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Effects of Low and Moderate Salinity on *Zinnia marylandica*

Abdulaziz Alturaifi[1*]; Hosam Osama Elansary[2] and Mokded Rabhi[1,3]

[1] Department of Plant Production and Protection, College of Agriculture and Veterinary Medicine, Qassim University, Buraydah, Saudi Arabia.
[2] Plant Production Department, College of Food and Agriculture Sciences, King Saud University, Riyadh 11451, Saudi Arabia.
[3] Laboratory of Extremophile Plants, Centre of Biotechnology of Borj-Cedria, 2050, Hammam-Lif, Tunisia.

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ABSTRACT

Soil and water salinity are considered among the main abiotic constraints especially in arid and semi-arid regions where saline groundwater is often used for crop irrigation since surface water is not easily available. The aim of the present investigation was to study the effects of low (25 mM NaCl) and moderate (50 mM NaCl) salinity on *Zinnia marylandica* (Double White cultivar) growth, water status, potassium and sodium contents, as well as K^+/Na^+ ratios. Plants were grown on inert sand and irrigated with one fourth-strength Hoagland's nutrient solution for 38 days under greenhouse conditions. Three treatments were considered: control (0 mM NaCl), low salinity (25 mM NaCl), and moderate salinity (50 mM NaCl). At the harvest, inflorescences were collected then plants were cut into shoots and roots. Results indicated that inflorescences produced under saline conditions were smaller than those produced under control conditions, but they maintained the same number per plant, water content, and days to first opening. In addition, whole plant dry weight decreased with the increasing salinity with no variation in root/shoot ratio. A preferential allocation of K^+ to shoots and Na^+ to roots was also observed, leading to higher K^+/Na^+ ratio in shoots. Moreover, shoot K^+/Na^+ ratio decreased with salinity. Based on these results, it could be concluded that *Zinnia marylandica* lacks the ability to maintain K^+/Na^+ ratio at an adequate level at higher salinity levels.

Keywords: growth; water content; inflorescence characteristics; K^+/Na^+ ratio.

INTRODUCTION

Soil and water salinity are considered among the main abiotic constraints especially in arid and semi-arid regions where saline groundwater is often used for crop irrigation since surface water is not easily available (Pereira *et al.*, 2009). Salinity level depends on the concentration of all soluble salts present in water or in soil solution (Ezlit *et al.*, 2010; Rengasamy, 2010). Soil salinization, that affected about 1125 million hectares worldwide, is a global threat that substantially affects plant growth and crop yields (Hossain, 2019). Recently, Munns and Gilliham (2015) reported that about one-third of the arable lands throughout the world are salt-affected soils. These soils are characterized by an excessive accumulation of salts (in particular sodium) at levels that seriously affect soil stability and crop yields (Aydemir and Sünger, 2011). In addition, 884 million people in the world are likely to suffer from the absence of freshwater (Vineis *et al.*, 2011). Indeed, freshwater salinization is an emerging global problem (Kaushal *et al.*, 2021).

It is known that salt stress induces four deleterious effects on plant growth: (1) osmotic stress (also called water stress) linked to the low osmotic potential of the soil solution, (2) salt stress due to the specific toxic effects of salt ions (such as Na^+ and Cl^- ions), (3) nutritional imbalance due to Na^+ - cations as well as Cl^- - anions antagonism and (4) a combination of all salt effects (Ashraf, 2004) together with oxidative stress that all negatively affect plant growth and development (Colin *et al.*, 2023). Na^+ and K^+ ions present in the soil solution are absorbed by roots using the same transporters, which make them in competition for these transporters (Greenway and Munns, 1980). K^+ is necessary for a variety of functions in plants, including its involvement in metabolic processes such as photosynthesis, protein synthesis, and enzyme activation and non-metabolic as well as its role in osmoregulation and ion homeostasis (Kanai *et al.*, 2007). Therefore, maintaining an adequate Na^+/K^+ ratio in cells is a key feature of plant survival under saline conditions (Yang and Guo, 2018).

It was shown that salinity tolerance in landscape plants is species-dependant and even cultivar-dependant (Niu *et al.*, 2012). The landscape species *Zinnia marylandica* (Asteraceae) is an artificial hybrid that was obtained from the hybridization of *Z. violacea* as male with *Z. angustifolia* var. *angustifolia* as female. This ornamental plant is characterized by its disease resistance (Spooner *et al.*, 1991). However, Niu *et al.* (2012) found that the seven cultivars of *Z. marylandica* they studied died as sub-irrigated with a saline water with electrical conductivity of 6 and 8.2 dS. m^{-1}. They concluded that this species is salt-sensitive and should not be grown under high salinity conditions. The aim of the present investigation was to study the effects of low (25 mM NaCl) and moderate (50 mM NaCl) salinity on *Z. marylandica* cv. Double White growth, water status, potassium and sodium contents, as well as K^+/Na^+ ratios.

MATERIALS AND METHODS

Plant material and culture conditions

Seeds of *Z. marylandica* cv. Double White were sown in pots filled with washed sand and irrigated with distilled water until germination. Thereafter, obtained seedlings were supplied with a diluted, one fourth-strength Hoagland's nutrient solution (Hoagland and Arnon, 1950) for 15 d then with a non-diluted one fourth-strength solution for 45 d. Subsequently, three treatments were started: 0 mM NaCl

* **Corresponding author.**
E-mail address: azaz44999@gmail.com
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(Control), 25 mM NaCl (Low salinity), and 50 mM NaCl (Moderate salinity).

Plant harvest and growth measurements

Days to the first inflorescence opening were recorded before harvest. Then, at the harvest (upon 38 days of treatment), inflorescences were collected, counted, and their diameters were measured. After that, plants were cut into shoots and roots, rinsed with distilled water then weighed fresh to determine fresh weight and after oven-drying at 80°C until constant weight to determine dry weight. Fresh and dry weights of inflorescences were also determined.

Determination of water content

Water contents (WC) of shoots, roots, and inflorescences were calculated as follows:

$$WC (\%) = (FW - DW) * 100 / FW,$$

where FW and DW stand respectively for fresh and dry weights.

Determination of Na^+ and K^+ concentrations

Dried plant samples were ground to a fine powder then Na^+ and K^+ ions were extracted using a 0.5% HNO_3 solution. Na^+ and K^+ concentrations were determined by a flame photometer (PEP7, Jenway LTD, Felsted, England).

Statistical analysis

Data were subjected to One-Way-ANOVA using IBM SPSS Statistics 25 and means were compared according to Duncan's multiple range test.

RESULTS AND DISCUSSION

Results

Inflorescence characteristics

The days to the first inflorescence opening and the number of inflorescences per plant showed no significant differences between treatments; they varied from 59 to 60 d from germination and from 9 to 10 inflorescences per plant, respectively (Table 1). In addition, no significant difference was found in inflorescence water content. However, their diameter and dry weight were reduced with salinity. Inflorescence diameter decreased by 16 and 38% at 25 and 50 mM NaCl, respectively. Inflorescence dry weight was more sensitive to salinity; it declined by 30.7% at 25 mM NaCl and by 59.3% at 50 mM NaCl.

Table 1. Inflorescence characteristics in *Z. marylandica* plants grown for 38 days at 0, 25, and 50 mM NaCl. Means (n = 8) followed by the same letter are not significantly different according to Duncan's multiple range test at *P*≤0.05.

	0 mM NaCl	25 mM NaCl	50 mM NaCl
Days to the first inflorescence opening	60 a	59 a	60 a
Number of inflorescences per plant	10 a	9 a	9 a
Inflorescence diameter (cm)	5.0 a	4.2 b	3.1 c
Inflorescence DW (g)	2.80 a	1.94 b	1.14 c
Inflorescence WC (%)	6.02 a	7.08 a	7.07 a

Biomass production and water content

Control plants exhibited a whole plant dry weight of 5.94 g (Table 2) distributed as follows: 4.93 g in shoots and 1.01 g in roots (Fig. 1). Under low salinity conditions, shoot growth was reduced by 17.4%, while under moderate salinity, it was declined by 38.5%. Root growth was decreased by quarter and half, under low and moderate salinities, respectively. Nevertheless, Root/Shoot ratio showed no significant differences between treatments (Table 2).

Table 2. Whole plant DW and root/shoot ratio in *Z. marylandica* plants grown for 38 days at 0, 25, and 50 mM NaCl. Means (n = 8) followed by at least one same letter are not significantly different according to Duncan's multiple range test at *P*≤0.05.

	0 mM NaCl	25 mM NaCl	50 mM NaCl
Whole plant DW (g)	5.94 a	4.83 b	3.51 c
Root/shoot ratio	0.20 a	0.19 a	0.16 a

Plant water status was less sensitive to salinity compared to biomass production. Indeed, shoot water content showed no significant difference between treatments; it was maintained at 85.7-88.3% (Fig. 1). Root water content, however, exhibited a slight decrease (-3.5%) at moderate salinity.

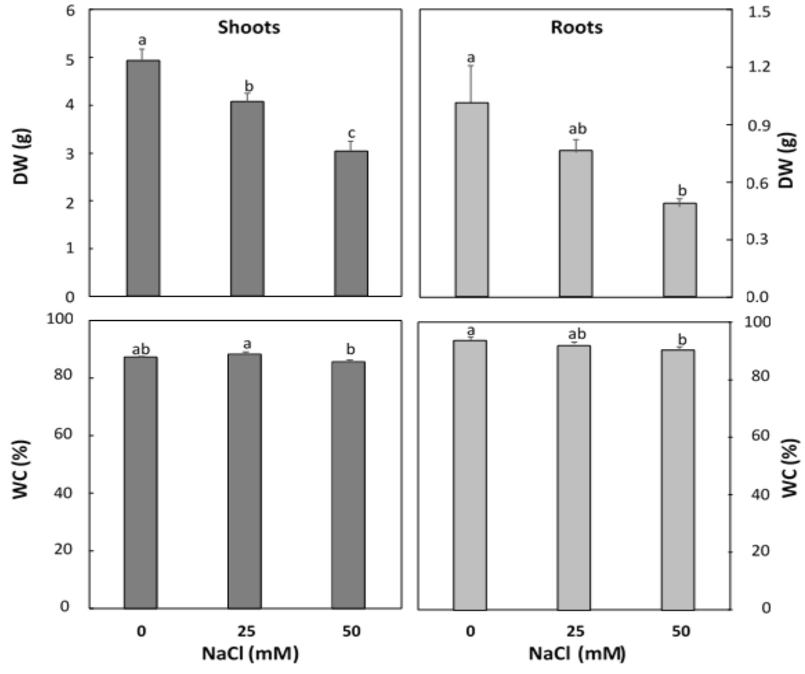

Figure 1. Shoot and root dry weights (DW) and water contents (WC) in *Z. marylandica* plants grown for 38 days at 0, 25, and 50 mM NaCl. Bars are means of 8 replicates ± SE. Bars labelled with at least one same letter are not significantly different according to Duncan's multiple range test at *P*≤0.05.

Na^+ and K^+ concentrations and K^+/Na^+ ratio

At low salinity, shoots accumulated 42.2% less Na^+ as compared to roots (Fig. 2), whereas at moderate salinity both shoots and roots showed similar contents (1.4-1.6 mmol Na^+. g^{-1} DW).

Shoot K^+ contents were maintained at 1.0-1.1 mmol. g^{-1} DW regardless of the treatment (Fig. 2). By contrast, root K^+ contents declined by half under both low and moderate salinity. Hence, K^+/Na^+ ratio decreased with the increasing salinity in shoots and was exhibited no significant variation in roots.

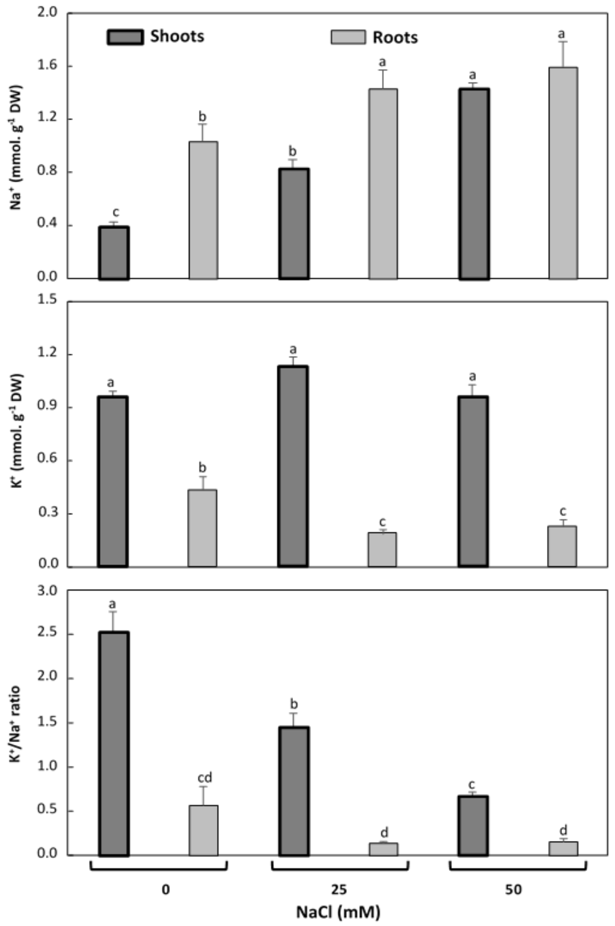

Figure 2. Na^+ and K^+ contents and K^+/Na^+ ratios in shoots and roots of *Z. marylandica* plants grown for 38 days at 0, 25, and 50 mM NaCl. Bars are means of 8 replicates ± SE. Bars labelled with at least one same letter are not significantly different according to Duncan's multiple range test at $P \leq 0.05$.

Discussion

In the present study, low (25 mM NaCl) and moderate (50 mM NaCl) salinity did not affect the date of first inflorescence opening as well as the number of inflorescences per plant. It seems that these parameters may be affected only by higher salinity levels in this species. Indeed, *Ornithogalum saundersiae* exhibited a delay in flowering of 14 and 30 d as subjected to 100 and 200 mM NaCl, respectively. However, it showed no variation in inflorescence number under saline conditions (Salachna et al., 2016). *Calendula officinalis*, however, displayed a decreased number of inflorescences per plant with the increasing salinity starting from 1000 ppm NaCl (≈ 43.5 mM) (Swaefy and El-Ziat, 2020). In the current study, *Z. marylandica*, inflorescence diameter and dry weight decreased with salinity level, while its water content was not affected by salinity stress. These results disagree with those of Carter and Grieve (2010) who found that *Z. elegans* inflorescence diameter was not affected by sea water dilutions in "Salmon Rose" cultivar, whereas it decreased at 10 dS. m^{-1} in "Golden Yellow" one.

Shoot and root dry weights were similarly affected by low and moderate salinity in *Z. marylandica*, leading to a relatively constant root/shoot ratio. Wu *et al.* (2016) studied the responses of nine ornamental species to saline irrigation water and found they presented different degrees of salt sensitivity. Among the nine studied species, only two showed unaffected shoot DW at 5 dS. m^{-1} (equivalent to 50 mM NaCl). Upreti and Murti (2010) and Singh *et al.* (2012) found an increase in root/shoot ratio in grape rootstocks and tomato, respectively. They explained such a result by a higher salt vulnerability of shoots compared to roots, which is in turn the result of photoassimilate repartitioning. The absence of an increase in root/shoot ratio in salt-treated *Z. marylandica* plants may be due to their incapacity to modulate photoassimilate reallocation under saline as a result of differential allocation of Na^+ and K^+ ions towards roots and shoots.

Shoots showed less Na^+ at low salinity and more K^+ regardless of the treatment as compared to roots, leading to a much higher shoot K^+/Na^+ ratio in all treatments. This may explain why root water content was reduced at moderate salinity while shoot water content was not affected. The tendency of *Z. marylandica* plants to accumulate Na^+ ions within root tissues to prevent their excessive accumulation in shoots reflects an "excluder" behaviour for these salt ions. In fact, sodium exclusion is a common natural feature in most plants (Munns, 2005) and can be considered as a key mechanism for high Na^+ level (sodicity) tolerance (Genc *et al.*, 2016). Moreover, salt-induced yield reduction has been correlated with K^+/Na^+ in plant tissues in several studies (Chunthaburee *et al.*, 2016; Reddy *et al.*, 2017) and leaf K^+/Na^+ was even suggested as a tool to predict rice yield under saline conditions (Mel *et al.*, 2019).

CONCLUSION

Although *Z. marylandica* produced smaller inflorescences under low and moderate salinity conditions, it maintained inflorescence number, days to first opening, and water status at the same level of the control. However, shoot growth decreased with the increasing salinity but their water content showed no variation under saline conditions. Nevertheless, root/shoot ratio was similar in all treatments, indicating that roots were more tolerant to salinity compared to shoots. In addition, shoots exhibited higher K^+/Na^+ ratio than roots regardless of the treatment. However, this ratio decreased with the increasing salinity, indicating the inability of *Zinnia marylandica* to maintain it at an adequate level at higher salinity levels.

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تأثير الملوحة المنخفضة والمتوسطة على نبات الزينيا

عبد العزيز الطريفي[1]، حسام أسامة الأنصاري[2] و مقداد رابحي[1،3]

[1] قسم إنتاج النبات ووقايته ، كلية الزراعة والطب البيطري ، جامعة القصيم ، بريدة ، المملكة العربية السعودية.
[2] قسم الإنتاج النباتي ، كلية علوم الأغذية والزراعة ، جامعة الملك سعود ، الرياض 11451 ، المملكة العربية السعودية.
[3] مخبر النباتات المقاومة للضغوطات البيئية القاسية ، مركز البيوتكنولوجيا ببرج السدرية ، 2050 ، حمام الأنف ، تونس.

الملخص

تعتبر ملوحة التربة والمياه من بين الإجهادات اللاأحيائية الرئيسية خاصة في المناطق الجافة وشبه الجافة حيث تستخدم المياه الجوفية المالحة لري المحاصيل نظرًا لعدم توفر المياه السطحية. يهدف هذا البحث إلى دراسة تأثير الملوحة المنخفضة (25 ملي مول كلوريد الصوديوم) والمتوسطة (50 ملي مول كلوريد الصوديوم) على نمو نبات الزينيا (*Zinnia marylandica* cv. Double White) ، وكذلك محتوى البوتاسيوم والصوديوم. تمت زراعة النباتات على رمل مغسول وتم ريها بمحلول هوجلاند المغذي مخففًا أربعة مرات لمدة 38 يومًا تحت ظروف البيت المحمي. كما تم استعمال ثلاث معاملات: الكنترول (0 ملي مول كلوريد الصوديوم) ، الملوحة المنخفضة (25 ملي مول كلوريد الصوديوم)، والملوحة المتوسطة (50 ملي مول كلوريد الصوديوم). عند الحصاد، تم جمع النورات ثم فصل المجموع الخضري عن الجذور. أثرت الملوحة على حجم ووزن النورات لكنها لم تؤثر على عدد النورات في كل نبات ومحتواها المائي وكذلك عدد الأيام حتى تفتح أول نورة. أما بالنسبة لبقية النبات، فقد انخفض الوزن الجاف للنبات الكامل مع ارتفاع مستوى الملوحة دون التأثير على نسبة المجموع الجذري إلى المجموع الخضري. لوحظ أيضًا نقل تفضيلي للبوتاسيوم إلى المجموع الخضري وتخزين الصوديوم في الجذور ، مما أدى إلى ارتفاع نسبة البوتاسيوم إلى الصوديوم في المجموع الخضري، مما يوحى بأن الجذور كانت أكثر تحملاً للملوحة مقارنة بالمجموع الخضري. علاوة على ذلك ، انخفضت نسبة البوتاسيوم إلى الصوديوم مع الملوحة ، مما يدل على عدم قدرة الزينيا على الحفاظ على النسبة المناسبة عند مستويات الملوحة العالية.

الكلمات الدالة: النمو، المحتوى المائي، خصائص النورة، نسبة البوتاسيوم إلى الصوديوم.