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Effect of irrigation water salinity on morphological and physiological characteristics of celery

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Abstract
The objective of this study was to investigate the effects of salinity levels of irrigation water on the morphological and physiological characteristics of celery (*Apium graveolens* L.) during early seedling development. Celery seedlings of Balena cultivar were grown with saline irrigation water consisting of different NaCl levels (0, 50, 100, 150, 200, 250, and 300 mM). The results showed that increasing salt stress inhibited plant growth by destroying physiological parameters. Each increase in NaCl resulted in a decrease in the length, diameter, number, and fresh and dry weight of leaves. Dry matter, chlorophyll content, leaf temperature, and turgor loss improved when NaCl levels were increased; however, salinity caused a reduction in leaf relative water content. Leaf fresh and dry weights were lower under salt stress, even at 50 mM NaCl. Leaf temperature was higher in plants grown under salinity and reached the maximum level at 100 mM NaCl. The stomata on the abaxial side of the leaves were smaller but more numerous under salinity than in the control plants. It was concluded that celery's plant growth was significantly influenced by salinity and that it could endure salinity lower than 100 mM NaCl.
Keywords: *Apium graveolens* L., NaCl, Plant growth, Chlorophyll content, Stomata density

INTRODUCTION

Celery (*Apium graveolens* L.) is a cool-season vegetable that belongs to the family *Umbelliferae* and is widely cultivated and consumed on a global scale. It is grown under irrigated conditions for both its leaves and roots, which are the edible parts (Ma et al. 2019). In Turkey, it is mainly cultivated for its roots, but its leaves are used to prepare cooked vegetables or raw in salads. It has high nutritional value and is rich in calcium, phosphorus, iron, carotene, vitamins, and other nutrients (Hedayati et al. 2019).

Several abiotic stress factors adversely affect plant growth from germination to harvest. Of these factors, salinity is the most hazardous stress that destroys the life cycle of crops (Munns 2005). It causes osmotic stress leading to physiological drought and/or ion toxicity due to excessive Na^+ and Cl^- ions (Eisa et al. 2012). Because low water potential in saline soils or irrigation water limits water uptake by plant roots, plants close stomata to prevent water evaporation (Flexas et al. 2007), which reduces photosynthetic activity (Huchzermeyer and Koyro 2005) and causes an increase in leaf temperature (Orzechowska et al. 2021).

Salinization results mainly from soil in arid and semi-arid regions or from the accumulation of salt ions in irrigation water (Rasool et al. 2013). About 1/3 of the irrigated land in the world suffers from salinity (Taiz and Zeiger 2002, FAO

2011). Celery is classified as a salt-tolerant species by Francois and Maas (1994); however, its production is limited by salinity in irrigation water (Gao et al. 2023). In this study, the effects of irrigation salinity in the form of different NaCl levels on plant growth, root morphology, physiological characteristics, stomata density and size of celery were investigated.

MATERIAL AND METHODS

This study employed seedlings of the celery hybrid cultivar Balena purchased from a local seedling supplier in a greenhouse in Eskişehir, Turkey. They were transferred to pots (0.5 L) containing a total of 160 g of the mixture of peat, perlite, and vermiculite (3:1:1), and then irrigated with distilled water. The plants were grown in a growth chamber with a temperature of 20^{0}C/10^{0}C during the day and night, and a photoperiod of 18/6 hours with a relative humidity of 65-70%. The pots were irrigated with the same amount of distilled water to stabilize moisture content and sustained until the start of salinity applications after four days of transplantation.

Irrigation water salinities were created with NaCl of 50, 100, 150, 200, 250, and 300 mM, and their electrical conductivities were read with EC meter WTW 3.15i as 5.4, 10.5, 15.3, 20.1, 24.8, and 29.4 dS m^{-1}, respectively. Distilled water was used as a control. Each pot was weighed on alternate days to complete the deficient water by adding respective NaCl solutions. Also, liquid N-P-K (8-8-8) was applied to the plants two times, 1 and 2 weeks after the transplantation. Thirty days after the salt treatments, when visual separation between salt treatments appeared, all measurements were taken.

Measurement of morphological characteristics

To determine leaf length, weight, diameter, and fresh and dry weights, above-ground parts of the plants were separated from the roots and the measurements were performed on these leaves. Root images were taken by a camera.

Measurement of physiological characteristics

The chlorophyll content was obtained by the portable chlorophyll meter SPAD-502 (Konica Minolta Corporation, Osaka, Japan) as the SPAD index. Leaf relative water content (LRWC) was determined with the use of the following formula (Eq. 1)

$$LRWC (\%) = (LFW - LDW)/(LTW - LDW) \times 100$$

Where, LFW= leaf fresh weight, LDW= leaf dry weight, and LTW= turgid weight. Dry weight was determined after drying at 80°C for 24 h and turgid weight was weighted after the leaf samples soaked in distilled water in a falcon tube for 24 h in the dark at 20°C (Kaya et al. 2003).

Measurement of stomatal characteristics

The impression technique for the stomata density (the number of stomata per mm^2 leaf area) on each plant was performed. The abaxial part of 3rd leaf from the top was carefully coated with transparent nail varnish in the middle between the main veins. The stomata number per unit area was counted at 400× magnification under the light microscope (Kaya 2023).

Statistical analysis

The data were analyzed by a completely randomized design with four replicates, and differences between means were compared by the Least Significant Differences (LSD) test at a 5% level.

RESULTS AND DISCUSSION

There were significant differences between salinity levels for morphological characteristics of celery (Table 1). Leaf number, height, diameter, and fresh and dry weights were significantly decreased by increasing NaCl levels. Each increase in salinity resulted in a decrease in these characteristics. Leaf length shortened with each increase in salinity, while no significant reduction occurred at 250 and 300 mM NaCl. Celery plants grown at increasing salinity had fewer leaves, with control plants having the highest leaf number with 10.25. Similar leaf numbers were obtained at 200, 250, and 300 mM NaCl. Leaf diameter was measured using a digital caliper to evaluate leaf thickness, and a significant reduction was observed at 50 mM NaCl compared to the control. However, celery plants exhibited similar leaf diameters at NaCl levels higher than 100 mM NaCl. Celery's leaf fresh weight declined dramatically as salinity increased, reaching a maximum value of 38.8 g per plant. Even the lowest salinity level of 50 mM NaCl had a hazardous impact on fresh weight. Similarly, a 50 mM NaCl concentration caused a decrease in leaf dry weight. As reported by Munns and Tester (2008), the main effects of salinity are the reduction in biomass growth by restricting mainly water uptake and accumulation of excessive Na^+ and Cl^- in tissues. Pardossi et al. (1999a) found an enhancement in the accumulation of Na^+ and Cl^- in mature leaves of celery under increasing salinity. In the present study, a significant reduction in leaf number, length, diameter, and fresh and dry weight of celery was determined and similar findings were reported by Soliman and El-Shaieny (2014), Ashmawi (2019), and Gao et al. (2023). This result agrees with the findings of Pardossi et al. (1999b) who found that fresh and dry weights of celery reduced as NaCl was increased. Although root properties were not measured, a reduction in root growth due to increasing salinity was displayed in Figure 1.

For the celery leaf temperature, chlorophyll content, relative water content, turgor loss, and dry matter, there were significant differences between salinity levels (Table 2). The highest leaf temperature was recorded in 100 mM NaCl with 26.2 °C, while the lowest was 24.6 °C in control plants. Chlorophyll content increased as salinity rose, although no significant variations in chlorophyll content

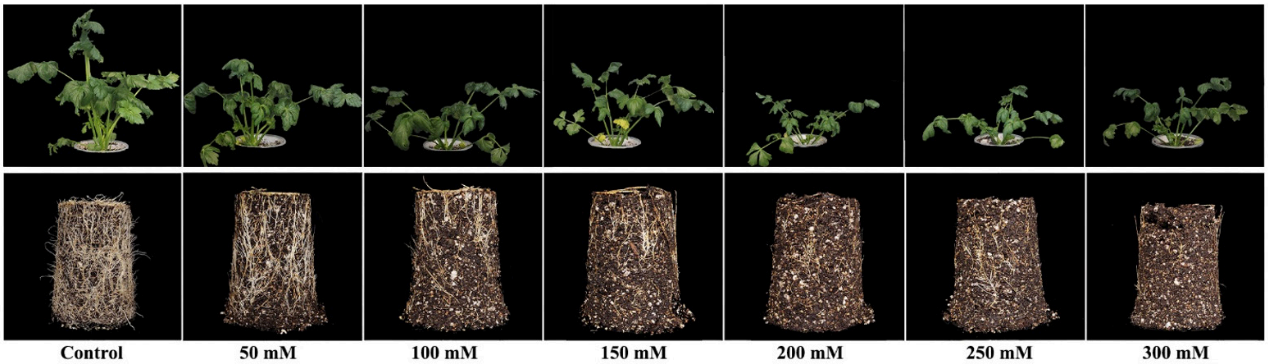

Figure 1. Visual inspection of celery roots and leaves exposed to different salinity (NaCl) levels.

Table 1. Effects of salinity on leaf length, number, diameter, and fresh and dry weights of celery.

Salinity (mM)	Leaf length (cm)	Leaf number	Leaf diameter (mm)	Leaf fresh weight (g plant^{-1})	Leaf dry weight (g plant^{-1})
Control	24.8^{a}	10.25^{a}	18.1^{a}	38.8^{a}	4.00^{a}†
50	21.0^{b}	8.00^{b}	13.8^{b}	22.2^{b}	2.45^{b}
100	19.4^{c}	7.50^{bc}	11.9^{c}	17.4^{c}	2.19^{b}
150	18.1^{cd}	6.75^{cd}	10.4^{d}	13.1^{d}	1.80^{c}
200	16.5^{de}	6.25^{de}	10.5^{d}	11.2^{de}	1.67^{cd}
250	16.1^{e}	6.00^{de}	10.3^{d}	9.2^{ef}	1.40^{d}
300	15.7^{e}	5.75^{e}	9.3^{d}	8.5^{f}	1.38^{d}
Significance	**	**	**	**	**

†: Letters connected with means in each column show significance levels at 5%. **: significant at 1%.

Table 2. Effects of salinity on leaf temperature, chlorophyll content, relative water content, turgor loss, and dry matter of celery.

Salinity (mM)	Leaf temperature (°C)	Chlorophyll content (SPAD)	Relative water content (%)	Turgor loss (%)	Dry matter (%)
Control	24.6^{d}	45.7^{c}	86.3^{a}	13.4^{e}	10.3^{f}†
50	25.5^{bc}	50.6^{b}	78.4^{b}	23.9^{d}	11.0^{d}
100	26.2^{a}	55.9^{a}	74.0^{c}	26.6^{c}	12.6^{d}
150	25.1^{c}	57.7^{a}	71.1^{d}	32.9^{b}	13.7^{c}
200	25.4^{bc}	57.0^{a}	70.9^{d}	33.3^{b}	14.8^{b}
250	25.7^{b}	58.7^{a}	70.7^{d}	34.4^{b}	15.2^{b}
300	25.4^{bc}	59.2^{a}	59.7^{e}	50.5^{a}	16.1^{a}
Significance	**	**	**	**	**

†: Letters connected with means in each column show significance levels at 5%. **: significant at 1%.

were recorded between 100 and 300 mM NaCl. Contrarily, Gao et al. (2023) determined lower chlorophyll content under salt-stressed celery plants. Increased salinity resulted in a decrease in relative water content, with the lowest value being 300 mM NaCl. Koyro et al. (2011) and Gao et al. (2023) recorded a similar trend in relative water content against salinity. There was an obvious increase in turgor loss due to salinity and the lowest salinity enhanced it two-fold. The dry matter content of leaves increased when salinity was increased. The control plants had the lowest dry matter, while the plants grown at 300 mM NaCl produced the highest dry matter.

Stomata density of celery was 90 per square millimeter (Figure 2). Stomata density was higher in the plants subjected to salt stresses than in the control; however, it reached the peak value (156 mm^{2}) at 150 mM NaCl and decreased at higher NaCl concentrations. A similar result was found by Kaya (2023) in lettuce. The size of the stomata decreased with increasing salinity, but no significant differences were observed between 100 mM and 300 mM NaCl. Salinities up to 100 mM NaCl caused an increase in stomata density and a decrease in stomata size. Increased salinity resulted in smaller size and more frequent stomata on the lower surface of celery leaves.

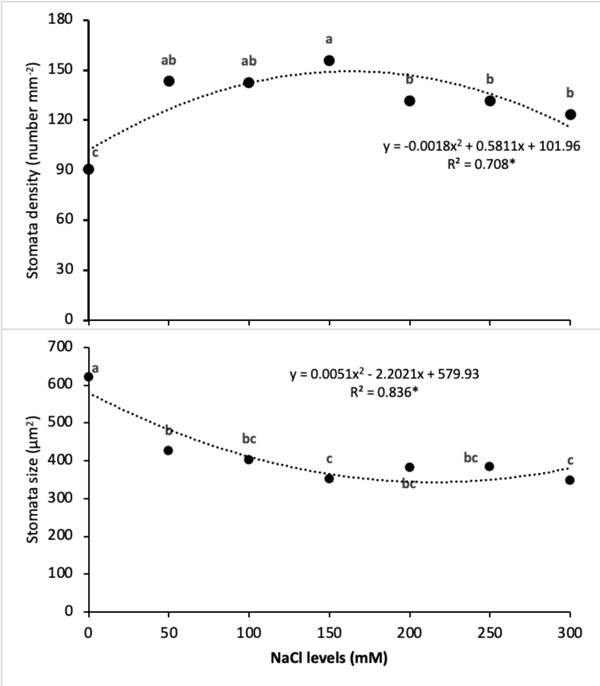

Figure 2. Stomata density (number per mm^2) and size (μm^2) of celery under different NaCl levels. Letters connected with each point show a significance level at 5%.

CONCLUSION

In the study conducted to determine the effects of salinity on celery plant growth, irrigation salinity inhibited remarkably aboveground and root growth of celery by reducing physiological activity. Smaller and denser stomata were observed under salt stress, although they were not significantly affected at NaCl levels higher than 100 mM NaCl. The results indicate that celery can be classified as moderately tolerant to irrigation salinity in the early growth stage and should be irrigated with water containing less than 100 mM NaCl.

COMPLIANCE WITH ETHICAL STANDARDS

Peer-review

Externally peer-reviewed.

Conflict of interest

The authors declared that for this research article, they have no actual, potential, or perceived conflict of interest.

Author contribution

The contribution of the authors to the present study is equal. All the authors read and approved the final manuscript. All the authors verify that the Text, Figures, and Tables are original and that they have not been published before.

Ethical approval

Ethics committee approval is not required.

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Data availability

Not applicable.

Consent for publication

Not applicable.

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