

Original Article

Modulation of salt-induced stress impact on common purslane growth by exogenous application of salicylic acid

Modulação do impacto do estresse induzido pelo sal no crescimento de beldroegas pela aplicação exógena de ácido salicílico

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Abstract

Common purslane (*Portulaca oleracea* L.), although considered a common weed, has high nutritional value. This study evaluated the effect of foliar application of salicylic acid (50, 100, 200 ppm) on the growth of common purslane under saline irrigation (250 mM NaCl). Saline irrigation decreased aboveground biomass and relative leaf water content. However, salicylic acid application, especially at 100 ppm, significantly improved these parameters. Growth inhibition was accompanied by a decrease in the production of chlorophyll pigments (chlorophyll-a and chlorophyll-b). Foliar application of salicylic acid resulted in plants with improved chlorophyll-a and chlorophyll-b levels under saline irrigation. Moreover, foliar application of salicylic acid resulted in higher values of the Mean Productivity index and the Harmonic Mean index than non-treated plants. In conclusion, application of salicylic acid at 100 ppm could be used to alleviate the harmful effects of saline water on common purslane.

Keywords: biomass production, photosynthetic pigments, salinity stress, salt tolerance indices.

Resumo

A beldroega comum (*Portulaca oleracea* L.), embora considerada uma erva daninha comum, possui alto valor nutricional. Este estudo avaliou o efeito da aplicação foliar de ácido salicílico (50, 100 e 200 ppm) no crescimento da beldroega comum sob irrigação salina (250 mM NaCl). A irrigação salina reduziu a biomassa da parte aérea e o teor relativo de água nas folhas. No entanto, a aplicação de ácido salicílico, especialmente a 100 ppm, melhorou significativamente esses parâmetros. A inibição do crescimento foi acompanhada por uma diminuição na produção de pigmentos clorofílicos (clorofila-a e clorofila-b). A aplicação foliar de ácido salicílico resultou em plantas com melhores níveis de clorofila-a e clorofila-b sob irrigação salina. Além disso, a aplicação foliar de ácido salicílico resultou em valores mais elevados dos índices de Produtividade Média e Média Harmônica em comparação com plantas não tratadas. Concluindo, a aplicação de ácido salicílico a 100 ppm pode ser usada para atenuar os efeitos nocivos da água salina nas beldroegas.

Palavras-chave: produção de biomassa, pigmentos fotossintéticos, estresse salino, índices de tolerância ao sal.

1. Introduction

Common purslane (*Portulaca oleracea* L.) is a broadleaf weed of arable crops, yet with a high nutritional value as an edible species, rich in proteins, vitamins, omega-3 fatty acids, and minerals (Uddin et al., 2014). Because of its diuretic, antiseptic, and antispasmodic properties, common purslane has been used in folk medicine (Lee et al., 2012). At the same time, health concerns with respect to oxalic acid content restrict recommendation for every-day use in the human diet (Petropoulos et al., 2016). Common purslane is an annual species with some tolerance to salinity and drought, according to the literature (Kafi and Rahimi, 2011; Alam et al., 2014; Jin et al., 2016; Hnilickova et al., 2019).

Salinity in soil is a constraint of the productivity of crop plants. It can largely affect seed germination, plant growth,

and crop yield (Munns and James, 2003). Saline soils may cause osmotic imbalance, accumulation of toxic ions, and mineral insufficiency, leading to cellular dehydration, water deficiency, and low productivity (Munns, 2002) at elevated salinity levels (Robinson and Jones, 1986). In addition, salt stress may trigger other stresses in plants, thus limiting their growth and development (Shao et al., 2005).

Mitigating salinity problems in crop production seems necessary in the coming years, taking into account the rising population of the earth and the resultant high demand for food in the planet. Nevertheless, efforts to ameliorate crop performance under environmental stresses are difficult because the mechanisms of tolerance to salt stress are complicated and poorly understood.

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Aside from improving saline soils, attempts to increase crops tolerance to salinity using agronomic techniques are tested. Electrical conductivity of the soil reaching 4 dS·m⁻¹ (equal to 40 mM NaCl) is harmful for most crops (Munns and Tester, 2008). Common purslane can withstand mild salinity levels (Yazici et al., 2007; Kafi and Rahimi, 2011; Sdouga et al., 2019). Experimental evidence showed that common purslane could grow hydroponically with 100 mM NaCl under LED lightings (He et al., 2021), but increasing salinity to 200 mM and 300 mM decreased shoot and root growth due to deficit in leaf water (He et al., 2021). Other research confirmed that salinity arrested growth, degraded photosynthetic pigments, and promoted osmolytes production in the leaves and roots of common purslane plants (Borsai et al., 2020). Evidently, agronomical techniques for stabilizing growth and yield under salinity stress might help improving crop growth and cultivation in saline environments (Zörb et al., 2019; Sergey, 2013).

Salicylic acid (SA) is engaged in physiological processes of plants that regulate the overall plant growth (El-Tayeb, 2005). It is often detected as an intermediate substance in plant metabolic processes under stressful environments (Senaratna et al., 2002). Foliar application of SA has been used as a means of improving crop growth under abiotic stress (Damalas and Koutroubas, 2022). Improvement of plant growth with SA under salinity is reported in several crops, including sunflower (Noreen and Ashraf, 2008), bean (Azooz, 2009), pearl millet (Hussain et al., 2010), maize (Gunes et al., 2007; Bagheri, 2014), wheat (Mutlu and Atici, 2013), faba bean (Orabi et al., 2013), mungbean (Khan et al., 2014), and rice (Jini and Joseph, 2017). Nevertheless, experimental data on the impact of SA on growth of common purslane plants growing under irrigation with saline water are lacking. This work studied the impact of foliar sprayings of SA on growth traits of common purslane plants irrigated with saline water. The hypothesis in this work is that application of SA in the foliage can improve the growth of common purslane plants when irrigated with saline water.

2. Materials and Methods

2.1. Plant material and experimental set up

Common purslane seeds were collected from a local population in Thermi area, Thessaloniki, Greece. Seeds

were air-dried, cleaned from waste material, and stored in paper bags, until the initiation of the trial. Seed disinfection with 5% NaOCl for 1 min, following washing with distilled water, was conducted to protect seeds from rotting. Seeds were planted in May 2020 in 2-L plastic pots (13.5 cm diameter by 15.5 cm height). The growth medium was a mixture of soil and sand 2:1 (v/v). The soil was silty clay loam (clay 32%, silt 56%, sand 12%), with organic matter 1.6%, CaCO₃ 7.4%, total N 1.44 g kg⁻¹, Olsen P 12.2 mg kg⁻¹, available K 455.2 g kg⁻¹, and pH (1:1 H₂O) 7.6. Pots were placed in the greenhouse (12 h light, temperature 18–25 °C, and relative humidity 60–80%).

2.2. Salinity and SA treatments applied

Initially, all pots were irrigated once daily with normal water (EC 0.5 dS m⁻¹). One week after seedling emergence, three plants remained per pot. Fifteen days after seedling emergence, half of the pots continued to receive irrigation with normal water (EC 0.5 dS m⁻¹), whereas the remaining pots started to receive irrigation with saline water of 250 mM NaCl (equal to EC 29.2 dS m⁻¹). Irrigations were applied once daily with 200 mL of normal or saline water. The salinity level applied was selected on the basis of recent research on common purslane tolerance to salinity (Hnilickova et al., 2019; He et al., 2021; Kaur et al., 2021).

One week and two weeks after irrigation with normal or saline water, SA was sprayed at rates 50, 100, and 200 ppm (using a volume 30 L ha⁻¹) with the addition of Tween-80 (nonionic surfactant) at 0.1% (v/v). The SA application rates were selected on the basis of recent research on a similar topic (Ferdosi et al., 2021). The trial was established in a completely randomized design with eight treatments: normal water without SA (control), normal water + SA 50 ppm, normal water + SA 100 ppm, normal water + SA 200 ppm, saline water without SA, saline water + SA 50 ppm, saline water + SA 100 ppm, and saline water + SA 200 ppm and four replicates (pots) per treatment (Figure 1). The study was conducted in a greenhouse (12 h light, temperature 18–25 °C, and relative humidity 60–80%) at the facilities of Democritus University of Thrace in Orestiada, Greece.

2.3. Samplings and measurements

Sampling was done at 35 days after SA treatments. Aboveground fresh weight, dry weight, shoot length, and relative water content (RWC) in the leaf were determined.

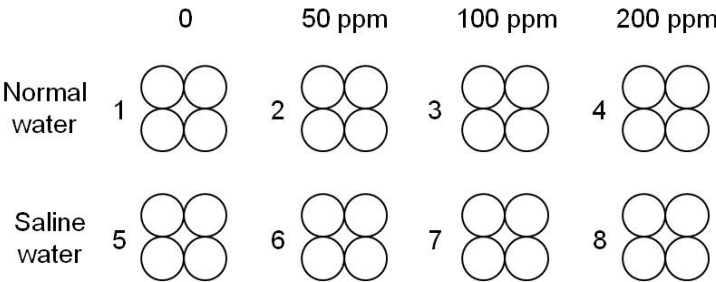


Figure 1. Experimental layout of the trial.

A proportion of the fresh material was oven-dried at 65 °C, until constant weight to record dry weight. The above data were then used to calculate the percentage of water content according to the following Formula 1 (Li et al., 2020):

$$WC(\%) = \frac{FW - DW}{FW} \times 100 \quad (1)$$

2.4. Salt tolerance indices

The Mean Productivity (MP) (Rosielle and Hamblin, 1981), the Harmonic Mean (HAR) (Jafari et al., 2009), and the Productivity Loss (PL) indices were calculated to assess the level of salt tolerance of common purslane plants using the following Equations 2 to 4:

$$\text{Mean Productivity (MP) index} = \frac{B_{st} + B_{op}}{2} \quad (2)$$

$$\text{Harmonic Mean (HAR) index} = \frac{2 (B_{st} \times B_{op})}{B_{st} + B_{op}} \quad (3)$$

$$\text{Productivity Loss (PL) index} = \frac{B_{op} - B_{st}}{B_{op} + B_{st}} \quad (4)$$

In the above equations, B_{st} represents the total biomass produced under irrigation with saline water and B_{op} represents the total biomass produced under irrigation with normal water. High values of the MP and HAR show better tolerance to salt stress, whereas high values of PL show higher losses due to salt stress.

2.5. Photosynthetic pigments

Chlorophyll-a (Chl-a) and chlorophyll-b (Chl-b) were determined according to the method of Arnon (1949) after extraction from fresh leaf tissue derived from well-developed leaves with 80% (v/v) acetone and centrifugation at 5000× g for 3 min. The optical density of the supernatant was determined by spectrophotometry at 663 and 645 nm.

2.6. Data analysis

Data underwent analysis of variance (ANOVA) considering a factorial approach. Main factors were the two salinity levels (normal water and saline water) and the four SA rates (control, 50, 100, and 200 ppm). Normality and homogeneity of variances of the data sets were checked before the analysis. Means differences were tested with the least significant difference test at $P < 0.05$.

3. Results

Irrigation with saline water negatively affected the aboveground fresh weight, dry weight, and shoot length of common purslane plants (Figure 2). However, the supplementation of SA advanced the above growth parameters under irrigation with saline water. The rate of 100 ppm had the maximum ameliorating effect (Figure 2).

Irrigation with saline water reduced RWC by 17.7%, but application of 100 ppm SA restored this parameter to a level comparable to non-stressed plants (Figure 3).

The effect of irrigation with saline water and foliar application of SA on selected salt tolerance indices of common purslane plants are illustrated in Figure 4. Plants sprayed with SA resulted in higher values of the Mean Productivity index and the Harmonic Mean index, showing higher tolerance to saline water than non-sprayed plants. The rate of 100 ppm had the maximum ameliorating effect (Figure 4). Additionally, high values of PL in non-sprayed plants (control) showed higher losses due to salt stress as opposed to the SA-sprayed plants (Figure 5).

Irrigation with saline water adversely affected Chl-a and Chl-b in common purslane leaves (Figure 6). However, SA-sprayed plants showed less adverse effects of saline water on both photosynthetic pigments.

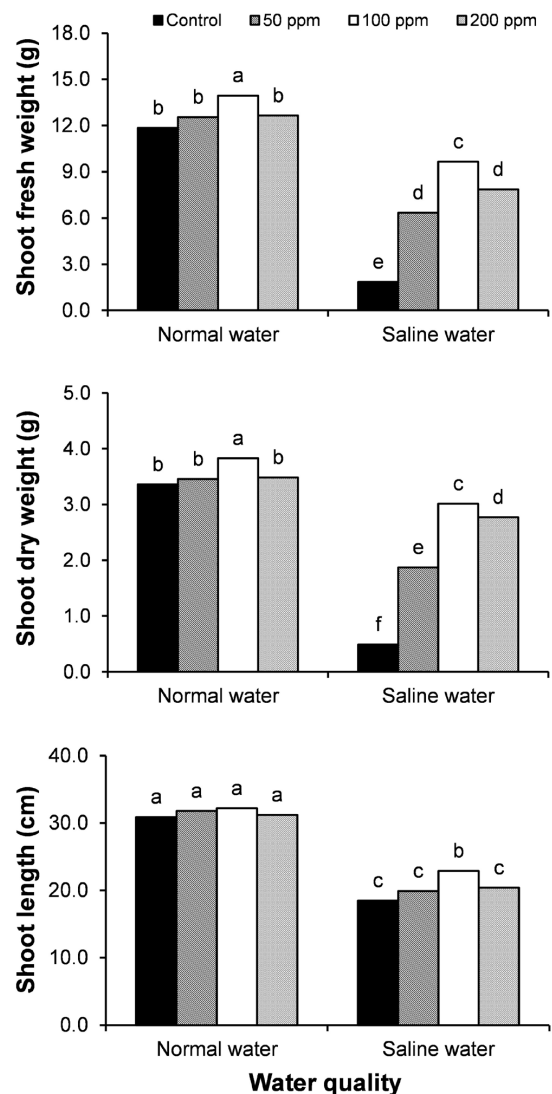


Figure 2. Aboveground fresh weight (g), dry weight (g), and shoot length (cm) of common purslane plants after irrigation with normal and saline water (Different letters in bars imply statistically significant differences among examined treatments at $P < 0.05$).

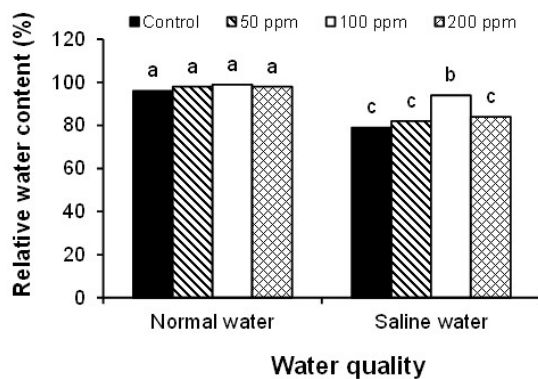


Figure 3. Relative water content (%) of common purslane plants after irrigation with normal and saline water. Different letters in bars imply statistically significant differences among examined treatments at $P < 0.05$.

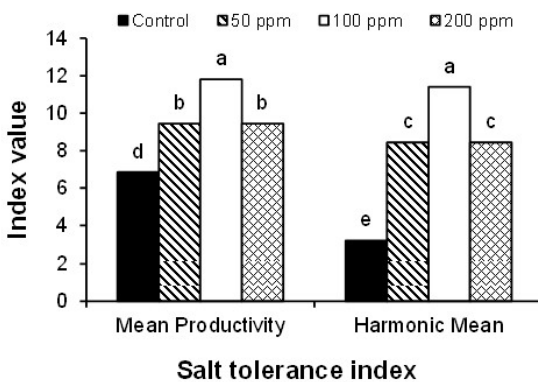


Figure 4. Mean Productivity and Harmonic Mean indices of common purslane plants with foliar application of SA. Different letters in bars imply statistically significant differences among examined treatments at $P < 0.05$.

4. Discussion

In this work, foliar sprayings of SA were tested on growth traits of common purslane plants irrigated with saline water. Experimental data on the impact of SA on growth of common purslane plants growing under irrigation with saline water are lacking. Saline water disrupted the growth of common purslane plants as manifested by the decrease in biomass production and shoot length of the plants, indicating that the normal development of the plants was slowed down. Plants receiving saline water showed lower values of Mean Productivity index and Harmonic Mean index, suffering the adverse effect of saline water. Previous research reported that increase in NaCl levels up to 200 mmol L⁻¹, increased the intercellular CO₂ concentration, while chlorophyll contents and net photosynthesis rate were decreased (Tang et al., 2020). Similarly, salt stress treatment of 200 mM decreased leaf number, stem length, and stem diameter of common purslane plants (Zaman et al., 2020).

Moreover, saline water reduced leaf RWC in common purslane plants probably due to low water absorption by

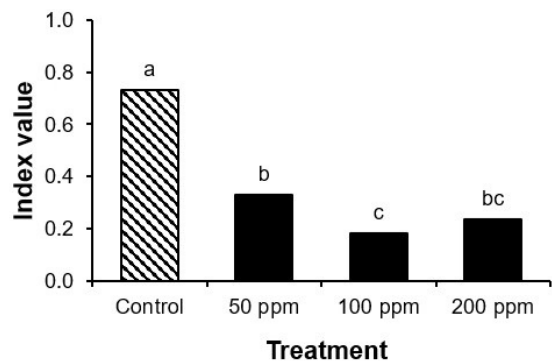


Figure 5. Productivity Loss index of common purslane plants with foliar application of SA. Different letters in bars imply statistically significant differences among examined treatments at $P < 0.05$.

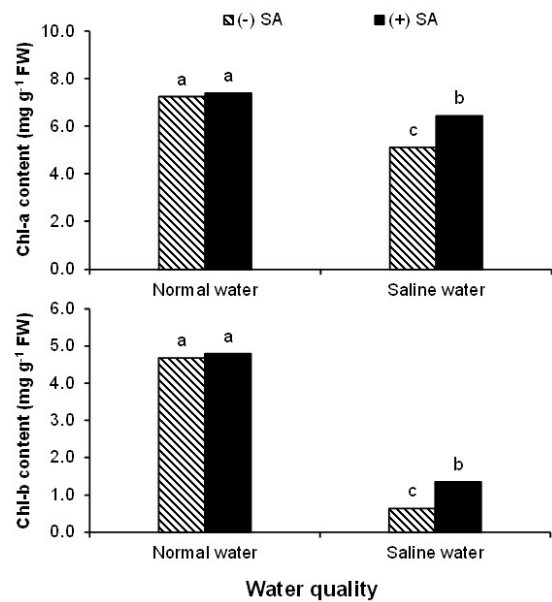


Figure 6. Leaf photosynthetic pigments (mg g⁻¹ of fresh weight) of common purslane plants after irrigation with normal and saline water (SA applied twice at 100 ppm). Different letters in bars imply statistically significant differences among examined treatments at $P < 0.05$.

the roots or high-water transpiration through the leaves. The decrease in the RWC in the leaves is an adverse effect of salinity, which deteriorates the turgor of plant tissues due to generation of osmotic stress. Osmotic stress hinders water absorption from the soil and translocation to the plant, disrupting metabolism and growth. Salinity reduces leaf water potential, prevents water absorption necessary for maintaining cell turgor, disturbs plant water relations, and generates osmotic stress, thereby lowers the plant weight (Arif et al., 2020). Nevertheless, previous research noted that electrical conductivity values of 0.8, 6.8, 12.8 and 24.2 dS m⁻¹ in irrigation solutions did not significantly affect the water content of common purslane leaves (Teixeira and Carvalho, 2009). This difference is probably due to

the lower salinity levels in the above study than that used in our study (EC 29.2 dS m⁻¹). The harmful impact of salinity stress on several parameters of chickpea growth (Chattha et al., 2022), broccoli (Sardar et al., 2023), and maize (Song et al., 2023) have been confirmed by recent research. However, foliar application of SA promoted the above growth parameters in common purslane plants receiving saline water. Water status in plants is sensitive to salinity stress and therefore is critical in determining response of plants to stress. The reduction in the RWC observed in the current study was probably a result of the high salinity in the external solution, which provoked osmotic stress and dehydration of the cells (Munns, 2002). However, certain plants react to high salinity levels by lowering tissue osmotic potential (Arif et al., 2020). Salinity hinders uptake of water by plants, which further reduces water potential and turgor in the aboveground plant part. Moreover, salinity alters the absorption of all mineral nutrients generating deficiencies.

Apart from growth parameters, irrigation with saline water in the current study lowered the levels of the photosynthetic pigments of common purslane plants. Chlorophyll is the main photosynthetic pigment in plants, playing a vital role in photosynthesis (Zhang et al., 2009). Consequently, photosynthetic performance directly reflects plant growth. Reduced photosynthesis of plants under conditions of salinity stress is a common effect of salinity, which has been attributed to stomatal closure and degradation of chlorophyll pigments (Ashraf, 2004) as well as to a decrease of carboxylase activity and increase of chlorophyllase activity (Abd El-Aziz et al., 2006). Concerning SA application, SA spraying increased chlorophyll content in summer squash (*Cucurbita pepo*) under salinity, with beneficial effects also on non-stressed plants, such as promoting the accumulation of potassium and lowering the accumulation of sodium in the shoots (Elwan and El-Shatoury, 2014). Similarly, application of SA protected carotenoids content under salinity in saffron (*Crocus sativus*) (Tajik et al., 2015), chicory (*Cichorium intybus*) (Poursakhi et al., 2019), and pennyroyal (*Mentha pulegium*) (Farhadi and Ghassemi-Golezani, 2020). Oxidative stress causes photo-oxidation and degradation of the pigments (Shahbaz et al., 2011). In particular, salinity causes instability of proteins in the photosystems and destruction of the chlorophyll through elevated activity of the chlorophyllase (Manaa et al., 2014). As multiple factors are involved in the SA ability to stimulate plant growth under abiotic stress, it seems possible that SA regulates the elongation and cell division (Li et al., 2022).

Treatment of common purslane plants with SA at 100 ppm improved all studied traits under salinity. Consequently, plants sprayed with SA recorded higher Mean Productivity index and Harmonic Mean index values, showing higher tolerance to saline water than non-sprayed plants. This response probably reflects the impact of SA on elongation and cell division within the plant meristem (Shakirova et al., 2003). The greatest effect of SA on RWC under salinity stress was noted at 100 ppm. Increased RWC level by the SA treatment reflects the protective role of SA in increasing the membrane stability, improving the antioxidant defense system, and promoting synthesis

of other protective substances (Urmi et al., 2023). SA is an important intermediate molecule related with plant response to environmental stresses. Similarly, foliar spray of SA advanced the growth of alfalfa plants under salinity much more than the application through the root medium method (Horchani et al., 2023). The method of application of chemicals can affect their level of availability in plant tissues (Souri and Hatamian, 2019). Initially, the roots face salinity, but then the leaves are the main target of toxic ions in saline conditions. Therefore, Na and Cl are harmful due to their toxicity on leaf biochemical processes, whereas spraying SA on the foliage activates all proposed protective functions of SA that strengthen plant defence under salinity stress.

5. Conclusion

Enhancing the ability of crops to tolerate salinity through suitable agronomic practices, such the use of growth regulators, can be a feasible way to lower the toxic effects of salinity on crop production. Experimental data on the impact of SA on growth of common purslane plants growing under irrigation with saline water are lacking. In the current study, SA improved growth parameters of common purslane plants under irrigation with saline water. In addition, the concentration of 100 ppm SA exhibited the greatest effect on the improvement of salinity tolerance in terms of higher RWC and higher levels of photosynthetic pigments in the leaves of common purslane plants. Hence, SA appears as an appropriate agent in the improvement of common purslane growth under saline environment. Future research endeavors on mitigating salinity stress on purslane growth with appropriate agronomic practices should prioritize understanding the physiological mechanisms of salt tolerance and exploring other agents, e.g., nutrient management and soil amendments that could improve crop tolerance to salinity. Given that the experiment was conducted under controlled conditions, validation of findings in the field is needed.

Data Availability Statement

The entire data set that supports the results of this study was published in the article itself.

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