ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
Brazilian Journal of Agricultural and Environmental Engineering
v.28, n.5, e276677, 2024
Campina Grande, PB – http://www.agriambi.com.br – http://www.scielo.br/rbeaa

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v28n5e276677 Original Article

Salt tolerance and foliar spectral responses in seedlings of four ornamental herbaceous species[1]

Tolerância à salinidade e respostas espectrais foliares em mudas de quatro espécies ornamentais herbáceas

Adriana C. de Oliveira[2*], Claudivan F. de Lacerda[2], Eduardo S. Cavalcante[2], Adunias dos S. Teixeira[2], Marcio R. R. de Oliveira[2], Jorge F. da S. Ferreira[3], Jonnathan R. da S. Sales[2], Juvenaldo F. Canjá[2] & Bruno G. M. da C. Bezerra[2]

[1] Research developed at Universidade Federal do Ceará, Departamento de Engenharia Agrícola, Fortaleza, Ceará, Brazil
[2] Universidade Federal do Ceará/Centro de Ciências Agrárias/Departamento de Engenharia Agrícola, Fortaleza, CE, Brazil
[3] U.S. Salinity Laboratory (USDA-ARS), Riverside, California, United States

HIGHLIGHTS:

The Celosia plumosa *tested in this study has satisfactory development with irrigation-water salinity up to 4.0 dS m^{-1}.*
Dry mass reduction by salinity is acceptable to the consumer when there is no harm to visual quality.
Salinity level affects leaf spectral curves of all species, most noticeable in the visible-spectrum region.

ABSTRACT: Studies on using brackish water for the irrigation of ornamental species are still scarce, mainly considering qualitative aspects of the plants. Therefore, the present study aimed to identify salt tolerance and characterize leaf spectral responses of herbaceous ornamental species at the stage of commercial seedling production. The research was carried out from December 2020 to February 2021, under greenhouse conditions, in Fortaleza - Ceará, Brazil. The experiment was conducted in a randomized block design with split plots, with main plots consisting of irrigation-water salinity levels (0.5, 2.0, 4.0, 6.0, and 8.0 dS m^{-1}), and subplots by the species *Catharanthus roseus, Celosia cristata, Celosia plumosa,* and *Chrysanthemum coronarium*, with four replications. The evaluation parameters were dry mass production, visual sensory analysis, salt tolerance, and leaf spectral responses. Plant visual quality was maintained up to 2.0 dS m^{-1} for *Chrysanthemum coronarium* and 4.0 dS m^{-1} for *Celosia cristata, Celosia plumosa,* and *Catharanthus roseus*, which were classified as moderately tolerant at those respective salinity levels. Salinity caused noticeable changes in leaf spectral responses, especially in the visible region.

Key words: biosaline agriculture, seedling production, sensory analysis, ornamental plants, remote sensing

RESUMO: Estudos sobre a utilização de águas salobras na irrigação de espécies ornamentais ainda são escassos, principalmente considerando aspectos qualitativos das plantas. Portanto, o presente estudo teve como objetivo identificar a tolerância à salinidade e caracterizar as respostas espectrais foliares de espécies ornamentais herbáceas na fase de produção de mudas para comercialização. O experimento foi realizado no período de dezembro de 2020 a fevereiro de 2021, em casa de vegetação, em Fortaleza - Ceará, Brasil. O experimento foi conduzido em delineamento de blocos casualizados, em parcelas subdivididas, sendo as parcelas compostas por níveis de salinidade da água de irrigação (0,5; 2,0; 4,0; 6,0 e 8,0 dS m^{-1}), e as subparcelas pelas espécies *Catharanthus roseus, Celosia cristata, Celosia plumosa* e *Chrysanthemum coronarium*, com quatro repetições. Foram avaliadas produção de matéria seca, análise sensorial visual, tolerância à salinidade e respostas espectrais foliares. A qualidade visual foi mantida até 2,0 dS m^{-1} para a espécie *Chrysanthemum coronarium* e até 4,0 dS m^{-1} para as espécies *Celosia cristata, Celosia plumosa* e *Catharanthus roseus,* sendo as especies classificadas como moderadamente tolerantes nas respectivas salinidades. A salinidade provocou alterações notórias nas respostas espectrais foliares, principalmente na região do visível.

Palavras-chave: agricultura biossalina, produção de mudas, análise sensorial, plantas ornamentais, sensoriamento remoto

• Ref. 276677 – Received 17 Jul, 2023
* Corresponding author - E-mail: drica_fj@hotmail.com.br
• Accepted 09 Jan, 2024 • Published 29 Jan, 2024
Editors: Ítalo Herbet Lucena Cavalcante & Hans Raj Gheyi

Introduction

The low availability of good-quality water resources in semi-arid regions has increased the interest in new alternative sources for irrigation, such as brackish water (Lacerda et al., 2021). In many irrigated areas of the Brazilian semi-arid region, groundwaters with electrical conductivity (ECw) ranging from 1.0 to 6.0 dS m^{-1} are commonly found and are used mainly in periods of scarcity of good-quality water (Lacerda et al., 2021).

Studies on the use of brackish water for irrigation and on the salt tolerance of crops that are economically important as ornamental species are still scarce (Oliveira et al., 2018). In ornamental plants, there is the need to assess salt tolerance in quantitative and qualitative terms, focusing mainly on products intended for commercialization. Recent studies confirm the potential of using moderately saline water in ornamental plants without harming the visual quality of the plants, despite reductions caused by salinity in plant growth (Neves et al., 2018; Oliveira et al., 2018; Bezerra et al., 2020).

The identification of the effects of salt stress on crops is usually done with intensive sampling and mostly by destructive methods, such as those used to quantify osmolyte production and enzymatic activity, which require the collection of plant samples. These procedures make salt-tolerance assessment time-consuming. In this regard, several studies suggest that the use of remote sensing tools, such as hyperspectral sensor images, can be applied as non-destructive techniques for the rapid quantification of biophysical and biochemical attributes of plants under stress, at the leaf or canopy level (Galieni et al., 2021).

Therefore, the present study aimed to identify salt tolerance and characterize leaf spectral responses of herbaceous ornamental species in the stage of commercial seedling production.

Material and Methods

The research was carried out from December 2020 to February 2021, in a greenhouse with a galvanized metal arched lattice structure, 3.50-m high at the ridge and 2.50-m in ceiling height, 6.40-m wide, and 12.50-m long. The cover consists of low-density polyethylene film of 0.15-mm thickness and treated with an ultraviolet radiation block, that allows 80% of solar radiation penetration, and with an anti-aphid screen on all four sides. The greenhouse was in the experimental area of the Agrometeorological Station, at the Universidade Federal do Ceará, Fortaleza - Ceará, Brazil (3º 44' 44" S; 38º 34' 50" W, 20 m above sea level).

The greenhouse's temperature and relative humidity data were monitored using a Data Logger (model HOBO® U12-012 Temp/RH/Light/Ext). The average daily values of air temperature inside the greenhouse ranged from 24.0 to 29.4 °C, while those of relative humidity ranged from 59.3 to 83.4%. Global solar radiation values were estimated based on data collected from the Fortaleza A305 climatological station at the National Institute of Meteorology - INMET and on the 80% solar radiation transparency allowed by the greenhouse plastic cover. Luminosity readings were taken between 6:00 a.m. and 6:00 p.m., which ranged from 80.90 to 402.21 W m^{-2} during the experimental period.

The experiment was conducted in a randomized block design, in a split-plot scheme, with four replications. The treatments in the plots consisted of five levels of irrigation-water salinity with the following electrical conductivity of water (ECw): 0.5 (Control), 2.0, 4.0, 6.0, and 8.0 dS m^{-1}, monitored with a portable conductivity meter. The subplots were composed of four herbaceous ornamental species: *Chrysanthemum coronarium, Celosia cristata, Celosia plumosa,* and *Catharanthus roseus*, totaling 80 experimental units. Each experimental unit consisted of 3 pots, with one seedling per pot, totaling 240 seedlings.

The control-treatment water (0.5 dS m^{-1}) was obtained by diluting well water (ECw = 0.82 dS m^{-1}) with distilled water. The preparation of the other saline treatments (2.0, 4.0, 6.0, and 8.0 dS m^{-1}) was carried out by adding NaCl, $CaCl_2.2H_2O$, and $MgCl_2.6H_2O$ salts to the well water in the equivalents of 7:2:1, respectively, obeying the relationship between ECw and its concentration (mmol$_c$ L^{-1} = ECw x 10), according to Silva et al. (1999) and Rhoades et al. (2000). The saline treatments were chosen based on previous studies on the visual quality of seedlings of ornamental species irrigated with saline waters (Oliveira et al., 2018; Bezerra et al., 2020).

Although the commercial propagation of *C. coronarium* is done by cuttings, we used seeds to produce seedlings of all species in the study with the aim of standardizing propagation. The seeds were sown (6 seeds per pot) directly in 725-mL plastic pots, filled with a substrate composed of carnauba (*Copernicia prunifera*) husks, sand, and earthworm humus in the proportion 2:1:1 (volume basis), respectively. The size of the pots and the substrate were chosen following information from local/regional ornamental plant producers. Before sowing, the substrate was irrigated with well water (ECw = 0.82 dS m^{-1}) to bring its moisture to the saturation level, followed by drainage of excess water for 24 hours.

The application of salt treatments started 12 days after sowing (DAS) when all species had emerged. Thinning was performed at 17 DAS, leaving only one seedling per pot. Each pot received 1g of NPK (10-10-10 formulation) and 0.5 g of FTE-BR12 (chemical composition: B - 1.80%, Cu - 0.8%, Mn - 2%, Zn - 9%, and S - 1%), 21 DAS, after seedlings were established and still in the vegetative stage (Bezerra et al., 2020).

Irrigation management was carried out according to the drainage lysimeter principle, seeking to maintain the soil at field capacity and applying a leaching fraction of 0.15, according to Ayers & Westcot (1999), to avoid excessive accumulation of salts in the root zone. For each species and ECw level, a pot was used as a microlysimeter. Irrigations were performed every other day, in the cooler hours of the morning, with manual application of water.

The analysis of the visual quality of the seedlings at the point of commercialization (when the plants entered the reproductive stage and flowers began to form) was performed according to Ureña et al. (1999) and Neves et al. (2018), at 53 DAS. To assess the general appearance (GA), the Hedonic scale discriminative method was applied, with nine distinct numerical points, with limits ranging from one (extremely disliked) to nine (extremely liked). Sensory analysis was carried out by a group of 100 judges, chosen at random, consisting in part of students, employees, professors at the Universidade Federal do Ceará, and, in a second location, by customers from the North Shopping Fortaleza, in Fortaleza, Ceará, Brazil. The grades assigned to the general appearance by the judges were converted into weighted averages. These notes were transformed into relative values and evaluated through regression analysis.

According to the methodology adapted from Bezerra et al. (2020), at 58 DAS, the plants were collected and split into roots, stems, leaves, and flowers to quantify the production of fresh biomass. Afterwards, the materials were placed in an oven at 65 °C for drying until reaching constant mass. Total dry mass and biomass partitioning were calculated from the data obtained after weighing the different parts of the plant, expressed in grams. Plant survival was evaluated at 58 DAS, with plants that had at least one green leaf being considered as surviving plants.

For the assessment of the salinity tolerance of the four species, data on plant height, photosynthetic rate, and shoot dry mass production were used. The height of the plants was measured from the surface of the substrate to the end of the main stem and expressed in cm. The evaluations of photosynthetic rates (A) – expressed in μmol CO_2 m^{-2} s^{-1}, were carried out on fully expanded leaves, at 50 DAS, in the morning, between 8:30 and 11:00 a.m., using a portable infrared gas analyzer (IRGA), LI-6400-40 Photosynthesis System (LI-COR Environmental, Lincoln, NE, USA). The saturating radiation used was 1,400 μmol m^{-2} s^{-1} and the CO_2 concentration was 400 mol mol^{-1} air, under ambient conditions of temperature and relative humidity.

The production of shoots dry mass (SDM) was considered the reference variable, as it indicates a better relationship with the accumulation of macromolecules and other biochemical processes. The percentages of reduction in the variables were estimated in comparison to the control treatment (ECw = 0.5 dS m^{-1}). According to this criterion, the plants were classified as: tolerant (up to 20% reduction), moderately tolerant (20.1 to 40%), moderately sensitive (40.1 to 60%), and sensitive (above 60 % reduction) (Fageria, 1985).

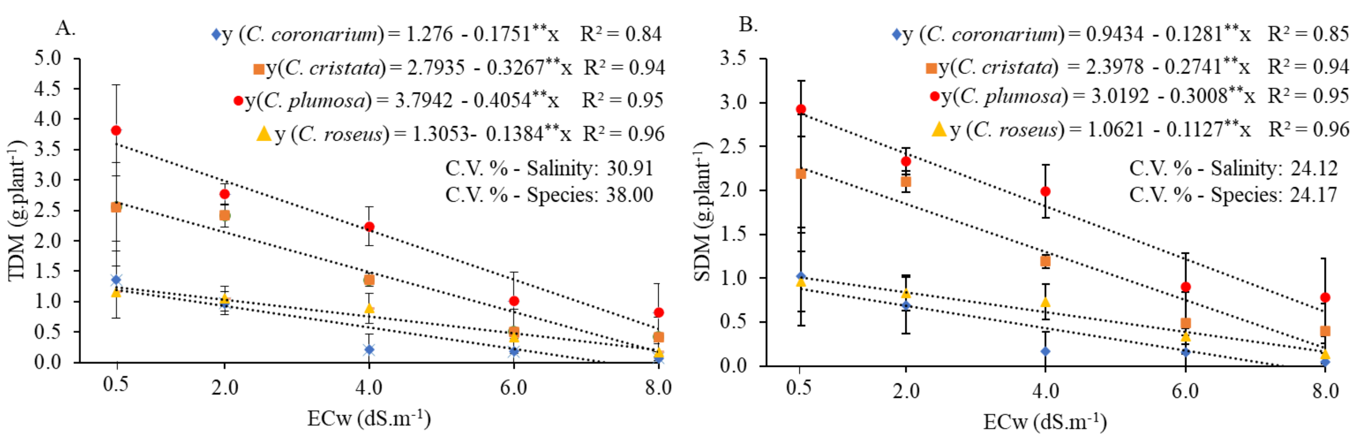
The method proposed by Oliveira et al. (2020) was used to obtain spectral readings in the laboratory. Fully expanded leaves of the middle third of each plant were collected 57 DAS, a day before the end of the experiment, identified, and immediately taken to the laboratory. The readings were carried out under constant temperature in a dark room, where the walls were coated with a dark color to avoid interference from any other light source (Oliveira et al., 2020). The spectroradiometer used in this study was the FieldSpec Pro FR 3® (Analytical Spectral Devices Inc.), whose operating range is between the 350 and 2500 nm bands, with a spectral resolution of 3 nm in the visible (VIS) and near-infrared ranges (NIR), and 10 nm in the short-wave infrared range (SWIR I and II), resampled to 1 nm.

Because some leaves were small, the Hi-Brite Contact Probe was used to collect spectral data. The probe was positioned on a fixed support, and the readings were performed on the leaves, which were stored with their respective labels. As a maximum reference standard, a high-reflectance white Spectralon plate was used for calibration at 20-minute intervals. From this value it was possible to obtain the Reflectance Factor (RF), by the proportion between the energy reflected by the leaf and the maximum reference value obtained by Spectralon. These values were converted into reflectance factors using ViewSpec Pro® software version 6.2.0 (ASD Inc., Boulder, CO, USA, www.asdi.com).

For general data analysis, the Kolmogorov-Smirnov test was applied to test normality, the F test for analysis of variance, and the Tukey test for comparison of means, all at 0.05 probability level, in addition to regression analysis. For these procedures, statistical software SISVAR®, version 5.3 was used (Ferreira, 2010).

Results and Discussion

The species *C. plumosa* and *C. cristata* had the highest means of total dry mass (Figure 1A), despite reductions of 0.41 and 0.33 g per plant for each increase of 1.0 dS m^{-1} in the electrical conductivity of the irrigation water. As irrigation-water salinity increased to the highest level, the total dry mass production of these species was reduced by 84.64 and



Vertical bars represent the standard deviation; ** - Significant at p ≤ 0.01 by the F-test

Figure 1. Total dry mass - TDM (A) and shoot dry mass - SDM (B) of tropical herbaceous ornamental species as a function of electrical conductivity of irrigation water (ECw)

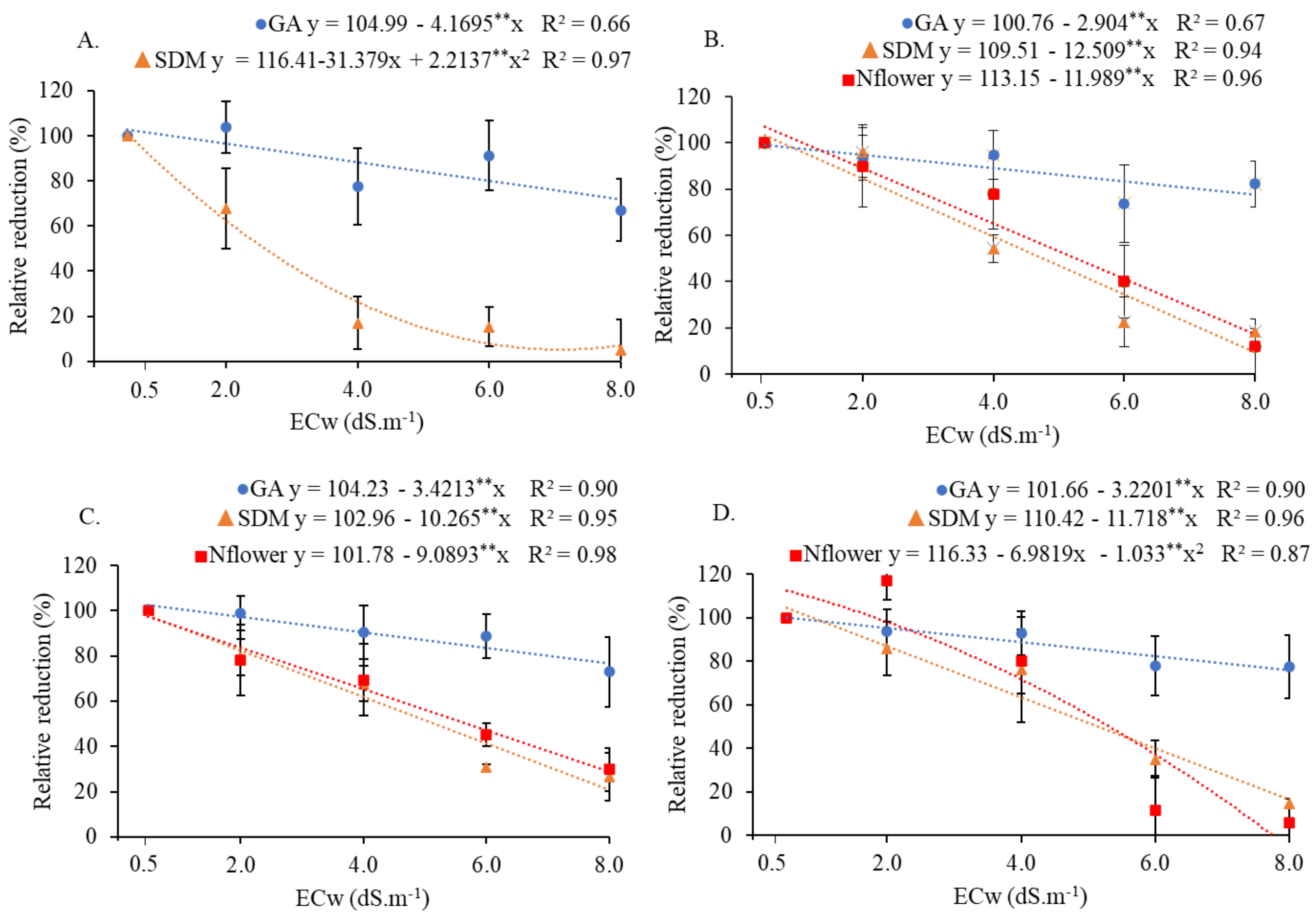
93.31%, respectively, when compared to plants irrigated with the control treatment. The species *C. roseus* and *C. coronarium* had low total dry mass production in all salinity levels, with reductions of 0.14 and 0.18 g per plant per unit increment in ECw, reaching relative reductions of 83.97 and 100%, respectively (Figure 1A).

Shoot dry mass was also reduced as irrigation-water salt concentrations increased (Figure 1B). After comparing the results of the treatments with higher and lower salinity, it was established that the reduction in shoot dry mass was more intense in *C. coronarium*, with 100%, followed by *C. cristata, C. roseus*, and *C. plumosa*, with 90.93, 84.04, and 78.64%, respectively. According to Mansour & Hassan (2022), shoots are more sensitive to short- or long-term salt stress than the underground organs (roots and tubers), with shoot dry mass being the variable more suitable for salt tolerance evaluation in ornamental plants (Oliveira et al., 2018). For both variables analyzed, total dry mass and shoot dry mass, *C. coronarium* had very low averages up to the highest level of salinity, which was established through regression analysis, in which the trend line did not reach the level of 8.0 dS m^{-1} (Figure 1A and B).

Salinity decreases soil osmotic potential and, consequently, creates a water deficit in plants, leading to a reduction in stomatal opening, reduced transpiration, inhibition of the photosynthetic process, and reduction of biomass accumulation (Pereira et al., 2020; Lacerda et al., 2020). Above the threshold salinity, a reduction in growth is observed, which may also be related to the increase in the metabolic energy demanded in the osmotic adjustment and by other adaptation mechanisms (Rhoades et al., 2000). However, species capable of performing osmotic adjustment and compartmentalization of ions in leaf cells have better rates of biomass production, growth, and survival, even under saline environments (Campos et al., 2021).

Data analysis in Figure 2 shows dissimilarity between quantitative and qualitative responses, depending on the salinity level imposed on the plants. Regardless of the species, the general appearance (visual analysis) of the plants was less impacted than the accumulation of shoot dry mass. It is possible that evaluators were influenced by the maintenance of other aspects of interest in the plants, such as color, presence or absence of flowers and absence of damage on leaves, even though the plants suffered a reduction in growth with the increase in irrigation-water salinity (Neves et al., 2018; Oliveira et al., 2018; Bezerra et al., 2020). The species *C. coronarium* showed discrepancies between the relative reductions in general appearance and shoot dry mass (Figure 2A). Decreases of 4.17% in the overall plant appearance were observed per each unit increase in ECw, while the relative reductions were more intense for shoot dry mass.

Both *C. cristata* and *C. plumosa* (Figures 2B and C) had relative reductions in relation to the control treatment, with similar trends. Above 2.0 dS m^{-1}, the number of flowers and



Vertical bars represent the standard deviation; ** – Significant at $p \leq 0.01$ by the F-test

Figure 2. Relative reduction of shoot dry mass (SDM), number of flowers (Nflower), and general appearance (GA) of *C. coronarium* (A), *C. cristata* (B), *C. plumosa* (C), and *C. roseus* (D) as a function of electrical conductivity of irrigation water (ECw)

shoot dry mass decreased sharply with increasing salinity. The general appearance of both species, however, suffered more subtle decreases. There were decreases of 12.0 and 12.5% in the variables Nflower and SDM, respectively, for the species *C. cristata*, and of 9.1 and 10.3%, respectively, for plants of *C. plumosa*, while there were reductions of 2.9 and 3.4%, respectively, for GA per unit increment in ECw.

Under the treatment of 2.0 dS m^{-1}, an increase in the number of flowers in the species *C. roseus* (Figure 2D) was observed in relation to the plants in the control treatment (0.5 dS m^{-1}), which can be an indicator of stress. However, the increase in the production of flowers under moderate salinity can contribute to a better evaluation of the visual quality of *C. roseus* plants, helping to maintain its commercial value even with lower shoot growth, as stated by Neves et al. (2018) and Oliveira et al. (2018), who evaluated *C. roseus* visual quality under salinity stress.

Table 1 presents the percentages of relative reduction applied to data on growth, photosynthesis, and shoot dry mass production of *C. coronarium*, *C. cristata*, *C. plumosa*, and *C. roseus*, according to the method proposed by Fageria (1985).

The results demonstrate that salinity impacted plant height and photosynthetic rate, but the effects were greater on dry mass production than on net photosynthetic rate. This may have different explanations, as follows: First, shoot growth may be inhibited by changes in cell wall properties, which limit cell expansion. In addition, stress can promote changes in the carbon partition, favoring greater growth of the root system. On the other hand, the rate of photosynthesis is a momentary measure, usually taken on a single leaf. Thus, it does not represent an integral measure of carbon accumulation over time, being an instantaneous expression of the effect of stress (Loudari et al., 2022; Ma et al., 2022; Dabravolski & Isayenkov, 2023).

The species *C. coronarium* had reductions of over 20% in SDM at 2.0 dS m^{-1}, being classified as moderately tolerant at this salinity level (Table 1). For the treatments of 4.0 dS m^{-1}, *C. coronarium* was classified as moderately sensitive, and as sensitive for salinities up to 6.0 and 8.0 dS m^{-1}. Plants of *C. coronarium* had sharp reductions under those salinities, indicating that irrigation of this species with water salinities above ECw 2.0 dS m^{-1} is not recommended.

The species *C. cristata* had a tolerance limit of 2.0 dS m^{-1} for SDM. However, with the increase in salinity levels, a gradual reduction in the salt-tolerance classification of this species was observed by the method proposed by Fageria (1985). These results differ from those obtained by Carter et al. (2005), who studied the production of *Celosia cristata* irrigated with saline water and stated that it was possible to produce them commercially under water salinities between 8.0 and 12.0 dS m^{-1}. These differences can be partially explained by the differences in genetic material (e.g., cultivars) tested in their study, but also due to different growing conditions, such as the use of irrigation with a complete nutrient solution and with an ECw = 2.5 dS m^{-1} during the first 20 days, before plants were subjected to treatments of higher salinity. However, this system does not represent the Brazilian commercial seedling production system.

The species *C. plumosa* can be classified as moderately tolerant up to 4.0 dS m^{-1}, considering the variables shoot dry mass production and plant height. Similar results were obtained by Bezerra et al. (2020), who studied the production of seedlings of *Celosia plumosa*, and obtained the salinity threshold of 3.5 dS m^{-1} for SDM, which supports the cultivation potential of this species under irrigation with waters of moderate salinity. Table 1 shows that the most susceptible variables for *C. plumosa*, at the same saline level, were SDM and plant height, diverging from the tolerance classification based on the net photosynthetic rate.

The species *C. roseus* also had a salinity-tolerance threshold of 2.0 dS m^{-1} and a moderate tolerance of up to 4.0 dS m^{-1} for SDM (Table 1). Similar results with this species were obtained by Oliveira et al. (2018), while Bezerra et al. (2020) stated that the tolerance threshold of *Catharanthus roseus* seedlings was 3.0 dS m^{-1}, although they reported that small reductions in shoot dry mass could be noticed at ECw = 1.5 dS m^{-1}.

Table 2 contains the percentages of plant survival at the end of the experiment for each salt treatment. It was verified that up to 4.0 dS m^{-1}, *C. plumosa*, *C. cristata*, and *C. roseus* had high survival rates of 100, 91.7, and 91.7%, respectively. Up to 8.0 dS m^{-1}, the species *C. plumosa* maintained a good survival percentage, although with severe growth inhibition. The species *C. roseus* and *C. cristata* had increasing mortality with increasing salinity and, at 8.0 dS m^{-1}, the percentage of

Table 1. Relative reduction of shoot dry mass (SDM), net photosynthetic rate (A), plant height (H), and classification regarding salt tolerance of *C. coronarium*, *C. cristata*, *C. plumosa* and *C. roseus* based on the electrical conductivity of the irrigation water (ECw)

Variables	Percent reduction (%) ECw (dS m^{-1})			
	2.0	4.0	6.0	8.0
	Chrysanthemum coronarium			
SDM	22.09 MT	51.54 MS	80.98 S	89.56 S
A	26.09 MT	50.80 MS	64.01 S	65.69 S
H	21.41 MT	49.97 MS	78.52 S	92.93 S
	Celosia cristata			
SDM	18.19 T	42.44 MS	66.68 S	90.93 S
A	8.11 T	20.57 MT	34.92 MT	51.14 MS
H	16.29 T	38.02 MT	59,75 MS	81.48 S
	Celosia plumosa			
SDM	15.73 T	36.69 MT	57.67 MS	78.64 S
A	0 T	6.31 T	28.27 MT	63.57 S
H	12.55 T	29.29 MT	46.03 MS	62.77 S
	Catharanthus roseus			
SDM	16.81 T	39.22 MT	61.63 S	84.04 S
A	6.69 T	14.21 T	20.14 MT	24.48 MT
H	16.99 T	39.65 MT	62.30 S	84.96 S

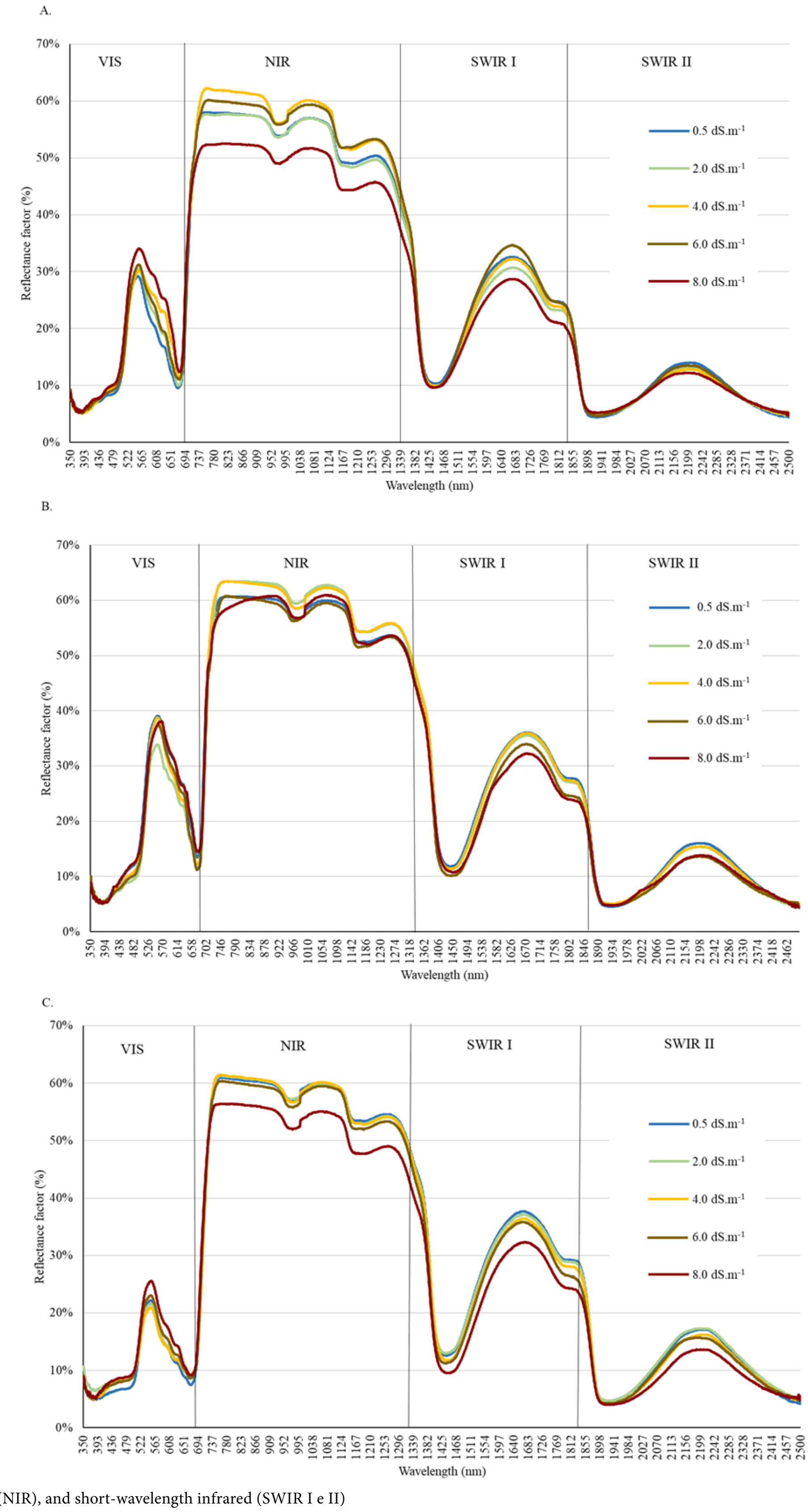
S - Sensitive; MS - Moderately sensitive; MT - Moderately tolerant; T - Tolerant; Salinity tolerance classification according to Fageria (1985)

Table 2. Survival percentage of herbaceous ornamental plants 58 days after sowing, based on the electrical conductivity of the irrigation water (ECw)

Species	Live plants at the end of the experiment (%) ECw (dSm^{-1})				
	0.5	2.0	4.0	6.0	8.0
Chrysanthemum coronarium	100	83.3	25	25	8.3
Celosia cristata	100	100	91.7	66.7	41.7
Celosia plumosa	100	100	100	83.3	91.7
Catharanthus roseus	100	100	91.7	83.3	75

dead plants reached 25 and 58.3%, respectively. *C. coronarium* plants were more sensitive to salt stress, with death rates of 16.7 and 75% in treatments of 2.0 and 4.0 dS m^{-1}, respectively.

Due to the low survival rates of *C. coronarium* plants under water salinities above 2.0 dS m^{-1}, spectral curves for this species were not generated. When analyzing the other species individually, more specific modifications were verified (Figure 3). For plants of the species *C. cristata* (Figure 3A), in the visible region (VIS), it was clear that the yellowing of the leaves followed an increasing pattern, proportional to higher



Visible (VIS), near-infrared (NIR), and short-wavelength infrared (SWIR I e II)

Figure 3. Reflectance factors (RF) in leaf samples of *Celosia cristata* (A), *Celosia plumosa* (B), and *Catharanthus roseus* (C), under different electrical conductivities of irrigation water

concentration of salts in the irrigation water. This same pattern was observed at 670 nm, which represents the red region. The deeper this valley is – that is, the lower the reflectance factor (RF) – the greater the presence of chlorophylls a and b available for photosynthesis (Xiaoyan et al., 2020). In addition, we can speculate that no difference was detected in water concentrations in the samples of all treatments because a greater water status for leaf tissues is manifested by greater depths in shortwave infrared - SWIR I and II, mainly in the absorption valleys at 1450 nm and 1900 nm (Quemada et al., 2021).

Analyzing the spectral behavior of *C. plumosa* (Figure 3B) against different levels of salt stress, it was concluded that salt was also an optically active parameter for *C. plumosa* since it triggered spectral changes. However, the particularity of this species is that there was a predominantly greenish aspect in its leaf samples under 2.0 dS m^{-1}, while salt concentration lower and higher than this value resulted in greater yellowing of the leaves.

The highest concentrations of salts in the irrigation water triggered a lower vegetative growth of the plants. The lowest depth at 670 nm and the lowest reflectance peak at 750 nm may be an indicative of adaptation to stress ensuring physiological activity of *C. plumosa* leaves. The reflectance peak around 1650 nm again appeared for this species, possibly associated with lower levels of starches, oils, and sugars for the maximum concentration of salts. Changes in the concentrations of these organic compounds are sensitive and directly proportional to the RF observed at this point in the spectrum (Lassalle, 2021).

For the species *C. roseus* (Figure 3C), it was evident that the lowest salt concentration produced the best spectral patterns among the evaluated treatments, given that in the visible region the absorption valleys at 490 nm and 670 nm were the deepest. This fact indicates a better photosynthetic potential of the leaves. According to Simkin et al. (2022), photosynthetic pigments are responsible for the predominant pattern in the visible region, reflecting incident radiation around 550 nm and absorbing electromagnetic radiation in the blue region (490 nm) and in the red region (670 nm). This pattern varies depending on the greater or lesser concentration of Chlorophyll a, an important keeper of plant biochemical functions (Gomes do Ó et al., 2021). On the other hand, leaves of *C. roseus* had a high level of reflectance factor (RF) in the near infrared (NIR) when the plants were subjected to high levels of salinity (6.0 and 8.0 dS m^{-1}), indicating an unfavorable condition for the photosynthetic process under severe salt stress.

For these three species represented in Figure 3, salinity was an optically active parameter, since it triggered changes in their spectral curves that became even more relevant in the visible region, considering that the main commercial allure of these crops is their appearance. Therefore, presenting satisfactory levels of texture, form, size, and color even when subjected to moderate levels of salinity would make an ornamental species desirable for commercial production with brackish water. However, it was not possible to detect differences in leaf water status in these three species based on spectral responses. Trindade et al. (2006), in a study with cowpea plants, showed that under saline stress, plants seek to maintain leaf hydration to regulate the concentration of salts in leaf tissues, which may contribute to reducing the harmful effects of salts on plant growth. This response, however, may vary among plant species and their cultivars, being more common in dicotyledonous species.

Conclusions

1. *Celosia plumosa, Catharanthus roseus,* and *Celosia cristata* were classified as tolerant and moderately tolerant up to 2.0 and 4.0 dS m^{-1} water salinity, respectively. *Chrysanthemum coronarium* was moderately tolerant (up to 2.0 dS m^{-1} water salinity) and moderately sensitive (up to 4.0 dS m^{-1}) to water salinity.

2. The visual quality of the plants was maintained up to water salinity of 2.0 dS m^{-1} for the species *Chrysanthemum coronarium* and up to 4.0 dS m^{-1} for the species *Celosia cristata*, *Celosia plumosa,* and *Catharanthus roseus*.

3. The spectral curves of *Celosia cristata*, *Celosia plumosa*, and *Catharanthus roseus* showed that salinity trigger changes in the spectral responses of the leaves of the plants, especially in the visible region.

Acknowledgments

Acknowledgments are due to the Conselho Nacional de Desenvolvimento Científico e Tecnológico - CNPq for the financial support provided for this research (Process number 309174/2019-8) and award of fellowship to the first author. The authors also thank the Agência de Desenvolvimento do Estado do Ceará - ADECE and Secretaria do Desenvolvimento Econômico do Estado do Ceará - SDE for additional financial support for our research.

Literature Cited

Ayers, R. S.; Westcot, D. W. A qualidade da água na agricultura. Estudos FAO: Irrigação e Drenagem, 29 Rev., 2.ed. Campina Grande: PB, 1999. 153p.

Bezerra, F. M. S.; Lacerda, C. F. de; Ruppenthal, V.; Cavalcante, E. S.; Oliveira, A. C. de. Salt tolerance during the seedling production stage of *Catharanthus roseus, Tagetes patula* and *Celosia argentea*. Revista Ciência Agronômica, v.51, p.1-9, 2020. https://doi.org/10.5935/1806-6690.20200059

Campos, A. J. de. M.; Santos, S. M.; Nacarath, I. R. F. F. Water stress in plants: a review. Research, Society and Development, v.10, p.1-7, 2021. https://doi.org/10.33448/rsd-v10i15.23155

Carter, C. T.; Grieve, C. M.; Poss, J. A.; Suarez, D. L. Production and ion uptake of *Celosia argentea* irrigated with saline wastewaters. Scientia Horticulturae, v.106, p.381-394, 2005. https://doi.org/10.1016/j.scienta.2005.04.007

Dabravolski, S, A.; Isayenkov, S., V. The regulation of plant cell wall organization under salt stress. Fronteirs in Plant Science, v.14, p.1-16, 2023. https://doi.org/10.3389/fpls.2023.1118313

Fageria, N. K. Salt tolerance of rice cultivars. Plant and Soil, v.88, p.237-243, 1985. https://doi.org/10.1007/BF02182450

Ferreira, D. F. Sisvar®: Sistema de análise de variância para dados balanceados, versão 5.3. Lavras: DEX/UFLA, 2010.

Galieni, A.; D'Ascenzo, N.; Stagnari, F.; Pagnani, G.; Xie, Q.; Pisante, M. Past and future of plant stress detection: an overview from remote sensing to positron emission tomography. Frontiers in Plant Science, v.11, e609155, 2021. https://doi.org/10.3389/fpls.2020.609155

Gomes do Ó, L. M.; Cova, A. M. W.; Silva, P. C. C.; Gheyi, H. R.; Azevedo Neto, A. D. de.; Ribas, R. F. Aspectos bioquímicos e fluorescência da clorofila a em plantas de minimelancia hidropônica sob estresse salino. Irriga, v.26, p.221-239, 2021. https://doi.org/10.15809/irriga.2021v26n2p221-239

Lacerda, C. F. de.; Gheyi, H. R.; Medeiros, J. F. de.; Costa, R. N. T.; Sousa, G. G. de.; Lima, G. S. de. Strategies for the use of brackish water for crop production in Northeastern Brazil. In: Taleisnik, E.; Lavado, R.S. (eds.). Saline and alkaline soils in Latin America. Cham: Springer, 2021. Chap.4, p.71-99.

Lacerda, C. F. de.; Oliveira, E. V. de.; Neves, A. L. R.; Gheyi, H. R.; Bezerra, M. A.; Costa, C. A. G. Morphophysiological responses and mechanisms of salt tolerance in four ornamental perennial species under tropical climate. Revista Brasileira de Engenharia Agrícola e Ambiental, v.24, p.656-663, 2020. https://doi.org/10.1590/1807-1929/agriambi.v24n10p656-663

Lassalle, G.; Monitoring natural and anthropogenic plant stressors by hyperspectral remote sensing: Recommendations and guidelines based on a meta-review. Science of the Total Environment, v.788, p.1-20, 2021. https://doi.org/10.1016/j.scitotenv.2021.147758

Loudari, A.; Mayane, A.; Zeroual, Y.; Colinet, G.; Oukarroum, A. Photosynthetic performance and nutrient uptake under salt stress: Differential responses of wheat plants to contrasting phosphorus forms and rates. Frontiers in Plant Science, v.13, p.1-16, 2022. https://doi.org/10.3389/fpls.2022.1038672

Ma, L.; Liu, X.; Lv, W.; Yang, Y. Molecular mechanisms of plant responses to salt stress. Fronteirs in Plant Science, v.13, p.1-16, 2022. https://doi.org/10.3389/fpls.2022.934877

Mansour, M.M.F.; Hassan, F.A.S. How salt stress-responsive proteins regulate plant adaptation to saline conditions. Plant Molecular Biology, v.108, p.175-224, 2022. https://doi.org/10.1007/s11103-021-01232-x

Neves, A. L. R.; Lacerda, C. F. de.; Oliveira, A. C. de.; Sousa, C. H. C.; Oliveira, F. I. F.; Ribeiro, M. da. S. de. S. Quantitative and qualitative responses of *Catharanthus roseus* to salinity and biofertilizer. Revista Brasileira de Engenharia Agrícola e Ambiental, v.22, p.22-26, 2018. https://doi.org/10.1590/1807-1929/agriambi.v22n1p22-26

Oliveira, E. V. de.; Lacerda, C. F. de; Neves, A. L. R.; Gheyi, H. R.; Oliveira, F. I. F.; Oliveira, D. R.; Viana, T. V. de. A. A new method to evaluate salt tolerance of ornamental plants. Theoretical and Experimental Plant Physiology, v.30, p.173-180, 2018. https://doi.org/10.1007/s40626-018-0112-7

Oliveira, M. R. R. de.; Queiroz, T. R. G.; Teixeira, A. dos. S.; Moreira, L. C. J.; Leão, R. A. de. O. Reflectance spectrometry applied to the analysis of nitrogen and potassium deficiency in cotton. Revista Ciência Agronômica, v.51, e20196705, 2020. https://doi.org/10.5935/1806-6690.20200074

Pereira, F. H. F.; da. S. e. Silva, L. J.; Silva, F. de. A. da.; Dias, M. dos. S. Trocas gasosas, eficiência fotoquímica e potencial osmótico de plantas de tomate submetidas a condições salinas. PesquisAgro, v.3, p.36-51, 2020. https://doi.org/10.33912/pagro.v3i1.656

Quemada, C.; Pérez-Escudero, J.M.; Gonzalo, R.; Ederra, I.; Santesteban, L. G.; Torres, N.; Iriarte, J.C. Remote sensing for plant water content monitoring: A review. Remote Sensing, v.13, p.1-37, 2021. https://doi.org/10.3390/rs13112088

Rhoades, J. D.; Kandiah, A. M.; Marshali, A. M. Uso de águas salinas para produção agrícola. Campina Grande: UFPB. 2000. 117p.

Silva, L. G. de A.; Gheyi, H. R.; Medeiros, J. F. de. Composição química de águas do cristalino do nordeste brasileiro. Revista Brasileira de Engenharia Agrícola e Ambiental, v.3, p.11-17, 1999. https://doi.org/10.1590/1807-1929/agriambi.v3n1p11-17

Simkin, A.J.; Kapoor, L.; Doss, C.G.P.; Hofmann, T. A.; Lawson, T.; Ramamoorthy, S. The role of photosynthesis related pigments in light harvesting, photoprotection and enhancement of photosynthetic yield in plant. Photosynth Research, v.152, p.23-42, 2022. https://doi.org/10.1007/s11120-021-00892-6

Trindade, A. R.; Lacerda, C. F. de; Gomes Filho, E.; Prisco, J. T.; Bezerra, M. A. Influência do acúmulo e distribuição de íons sobre a aclimatação de plantas de sorgo e feijão-de-corda, ao estresse salino. Revista Brasileira de Engenharia Agrícola e Ambiental, v.10, p.804-810, 2006. https://doi.org/10.1590/S1415-43662006000400004

Ureña, M. P.; D'árrigo, M. H.; Girón, O. M. Evaluación sensorial de los alimentos. Lima: Universidade Nacional Agrária La Molina. 1999, 197p.

Xiaoyan, W.; Zhiwei, L.; Wenjun, W.; Jiawei, W. Chlorophyll content for millet leaf using hyperspectral imaging and an attention-convolutional neural network. Ciência Rural, v.50, e20190731, 2020. https://doi.org/10.1590/0103-8478cr20190731