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Research Article
Ability of *Sesuvium portulacastrum* to Accumulate Sodium and Potassium from Saline Media

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Abstract

Background and Objective: The shoot succulent halophyte *Sesuvium portulacastrum* was previously shown to take up sodium (Na^+) from the soil and accumulate it within its shoot tissues and was therefore chosen as a good plant for the phytodesalination of saline-sodic soils. The present investigation aimed to evaluate the ability of this halophyte to take up sodium and potassium (K^+) from a saline medium and to check therefore its possible use in the phytodesalination of saline waters such as reject brines. **Materials and Methods:** Plants were hydroponically grown for one month in the presence of 200 mM NaCl, KCl or Na_2SO_4. At the harvest, leaves, stems and roots were weighed fresh and oven-dried then analyzed for K^+ and Na^+ contents. A One-Way-ANOVA test was used for data analysis. **Results:** *Sesuvium portulacastrum* showed a high tolerance to the three salts in terms of biomass production and water content. Plants accumulated high Na^+ and K^+ quantities, Na^+ being more accumulated. **Conclusion:** The accumulated K^+ quantities allow this halophyte to be used in the phytodesalination of saline waters such as reject brines

Key words: Halophyte, salt distribution, threshold, phytodesalination, reject brine

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Soil salinity is one of the major global threats, it affects about 20% of the irrigated land worldwide and is responsible for the reduction of several crop yields[1], through harmful effects on all plant growth and development stages[2]. These effects can be divided into three main components: Water stress (osmotic effect), cytotoxicity due to the accumulation of saline ions at toxic levels in plant tissues (toxic effect) and nutritional imbalance due to the antagonistic effects of Na^+ for example on other cations and those of the Cl^- on other anions (nutritional effect). A fourth effect (oxidative effect) is often described and is induced by the three previous ones via the overproduction of Reactive Oxygen Species (ROS)[3].

Plant responses to salt stress are complex[4,5] and can be classified into two major strategies: Ion exclusion based on the reduction of toxic ion accumulation in shoots using several mechanisms and tissue tolerance based on the management of the absorbed toxic ions through their compartmentalization at all levels from the whole plant to cell level[6]. According to their ability to tolerate high salinity levels, plants were classified into halophytes (plants native to saline environments) and glycophytes (plants native to non-saline environments) although no real limit was established between them. If one considers that[7], halophytes are plants able to complete their life cycle from grain to grain at a salinity of 200 mM NaCl or higher and represent 1-2 of the world flora.

In the last decades, halophytes have been attracting more and more researchers for their cultivation on salt-affected soils for several purposes such as human food, forages and animal feeds, oilseeds and protein crops, energy crops (biofuels and fuelwood), medicinal plants and other commercial products as well as phytoremediation[8,9]. The latter use of halophytes includes a variety of pollutants but also salts[10]. Several plants were evaluated for their phytodesalination potential and showed that this technique may be a cheap solution to reduce soil salinity/sodicity in arid and semi-arid regions[11-13].

Sesuvium portulacastrum L. (Aizoaceae) showed promising results when tested for the phytodesalination of salt-affected soils due to its fast growth rate and its ability to accumulate high Na^+ amounts within its shoots if Na^+ and Cl^- are the dominant ions[11-13]. The present investigation aimed to check whether this halophyte can accumulate K^+ (another cation) and accumulate Na^+ when present as Na_2SO_4 (a dominant anion other than Cl^-).

MATERIALS AND METHODS

Study area: This study was carried out in a growth chamber in Qassim University, College of Agriculture and Veterinary Medicine, Department of Plant Production and Protection from the 2nd September, 2020 to the 25th October, 2020.

Plant culture conditions and harvest: Plants used in this study were obtained from cuttings taken from mother plants cultivated under non-saline conditions. After rooting in pots filled with distilled water, obtained seedlings were hydroponically grown in a growth chamber under controlled conditions: A day/night temperature regime of 22/25°C, a light intensity of 250 µmol photons m^{-2} sec^{-1} and photoperiod of 14 hrs. Seedlings were pretreated with a diluted nutrient solution[14] for 14 days then obtained plants were subjected to 4 different treatments (7 plants per treatment). Plants were either grown on a control nutrient medium or subjected to 200 mM salt (NaCl, KCl or Na_2SO_4). On the 30th day of treatment, plants were harvested and cut into leaves, stems and roots then weighed fresh and after oven-drying for 1 week.

Mineral analysis: Dried samples were ground to a fine powder then aliquots of 25 mg were used for mineral analysis. Extraction was carried out with HNO_3 0.5% for three days and Na^+ and K^+ concentrations in the extracts were determined by a Corning 480 flame photometer (Corning Medical and Scientific Ltd., Halstead, Essex, England).

Calculated parameters:

- Water content in plant organs was calculated using Fresh Weight (FW) and Dry Weight (DW) as follows:

$$WC\ (\%) = \frac{FW - DW}{FW} \times 100$$

- K^+ and Na^+ quantities per plant were determined by multiplying their concentrations (mmol g^{-1} DW) in each organ by the DW of that organ then adding the quantities in all organs (leaves, stems and roots)

Statistical analysis: Data (means of 7 replicates) were subjected to One-Way ANOVA by SPSS 16.0 using Duncan's multiple range test at 5%.

RESULTS

Plant growth: Control plants showed biomasses of 18.6 g FW in leaves in Fig. 1a, 8.4 g FW in stems in Fig. 1b and 4.2 g FW in roots in Fig. 1c, which means a whole plant biomass 31.2 g

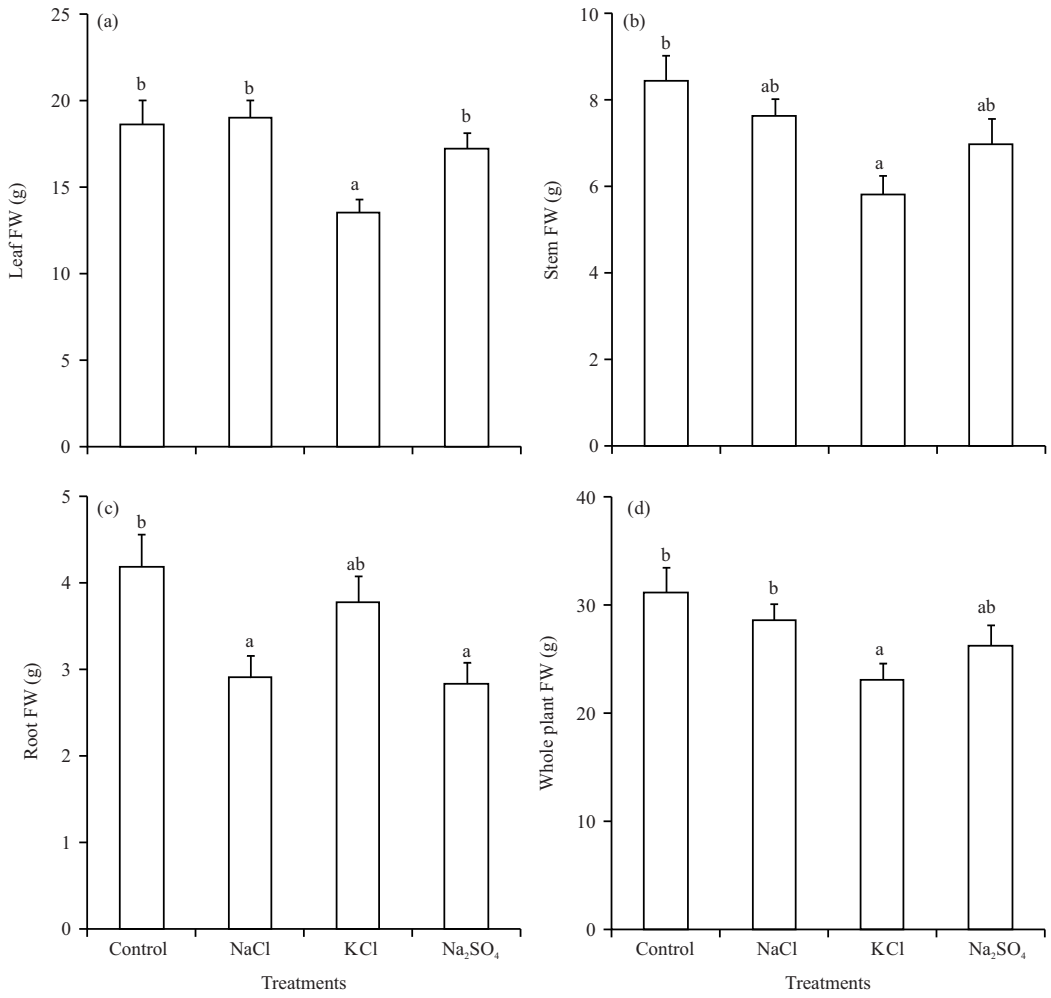

Fig. 1(a-d): Fresh weights (FW) of *S. portulacastrum* plants grown for 30 days under control conditions, (a) Leaf fresh weights (FW), (b) Stem fresh weights (FW), (c) Root fresh weights (FW) and (d) Whole plant fresh weights (FW)
Different alphabetical letters exhibit a different significant level

Table 1: Leaf, stem and root water contents in *S. portulacastrum* plants grown for 30 days under control conditions or subjected to 200 mM salt (NaCl, KCl or Na_2SO_4)

Plant parts (%)	Control	NaCl	KCl	Na_2SO_4
Leaf water content	93.5[b]	93.2[b]	92.3[a]	91.9[a]
Stem water content	89.0[a]	88.1[a]	87.9[a]	88.9[a]
Root water content	93.1[ab]	91.7[a]	94.1[b]	91.4[a]

Different alphabetical letters exhibit different significant level

FW in Fig. 1d with. The application of NaCl and Na_2SO_4 showed no significant effect on the whole plant FW (Fig. 1d) although it reduced root growth from 4.2 g FW to 2.8 g FW (Fig. 1c). KCl treatment, however, did not significantly affect root growth (Fig. 1c) whereas it decreased leaf growth from 18.6 g FW to 13.5 g FW, stem growth from 8.4 g FW to 5.8 g FW and whole plant growth from 31.2-23.0 g FW (Fig. 1a, b and d).

Water content: As a succulent halophyte, *S. portulacastrum* exhibited high water contents in all organs under control conditions varying from 89.0-93.5% in Table 1. As a whole, tissue hydration was maintained unchanged under saline conditions except for a slight decrease in leaf water content in KCl and Na_2SO_4 treatments and a slight increase in root water content in KCl treatment.

Potassium concentration, quantity and distribution: NaCl treatment did not affect potassium status in all plant organs, while Na_2SO_4 decreased K^+ concentrations in leaves from 2.12-1.48 mmol K^+ g^{-1} DW and in roots

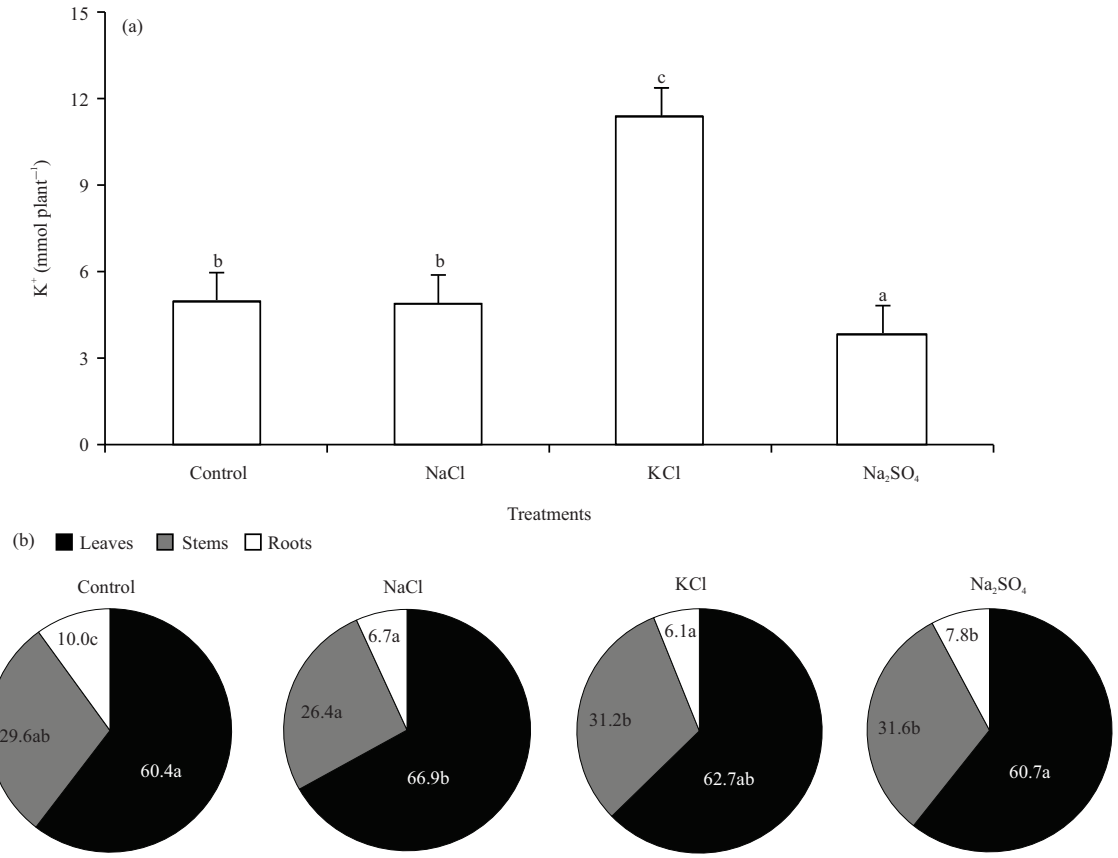

Fig. 2(a-b): K^+ accumulation and distribution within *S. portulacastrum* plants grown for 30 days under control conditions, (a) K^+ quantity in the whole plant and (b) Percentage of K^+ accumulated in each organ
Different alphabetical letters exhibit different significant level

Table 2: Leaf, stem and root K^+ and Na^+ concentrations (mmol g^{-1} DW) in *S. portulacastrum* plants grown for 30 days under control conditions or subjected to 200 mM salt (NaCl, KCl or Na_2SO_4)

Concentration	Control	NaCl	KCl	Na_2SO_4
Leaf K^+	2.12^b	2.46^b	5.60^c	1.48^a
Stem K^+	1.41^a	1.47^a	4.93^b	1.27^a
Root K^+	1.62^b	1.41^b	3.22^c	1.19^a
Leaf Na^+	3.64^a	10.42^d	6.27^b	9.17^c
Stem Na^+	3.13^a	3.72^b	3.49^{ab}	4.70^c
Root Na^+	2.98^a	5.33^c	4.23^b	4.07^b

Different alphabetical letters exhibit a different significant level

from 1.62 to 1.19 mmol K^+ g^{-1} DW in Table 2. In KCl treatment, leaves showed the highest K^+ concentration (5.6 mmol K^+ g^{-1} DW), followed by stems (4.9 mmol K^+ g^{-1} DW) then roots (3.2 mmol K^+ g^{-1} DW). Taking into account biomass production, KCl-treated plants accumulated 11.4 mmol K^+ $plant^{-1}$ (ca. 443 mg K^+ $plant^{-1}$) in Fig. 2a. In control plants, K^+ distribution was as follows: 60.4% in leaves, 29.6% in stems and 10% in roots in Fig. 2b. A slight decrease in root K^+ accumulation was recorded in all salt treatments while a 10% increase was detected in leaf K^+ accumulation in NaCl treatment.

Sodium concentration, quantity and distribution: Na^+ concentrations increased in all organs under saline conditions except in stems of KCl-treated plants, the highest concentration was found in leaves of NaCl-treated plants followed by those of Na_2SO_4-treated plants (Table 2). The accumulated Na^+ quantities reached 19.8 mmol Na^+ $plant^{-1}$ (456 mg Na^+ $plant^{-1}$) in Na_2SO_4 treatment and 18.4 mmol Na^+ $plant^{-1}$ (422 mg Na^+ $plant^{-1}$) in Na_2SO_4 treatment in Fig. 3a. Under non saline conditions, only 55.8% of the absorbed Na^+ was accumulated in leaves in Fig. 3b. However, under saline conditions, a preferential Na^+ allocation towards leaves was observed.

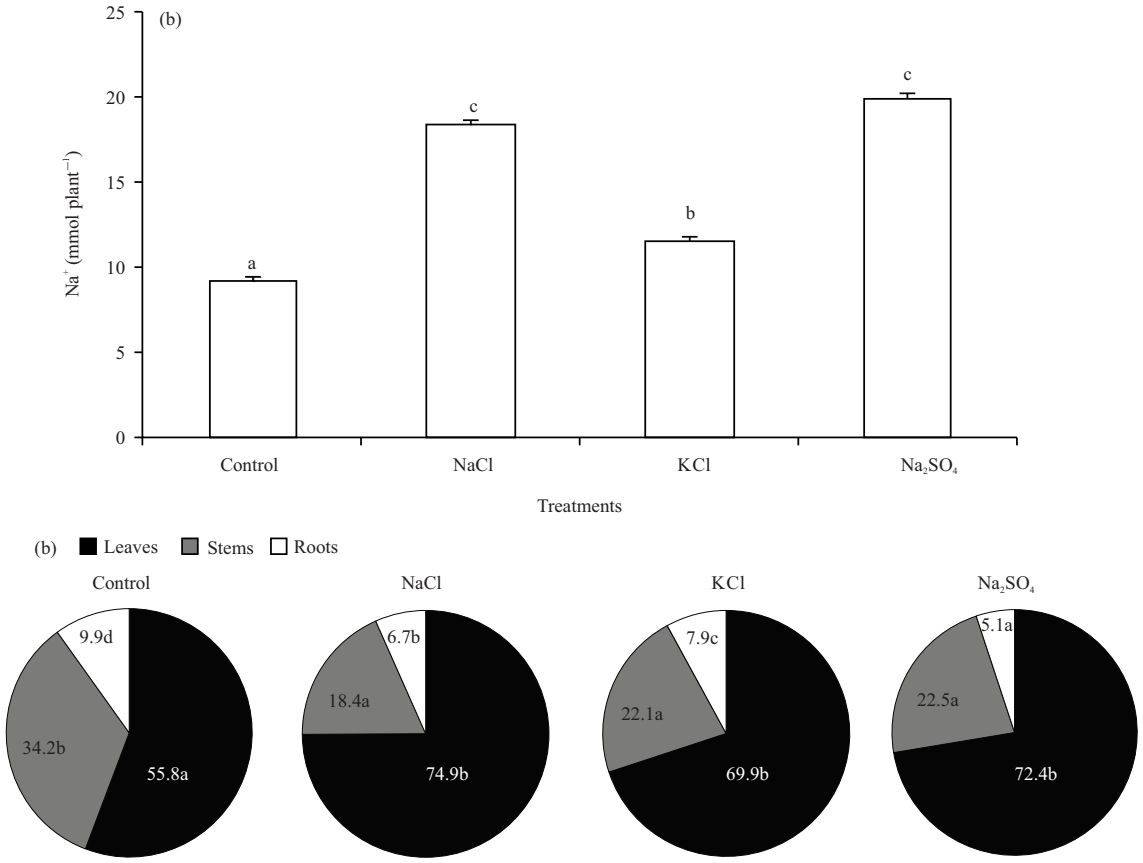

Fig. 3(a-b): Na^+ accumulation and distribution within *S. portulacastrum* plants grown for 30 days under control conditions, (a) Na^+ quantity in the whole plant and (b) Percentage of Na^+ accumulated in each organ

Different alphabetical letters exhibit a different significant level

DISCUSSION

KCl treatment showed the only significant effect on whole plant FW of *S. portulacastrum*. This suggests that this halophyte is more tolerant to sodium than potassium salts, in particular when the KCl effect (200 mM K^+) is compared to that of Na_2SO_4 (400 mM Na^+). Current results are not following previous findings[15] who found that both 200 mM KCl and Na_2SO_4 significantly reduced whole plant biomass in the halophytic grass *Aeluropus littoralis*, Na_2SO_4 effect being more pronounced. In *Brassica rapa*, sulphate salts (50 mM Na_2SO_4 and 50 mM K_2SO_4) exhibited more pronounced effects as compared to those of chloride salts (100 mM NaCl and 100 mM KCl), the effect of Na_2SO_4 being the most detrimental[16]. By contrast, it was shown in four forage species (*Agropyron* sp., *Lolium perenne, Eleusine coracana* and *Chloris gayana*) that at 27 dS m^{-1}, sodium salts (NaCl and Na_2SO_4) were more detrimental to plant growth than those of potassium salts (KCl and K_2SO_4)[17]. Considering the responses of the above-mentioned plant species to different salts, it seems that there is no clear conclusion to draw about plant growth responses to different salts, differences exist within halophytes as well as within glycophytes.

Considering the responses of each organ apart, we noticed that potassium salt-affected leaf and stem growth in *S. portulacastrum*, whereas sodium salts affected root growth. In *A. littoralis*, the most affected organs were stems especially under 200 mM Na_2SO_4 while leaves and roots were not affected by all salt types except roots of Na_2SO_4-treated plants[15]. In the halophyte *Prosopis strombulifera*, shoot dry weight was increased by both NaCl and Na_2SO_4 at Ψo = -1.9 MPa and below, while root dry weight was enhanced only at Ψo = -2.6 MPa[18]. Hence, one can speculate that the response of each organ is a function of its ability to manage the number of salts reaching it.

The fact that water content was maintained unchanged in roots and stems in all treatments and that only a slight decrease was noticed in leaves of plants subjected to KCl and

Na_2SO_4 indicates that the osmotic effects of all studied salts were neglectable. This means that the detrimental effect of each salt on a given organ is of nutritional, toxic or oxidative nature[3]. It means also that the amounts of salts accumulated within plants were well compartmentalized at the cell level[6,18,19].

As a whole, leaves exhibited the highest K^+ and Na^+ concentrations and the greatest biomass production. Therefore, 55.8-74.9% of the absorbed quantities of these two cations were accumulated in leaves. Although NaCl and KCl salts were added at the same concentration (200 mM) Na^+ was more accumulated in *S. portulacastrum* leaves (10.42 mmol g^{-1} DW) than K^+ (5.60 mmol g^{-1} DW). This preferential Na^+ accumulation allowed *S. portulacastrum* to be one of the most efficient halophytes in phytodesalination[11,13]. The comparison between NaCl and Na_2SO_4 treatments showed the existence of a threshold of Na^+ concentration within the tissues of this halophyte as previously mentioned by[13]. In terms of salt (K^+ or Na^+) quantity per plant, *S. portulacastrum* was more able to accumulate Na^+ than K^+.

CONCLUSION

Sesuvium portulacastrum can accumulate relatively high quantities of K^+ and therefore it can be used for the phytodesalination of saline waters with high K^+ concentrations such as reject brines.

SIGNIFICANCE STATEMENT

This study discovered the ability of the halophyte *S. portulacastrum* to accumulate K^+ and Na^+ from different salts, which can be beneficial for further studies that can be quantified in advance to which extent this halophyte can be considered as a salt-hyperaccumulating species (not only a Na^+-hyperaccumulating one). This study will help the researchers to uncover the critical areas of halophyte use in the desalination of saline waters such as reject brines that many researchers were not able to explore. Thus a new theory on saline water phytodesalination may be arrived at.

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