no significantly difference (p<0.05)

Treatment (NaCl mM)	Pn μmol CO ₂ /m ² /s	gs mol H ₂ O/m ² /s	Ci μmol CO ₂	Tr mol H ₂ O/m ² /s
New Zealand spinach				
0	22.5±0.8a	1.3±0.2a	2.9±1.5a	6.6±0.3a
50	16.9±1.7a,b	0.4±0.1b	2.5±0.1b	2.6±0.2b
100	15.7±1.4b	0.2±0.03b	2.3±0.3c	1.8±0.1c
200	8.7±2.7c	0.1±0.03b	2.1±0.9d	1.1±0.3c
Water spinach				
0	21.0±0.2a	0.6±0.1a	2.8±2.1a	3.3±0.2a
50	11.9±0.7b	0.1±0.02b	1.9±1.9c	1.4±0.2b
100	10.7±0.2b	0.08±0.04b	1.7±2.4d	0.9±0.4b
200	0	0	0	0

Fig. 1: Effect of salt treatment on the dry weight of the leaves, stems and roots of New Zealand spinach and water spinach, Values represent means ± SE. Bars with different letters significantly differed at P<0.05



Na⁺ ions in the leaves, as observed in many reports, whereby halophytic plants accumulate and compartmentalize large amounts of Na⁺ in vacuoles to lower the osmotic potential (Cheeseman, 1988; Munns, 2002; Ashraf, 2004; Song *et al.*, 2009).

The relationship between the salinity and mineral nutrition of plants is extremely complex. Plant growth

adversely affected by salinity induces nutritional disorders,

Fig. 2: Effect of salt treatment on Na accumulation in the leaves, stems and roots of New Zealand spinach and water spinach, Values represent means ± S.E. Bars with different letters significantly differed at P<0.05

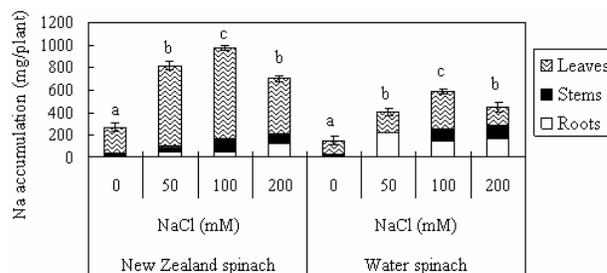
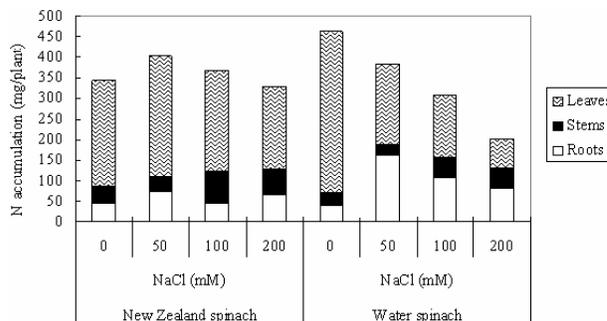


Fig. 3: Effect of salt treatment on N accumulation in the leaves, stems and roots in New Zealand spinach and water spinach



which may result from the effect of salinity on nutrient availability, competitive uptake, transport, or partitioning within plant organs (Greenway & Munns, 1980). In the present study, salt stress reduced K⁺ uptake and the Na⁺/K⁺ ratio increased and K⁺ concentration decreased significantly (Table III). Compared with water spinach, the Na⁺/K⁺ ratio in Na⁺/K⁺ ratios reportedly increased under salt stress in many halophytic plants (Moghaieb *et al.*, 2004; Yang *et al.*, 2007). The Ca²⁺ and Mg²⁺ concentrations in leaves of New Zealand spinach decreased on salt treatment; however, both elements in leaves of water spinach were not changed by

salinity (Table III). The increase of Na^+ accumulation in New Zealand spinach was associated with reduced K^+ , Mg^{2+} and Ca^{2+} , indicating a restriction in the uptake of these nutrients, as noted in other halophytic plants (Maggio *et al.*, 2000; Debez *et al.*, 2004).

Nitrogen is an essential nutrient element in the biosynthesis of nitrogenous organic solutes in plants. Salt stress reduces N uptake in many plants and this is attributed to antagonism between NO_3^- and Cl^- (Gouia *et al.*, 1994; Parida & Das, 2004). In the present study, the N uptake of New Zealand spinach was increased on 50 mM NaCl treatment and was un-changed on 100 and 200 mM NaCl treatment relative to the control (Fig. 3). On the other hand, N uptake of water spinach was markedly decreased in the presence of salt stress. Also in New Zealand spinach, the N partitioning rate from the roots and stems to the leaves was 60 to 70%; however that of water spinach was 30 to 50%. Nitrogen is the mineral element that plants require in the largest amounts and is a constituent of many plant cell components, including amino and nucleic acids; therefore nitrogen deficiency rapidly inhibits plant growth (Hu & Schmidhalter, 2005). The results of the present study suggested that New Zealand spinach showed more active N uptake under saline conditions.

In response to salt stress, the Pn of both species was decreased (Table IV). The reduction of the Pn was lower in New Zealand spinach compared to water spinach on 50 and 100 mM NaCl treatment. The Pn of water spinach was $0 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ S}^{-1}$, but that of New Zealand spinach was un-changed on 200 mM NaCl treatment. Along with the decreasing Pn, the gs and Ci were decreased with increasing salinity. In both species, gs reduction was marked compared to that of the Ci. These parameters suggest that stomatal closure limited the leaf photosynthetic capacity under saline conditions. On the other hand, the Tr of both species decreased with increasing salinity and the Tr reduction was high in water spinach relative to that of New Zealand spinach. New Zealand spinach still maintained transpiration under marked saline conditions. Based on the results obtained, it is assumed that New Zealand spinach maintained open stomata under saline conditions, which increased transpiration. Consequently water transpiration through the stomata stimulated the translocation of water through the xylem from the roots. This water flow appeared to be regulated mainly by stomatal opening, and might promote the translocation of Na^+ and N from the roots to shoots.

In conclusion, the growth of New Zealand spinach was promoted under saline conditions but that of water spinach was markedly decreased, indicating that New Zealand spinach is halophytic. The main strategy of salt tolerance in New Zealand spinach seems to be increased of osmotic adjustment through the accumulation of Na^+ in leaves and the marinating of a higher capacity for water uptake and water supply to the leaves.

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