https://doi.org/10.1186/s43170-024-00216-3

CABI Agriculture and Bioscience

RESEARCH

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Contrasting salinity effects of artificial seawater and sodium chloride on *Carica papaya* L. cultivar Red Lady physiology and growth

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Abstract

Background Many coastal areas of the world will be impacted by seawater intrusion inland exposing crops to increasing levels of soil salinity. Studies of salinity stress in horticultural crops, including papaya, invariably use NaCl as the salt source, which may not be indicative of seawater.

Methods This study compared plant growth, physiological, and nutritional responses, including leaf gas exchange, maximal potential quantum efficiency of photosystem II (the ratio of variable to maximum chlorophyll fluorescence; *Fv/Fm*), the leaf chlorophyll index (*LCI*), electrolyte leakage (*EL*), leaf relative water content (*RWC*), leaf water potential (Ψw), leaf osmotic potential (Ψo), leaf and root N, P, K, Ca, Mg, Na and Cl contents, and growth of potted 'Red Lady' papaya plants, in a calcined clay substrate, irrigated with NaCl or artificial seawater (Instant Ocean®) at six soil electrical conductivity (EC) levels (0, 1, 2, 3, 4 or 6 dS m^{-1}).

Results There were slight significant reductions in Ψw, Ψo, net CO_2 assimilation (*A*), stomatal conductance (g_s), and transpiration (*Tr*) with increasing EC regardless of the salt source. Leaf Ca, Mg, Na and Cl contents and root Mg, Na, and Cl increased significantly with increasing EC levels. For both salt sources, there was an indication of osmotic adjustment and tolerance of papaya up to an EC level of 6 dS m^{-1}. A significant difference between the response to NaCl and artificial seawater was observed for plant height, leaf Mg and Cl contents, and root Mg and Na contents.

Conclusion The use artificial seawater may be a better source than NaCl for studying papaya responses to increasing soil salinity.

Keywords *Carica papaya*, Turface, Leaf gas exchange, Instant Ocean®

Background

Soil salinity is one of the main abiotic stresses affecting crop plants worldwide resulting in yield reductions due to osmotic effects, ionic toxicity, and nutritional deficiencies (Dourado et al. 2022; Khasanov et al. 2023). Many coastal areas of the world are expected to be impacted by increasing sea levels and saltwater intrusion inland due to global climate change, which may lead to the exposure of crops to increasing levels of soil salinity (Jeen et al. 2021; Panthi et al. 2022). Seawater intrusion can cause groundwater salinization, which is characterized by increased concentrations of major groundwater constituents, such as Na, Mg, Cl, and SO_4, and high electrical conductivity (EC) or total dissolved solids (TDS) (Jeen et al. 2021). Thus, the phenomenon degrades the

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quality of groundwater and is therefore of significant concern in many regions of the world.

Effects of root-zone salinity on plants have been studied for many vegetable and fruit crops, including cucumber (*Cucumis sativus* L.) (Wang et al. 2023), sugar beet (*Beta vulgaris* L.) (Liu et al. 2023), sorghum (*Sorghum bicolor* (L.) Moench.) (Dourado et al. 2022), bean (*Vigna unguiculata* L.) (Dourado et al. 2019), maize (*Zea mays* L.) (Shabaan et al. 2022), mango (*Mangifera indica* L.) (Laxmi et al. 2021), cashew (*Anacardium occidentale* L.) (Sousa et al. 2023), grape (*Vitis vinifera* L.) (Mozafari et al. 2018) and guava (*Psidium guajava* L.) (Bezerra et al. 2018). To our knowledge, all previous studies with fruit and vegetable crops used NaCl as the salt source. An exception to this is a preliminary study by Marler (2018), who found that young papaya (*Carica papaya* L.) and sapodilla (*Manilkara zapota* Van Royen) plants exhibited different growth and developmental effects when roots were exposed to salinity from seawater versus exposure to NaCl. Thus, plant responses to root zone salinity from seawater can be different from those of exposure to NaCl. Some ecological and physiological studies of native riparian or seashore plants used artificial seawater as the salt source (Tootoonchi and Gettys 2019; Hanley et al. 2020; Tootoonchi et al. 2020, 2022) because it more closely resembles seawater without the variability of natural seawater. To be able to mitigate crop salinity stress, it will be important to understand the physiological crop responses to soil salinity and determine if root exposure to NaCl elicits the same response as root exposure to seawater.

Papaya is one of the most cultivated fruit crops in tropical and subtropical areas (Álvarez-Méndez et al. 2022; Koul et al. 2022; Ruas et al. 2022). Previous studies of salt tolerance of this species have yielded conflicting results (Peçanha et al. 2017; Dias et al. 2020; Álvarez-Méndez et al. 2022; Targino et al. 2023). Peçanha et al. (2017) investigated the influence of five levels of salinity (1.0, 1.6, 2.2, 2.8 or 3.4 dS m^{-1}) on leaf gas exchange of papaya and suggested that the photochemical capacity of the plants was not negatively affected up to EC levels of 3.4 dS m^{-1} and highlighted the importance of considering salinity as a relevant abiotic condition for papaya plantations and the need for more research in this area. All reports of salinity effects on papaya, with the exception of Marler's (2018), used NaCl as the salt source added either to the soil (Sousa et al. 2019), a potting medium (Dias et al. 2020; Álvarez-Méndez et al. 2022; Targino et al. 2023), or a hydroponic solution (Refahi and Shahsavar 2017). The objective of this study was to evaluate differences in responses of papaya between root zone exposure to NaCl versus exposure to artificial seawater. The hypothesis tested was that physiological plant responses to salinity from root zone exposure to NaCl are different from those of exposure to artificial seawater. The specific objectives were: to compare leaf gas exchange [net CO_2 assimilation (*A*), stomatal conductance (*gs*), and transpiration (*Tr*)], the ratio of variable to maximum chlorophyll fluorescence (*Fv/Fm*), the leaf chlorophyll index (LCI), leaf water (Ψw) and osmotic (Ψo) potentials, electrolyte leakage, relative water content (RWC), leaf and root N, P, K, Ca, Mg, Na and Cl contents and growth of papaya plants at six different salinity levels (EC of 0, 1, 2, 3, 4, or 6 dS m^{-1}) from applications of either artificial seawater or NaCl.

Methods

Study site and plant material

The experiment was conducted in a temperature-controlled greenhouse at the University of Florida, Tropical Research and Education Center, Homestead, Florida, USA (25.5°N longitude and 80.5°W latitude) from February to May 2022. Air temperature and relative humidity in the greenhouse were monitored with a HOBO Prov v2 datalogger (Onset Computer Corp., Bourne, MA, USA) located 1 m above the top of the plant canopies. The temperature ranged from 14 to 33 °C with an average of 25 °C. Relative humidity ranged from 20 to 89%, with an average of 53% (Fig. 1).

'Red Lady' papaya seeds were sown in trays with ProMix® substrate (Premier Tech, Quebec, Canada). After 70 days, the seedlings were transplanted into 3.79-L (volume) plastic pots with the same substrate, where they remained for 5 months. After transplanting, plants were fertilized with 20–20–20 (N–P–K) soluble fertilizer (Peters Professional®, J.R. Peters Inc., Allentown, PA, USA) at a rate of 1 g N $plant^{-1}$ $month^{-1}$ and irrigated daily with tap water. After five months, plants were transplanted into 8.5-L (volume) plastic pots filled with 5 kg of a 1:1 (v/v) mixture of Turface MVP® and Turface Profile Greens Grade® (Profile Products LLC, Buffalo Grove, IL, USA), an inert calcined clay substrate. Plants in the greenhouse were manually irrigated with deionized water daily until there was slight drainage from the bottom of the pots to guarantee good plant establishment before the salinity treatments were initiated. After one month of irrigation with deionized water, salinity treatments were applied for 8 weeks. During the eight weeks of the experiment, plants were fertilized with 500 mL per pot of Hoagland's solution (Hoagland and Arnon 1950) every 3 weeks.

Experimental design

Treatments consisted of six levels of EC corresponding to 0 (deionized water), 1, 2, 3, 4, or 6 dS m^{-1} from NaCl salts or artificial seawater from Instant Ocean® (Aquarium Systems, Blacksburg, VA, USA) formulated to represent the chemical composition of seawater (https://www.insta

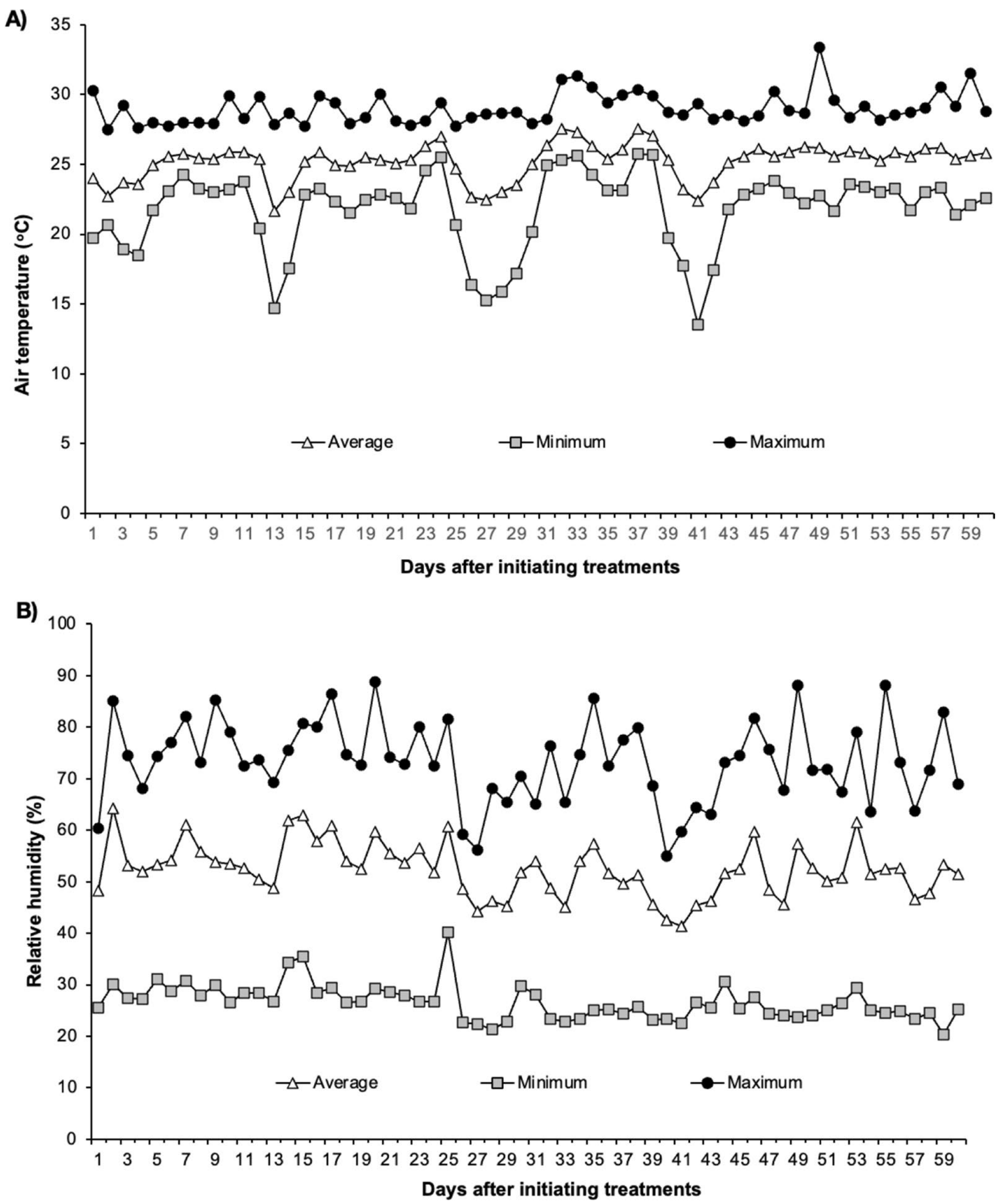

Fig. 1 Minimum, average, and maximum air temperature (**A**) and relative humidity (**B**) in the greenhouse during the 60 days of the experiment

ntocean.com/products/sea-salt-mixes/sea-salt-mixture.aspx). There were five-single plant replicates per treatment arranged in a randomized complete block design.

Leaf gas exchange

Net CO_2 assimilation (*A*), stomatal conductance of water vapor (*gs*), and transpiration (*Tr*) were measured with a CIRAS-3 portable gas analyzer (PP Systems, Amesbury, MA, USA) at a photosynthetic photon flux in the leaf cuvette of 1000 μmol quanta m^{-2} s^{-1}, a reference CO_2 concentration in the leaf cuvette of 375 μmol CO_2 mol^{-1}, and an air flow rate of 200 ml min^{-1} into the cuvette. Measurements were made on the first fully expanded leaf (usually the 5th leaf from the stem apex) according to Vincent et al. (2018) on each plant at 2, 8, 26, 38, and 60 days after initiation of the salinity treatments.

Chlorophyll fluorescence and leaf chlorophyll index

The maximal potential quantum efficiency of photosystem II (the ratio of variable to maximum chlorophyll fluorescence; *Fv/Fm*) was measured with a OS30p+portable fluorometer (Opti-Sciences, Inc., Hudson, NH, USA) at 2, 8, 26, 38, and

60 days after initiation of salinity treatments. The measured leaf section was adapted to the dark for 30 min prior to each chlorophyll fluorescent measurement. The leaf chlorophyll index (LCI) was measured with a SPAD meter (Minolta Instruments, Kyoto, Japan) on the same dates.

Leaf water and osmotic potentials

Leaf water potential (Ψw) was determined at noon for 8 weeks after starting the salinity treatments with a Scholander pressure chamber (1515D, PMS Instrument Company, Albany, Oregon, USA). The total osmolality of the leaf tissue used to determine the osmotic potential (Ψo) using leaf sap samples was obtained by leaf maceration in liquid nitrogen. The sap samples were placed in Eppendorf tubes and centrifuged at 10,000*g* for 15 min at 4 °C. A 10 μL aliquot of the supernatant was used to determine the total osmolality of the leaf tissue using a vapor pressure osmometer (Vapro 5600, Wescor, Inc., Logan, UT, USA). The Ψo was calculated using the Van't Hoff equation (Paulino et al. 2020).

Electrolyte leakage

Cell membrane integrity was evaluated 8 weeks after the beginning of the salinity treatments by determining the leakage of electrolytes from the leaf tissue. Ten 1-cm diameter leaf discs were immersed in 30 mL of distilled water for 24 h, followed by the determination of free electrical conductivity (EC_F) of the solution with a benchtop conductivity meter. The samples were then subjected to a water bath at 95 °C for 1 h for subsequent determination of the total electrical conductivity (EC_T). These data were used to calculate the percentage of electrolyte leakage using the EC_F/EC_T ratio *100 (Paulino et al. 2020).

Relative water content (RWC)

Leaf relative water content (RWC) was measured by sampling one leaf disc per plant from 11:00 to 12:00 h at 8 weeks after the beginning of the salinity treatments, measuring the fresh weight, floating the disc on deionized water for 24 h, re-weighing, and oven drying the disc at 70 °C for 24 h. The oven-dry leaf disc weight was then determined, and the leaf RWC was calculated as:

$\%RWC = (\text{Fresh weight} - \text{Dry weight}) / (\text{Turgid weight} - \text{Dry weight}) \times 100$ (Barrs and Weatherley 1962)

Plant growth and nutrient contents

At the end of the experiment, height of all plants was measured. Plant tissues were then oven dried at 70 °C to a constant weight and root, stem, and leaf dry weights were determined.

Dried tissue samples were ground to a fine powder using an electrical blender. Leaf and root Cl concentrations were determined by extraction in water and titration with silver nitrate (Malavolta et al. 1997). Leaf and root tissue N, P, K, Ca, Mg, and Na were determined at the University of Florida, USA, Analytical Research Laboratory in Gainesville, Florida where N concentrations were determined by the Kjehdahl technique and P, K, Ca, Mg, and Na concentrations were determined by inductively coupled plasma emission spectrometry (Hanlon et al. 1994).The electrical conductivity of the drainage water was measured 6 weeks after starting the salinity treatments (Fig. 2).

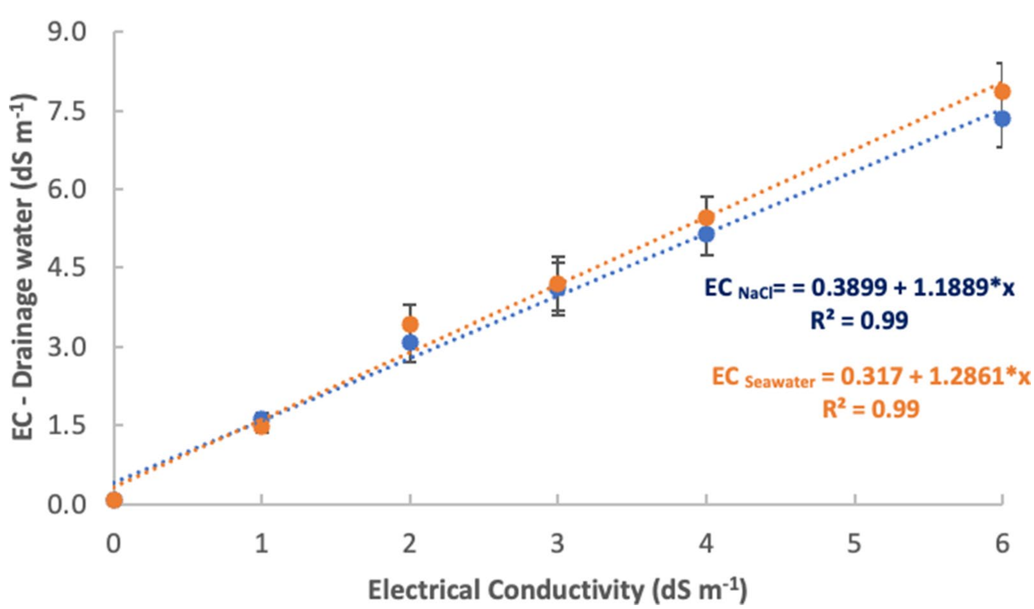

Fig. 2 Electrical conductivity of the drainage water for each EC treatment 6 weeks after starting the salinitytreatments. Symbols represent the means of each treatment and bars indicate ± std. dev. An asterisk indicates asignificant difference with P < 0.05

Data analyses

Plant physiology and growth data were analyzed by a two-way analysis of variance (ANOVA) to determine interactions between water source (NaCl and artificial seawater) and salinity treatment (soil EC level). Effects of salinity level were determined by linear and quadratic regression and differences between salinity source were compared using a Student's T-test. All data were analyzed with SAS statistical software (SAS Institute, Cary, NC, USA).

Results

Statistical overview

There were no significant interactions ($P > 0.05$) between salt source and EC level for any of the variables analyzed. There was a significant effect ($P > 0.05$) of the EC level on *A*, *gs*, *Tr*, Ψw, Ψo, and Ca, Mg, Na and Cl contents in the leaf, as well as Mg, Na and Cl contents in the root. A significant difference ($P \leq 0.05$) between salt source was observed for plant height and Mg and Cl contents in the leaves, and Mg and Na contents in the roots. There was no significant effect ($P > 0.05$) of salt source on leaf, stem, or root dry weights, leaf N, P, K contents, root N, P, K, Ca contents, electrolyte leakage, RWC, *Fv/Fm*, or the LCI on all measurement dates.

Leaf water and osmotic potentials

Slight linear decreases in Ψw and Ψo (Fig. 3a, b) were observed with increasing EC of the irrigation water. There was no significant difference ($P > 0.05$) between NaCl and artificial seawater for these variables. Leaf water potential ranged from – 0.75 Mpa for the EC of 0 dS m^{-1} to – 1.31 Mpa for the EC of 6 dS m^{-1} (Fig. 3a).

Table 1 Mean and standard deviation of maximum potential quantum efficiency of photosystem II (ratio of variable to maximum chlorophyll fluorescence; *Fv/Fm*) and leaf chlorophyll index (LCI; SPAD values) at 2, 8, 26, 38 and 60 days after initiation (DAI) of salinity treatments

DAI	Fv/Fm		LCI	
	NaCl	Seawater	NaCl	Seawater
2	0.73 ± 0.06	0.76 ± 0.05	55.81 ± 4.18	55.28 ± 5.06
8	0.82 ± 0.01	0.82 ± 0.01	56.35 ± 5.43	55.13 ± 5.31
26	0.81 ± 0.01	0.81 ± 0.01	45.78 ± 5.48	45.89 ± 5.64
38	0.81 ± 0.01	0.82 ± 0.01	42.39 ± 3.00	42.63 ± 4.67
60	0.81 ± 0.02	0.81 ± 0.01	43.79 ± 3.70	44.65 ± 4.34

For Ψo, values ranged from – 1.40 MPa for the EC of 0 dS m^{-1} to – 1.90 MPa for the EC of 6 dS m^{-1} (Fig. 3b).

Leaf gas exchange

For all leaf gas exchange variables, there was no significant difference among salinity levels on days 2, 8, 26, and 38 for each salinity source. On day 60, significant differences in *A*, g_s, and *Tr* were observed between EC levels of 0 and 6 dS m^{-1} for each salinity source (Fig. 4A–C).

Chlorophyll fluorescence and leaf chlorophyll index

There was no significant effect of salinity levels and water sources on *Fv/Fm* or the LCI (Table 1).

Leaf, stem, and root dry weights, plant height, relative water content and electrolyte leakage

There was no significant effect of salinity level or salinity source on leaf, stem, or root dry weight, RWC, electrolyte

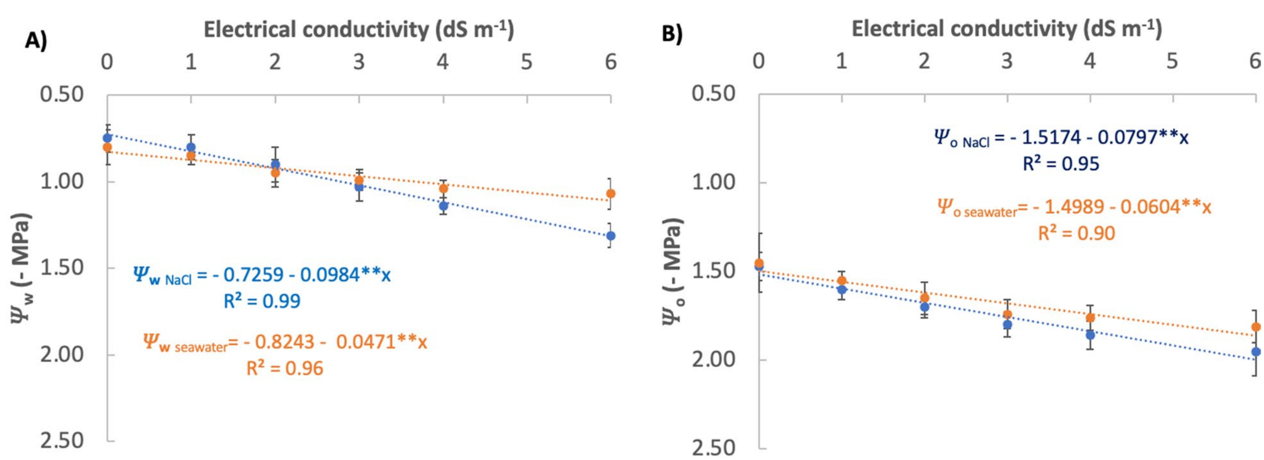

Fig. 3 **A**) Leaf water potential (Ψw) and **B**) leaf osmotic potential (Ψo) of papaya irrigated with saline water at different electrical conductivities after 8 weeks of application of the salinity treatments. Symbols represent the means of each treatment and bars indicate ± std. dev. Double asterisks indicates a significant difference with P<0.05

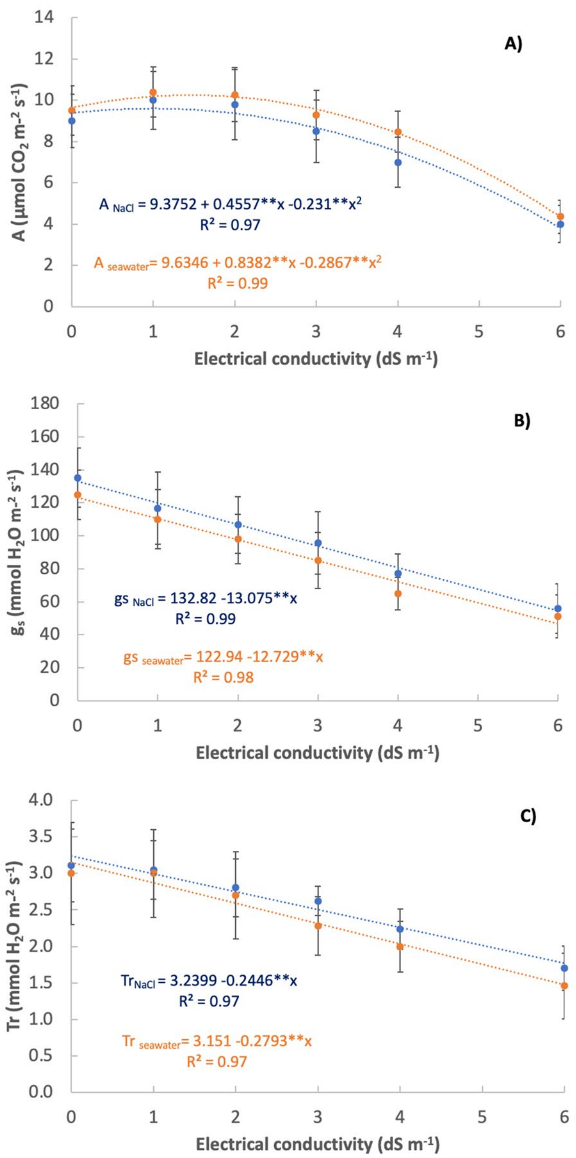

Fig. 4 **A**) Net CO2 assimilation (A), **B**) Stomatal conductance (gs), and **C**) Transpiration (Tr) of papaya 60 days after starting the salinity treatments. Symbols represent the means of each treatment and bars indicate ± std. dev. Double asterisks indicate a significant difference with P

leakage or plant height (Fig. 5A–E). Plant height was greater for the seawater (148 cm) than the NaCl (140 cm) source (Fig. 5F).

Nutrient contents in leaves and roots

The levels of Ca, Mg, Na, and Cl in the leaves and Mg, Na, and Cl in the roots increased as a function of the electrical conductivity level, regardless of the source of water used (Fig. 6). The contents of Mg in the leaves and roots and Ca in leaves were higher for the artificial seawater treatment, whereas for the NaCl treatment, Na and Cl in the leaves and roots were higher for all salinity levels.

The Mg and Cl contents in the leaves (Fig. 7A) and Mg and Na contents in the roots (Fig. 7B) were affected by salinity source. The Mg content was higher in the leaves and roots when plants were irrigated with artificial seawater compared to irrigation with NaCl. The Cl content in the leaves and Na content in the roots were higher for plants irrigated with NaCl than with seawater.

There was no significant effect of salinity level or salinity source on N, P, K, or Ca in the roots (Table 2).

Discussion

There were some effects of the source of salt in the irrigation water (NaCl or artificial seawater) or the salinity levels tested on plant physiology and growth of 'Red Lady' papaya in the inert potting medium tested. For each salt source, there was no effect of salinity on physiology or growth until salinity of the irrigation water was 6 dS m^{-1}, which may be indicative of a possible tolerance of this cultivar to salinity according with Zahra et al (2022). The slight significant decrease observed in *A*, g_s, *Tr, Ψw, Ψo,* due to the increase in salinity for the two salt sources, were not sufficient to reduce papaya growth, since there was no significant difference in leaf, stem or root biomass among salinity treatments. Marler (2018) found significative differences in foliar concentrations of Na and Cl for papaya between natural seawater and NaCl sources at EC levels of 8 and 20 dS m^{-1}. However, biomass and physiological data were not presented in that study, which prevents direct comparison with our results. For assessing crop responses to salinity, it is important to assess the EC of the soil solution or drainage water, because interactions between the salts in the irrigation water and the type of substrate may occur. Usually, the EC of the soil solution is higher than the EC of the irrigation water, especially in the field. In the present study the inert calcined clay substrate (Turface) allowed the EC of the potting medium to be close to the EC of the irrigation water (Fig. 7). Leal et al. (2020) observed that the EC of the soil saturation extract can reach twice the EC of the irrigation water, depending on the type of soil and irrigation management. In this context, papaya tolerance to salinity should be evaluated with higher salinity levels in actual soil. In a subsequent, preliminary study of the response of 'Red Lady' papaya in Krome very gravelly loam soil (the soil in the papaya production areas of southern Florida), potted plants showed similar sensitivity to irrigation with artificial seawater (Instant Ocean®) as was observed in the present study using calcined clay as the substrate (unpublished data).

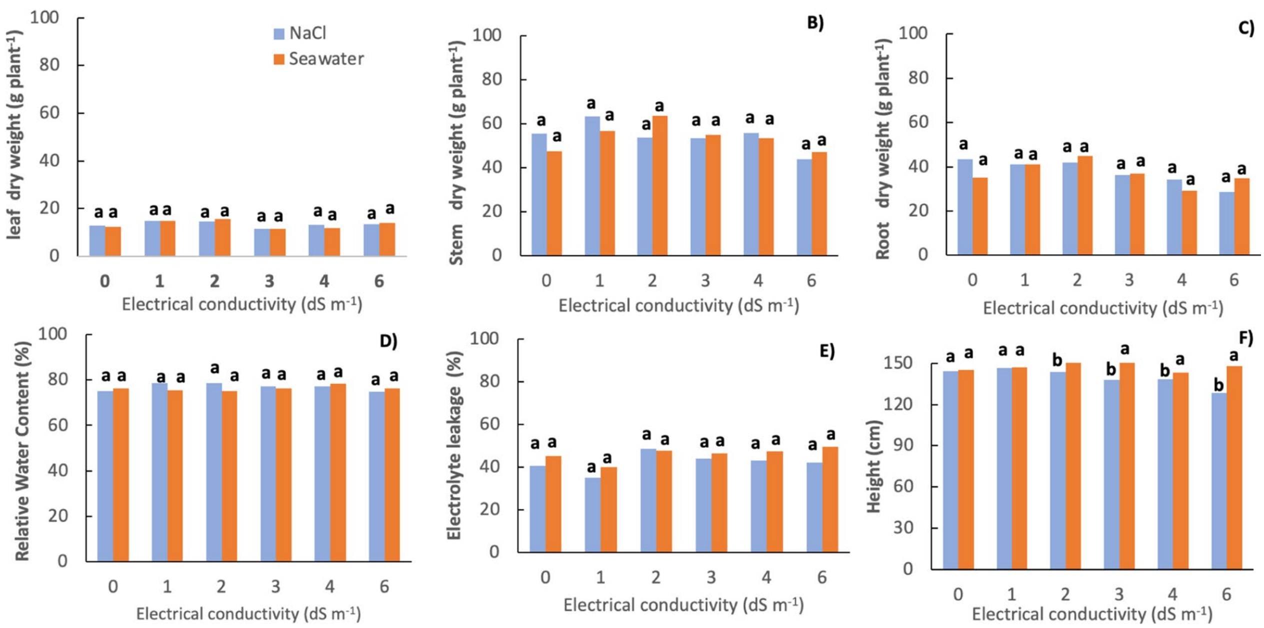

Fig. 5 Dry weight of **A**) leaves, **B**) stems, **C**) roots, **D**) Relative water content (RWC), **E**) Electrolyte leakage, and **F**) height of papaya plants eight weeks after the start of the salinity treatments. Orange bars represent seawater and blue bars represent NaCl. Different lowercase letters indicate a significantly difference between salt sources ($P \leq 0.05$)

Tootoonchi and Gettys (2019) tested the influence of four salt sources (seawater, Instant Ocean®, NaCl and Morton Sea Salt) on the growth of two aquatic plants, *Vallisneria americana* and *Hydrilla erticillata* under four salinity levels (0.5, 1.0, 2.5 or 5.0 ppt—parts per thousand equivalent to EC of 0.9, 1.6, 3.8 and 7.5 dS m^{-1} for seawater and 1.0, 2.0, 4.8 and 9.6 dS m^{-1} for NaCl) in a potted plant experiment in two types of substrates, sand and a soil. Their results showed that the effects on plant biomass were similar for Instant Ocean® and natural seawater, leaving them to conclude that the use of Instant Ocean® to mimic the seawater is appropriate. The salt source did not affect biomass of *H. erticillate* until salinity levels were 2.5 ppt or higher. Evidence of stress in *H. erticillate* was more obvious at higher salinities. In contrast, salt source significantly affected biomass of *V. americana* regardless of the salinity level. Both plant species were more susceptible to damage when salinity was induced using Morton table salt or NaCl as a salt source versus Instant Ocean® or natural seawater. The authors did not evaluate the nutrient content in the plant tissue or leaf gas exchange. They highlighted that the Na content was about 16% higher in a 5.0 ppt solution when salinity was induced using NaCl or Morton table salt versus Instant Ocean® or natural seawater, which negatively impacted plant growth.

Monteiro et al. (2021), Melo et al. (2018), Oliveira et al. (2016) and Duarte and Souza (2016) evaluated crop responses to two salt source in the irrigation water, only NaCl and a mixture of salts including NaCl, KCl, $MgCl_2$ and $CaCl_2$, and did not observe differences among the salt sources for *Ψw* or *Ψo* of sorghum (*Sorghum bicolor* L.), atriplex (*Atriplex nummularia* L.), bean (*Vigna unguiculata* L.), or bell pepper (*Capsicum annuum* L), respectively. In the present study, there was a reduction of *Ψw* and *Ψo* in papaya irrigated with water at 6 dS m^{-1}, which may be indicative of a possible salinity tolerance, at least in an inert medium, especially when associated with no difference in biomass, and the content of foliar nutrients, especially Na, Cl, Ca, and Mg. We did not find results of *Ψw* in papaya under salinity in the literature. However, Mahouachi et al. (2006) investigated the effects of water deficit stress on papaya and found water potential values ranging from – 0.6 to – 0.7 MPa and – 0.7 to – 0.8 MPa in control and in water-stressed plants, respectively. Peçanha et al. (2017) emphasized the importance of measuring the Ψo to determine if papaya can increase salinity tolerance via osmotic adjustment. Our results of the decreasing of leaf osmotic potential and no effect of salinity treatment on dry biomass indicate that in a calcined clay medium, there was osmotic adjustment in papaya. Peçanha et al. (2017) also observed a decrease in *A*, *gs* and *Tr* in two cultivars of papaya ('Sunrise Golden' and 'Uenf-Caliman 01' hybrid) with increasing EC up to 3.4 dS m^{-1} in a potted plant experiment using washed sand medium and evaluating the response 60 days after beginning the salinity treatments. In contrast, Targino et al. (2023) did not find any decreases of *A*, *gs* and *Tr* in

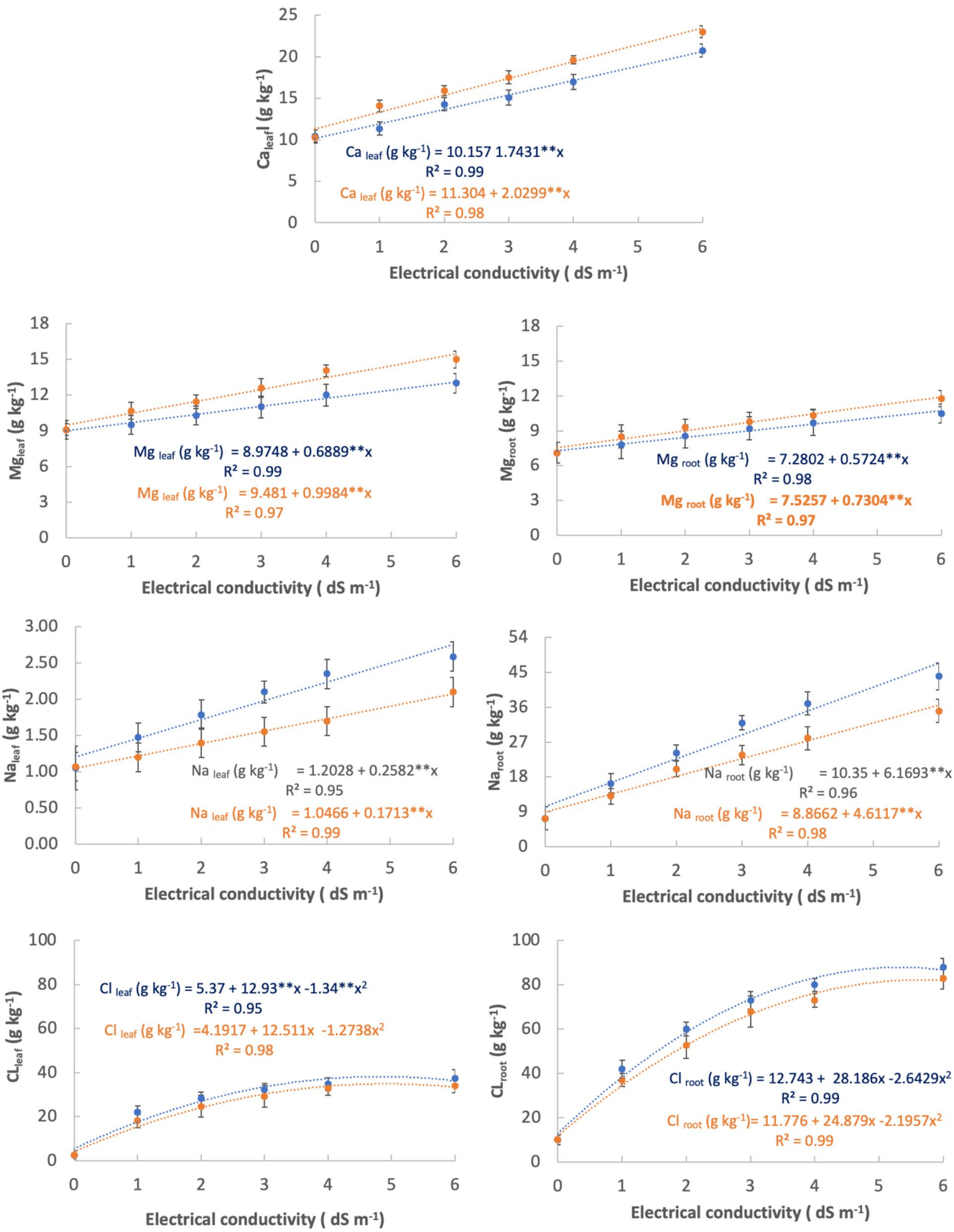

Fig. 6 Leaf Ca, Mg, Na, and Cl and root Mg, Na, and Cl contents eight weeks after beginning the salinity treatments. Symbols represent the means of each treatment and bars indicate ± std. dev Double asterisks indicate a significant difference with $P < 0.05$

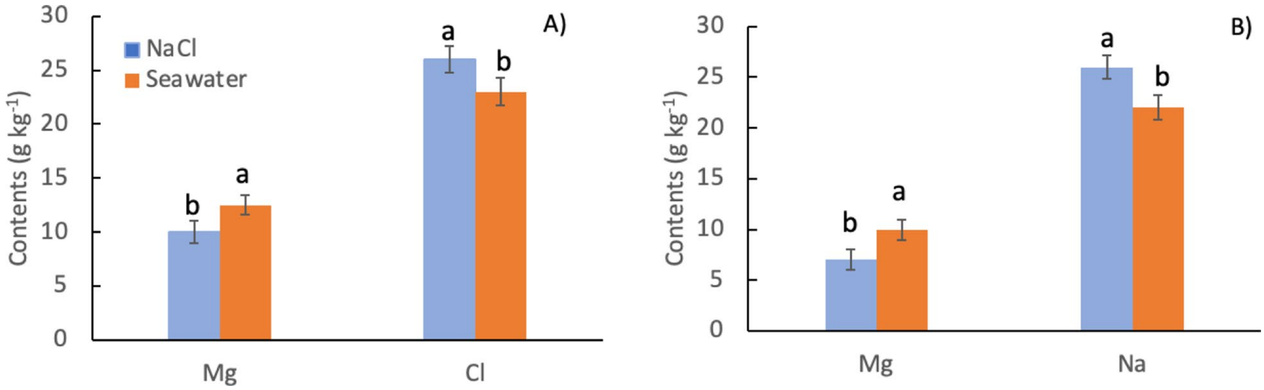

Fig. 7 Contents of Mg and Cl in the leaves (*A*) and Mg and Na in the roots (**B**) 8 weeks after the beginning the salinity treatments. Different letters indicate as significant difference between salinity sources (NaCl or artificial seawater) at P<0.05

Table 2 Contents of N, P and K in papaya leaves and roots 8 weeks after the start of saline treatment

Nutrients	Leaf contents (g kg^{-1})		Root contents (g kg^{-1})	
	NaCl	Seawater	NaCl	Seawater
N	31.11 ± 2.80	33.93 ± 3.62	10.61 ± 2.65	10.22 ± 2.72
P	4.33 ± 0.21	4.38 ± 0.26	4.67 ± 0.90	4.34 ± 1.10
K	65.31 ± 2.69	69.99 ± 2.59	60.92 ± 3.54	65.05 ± 4.05

The values represent the mean ± std. dev

'Sunrise' papaya irrigated with saline water up to 5.0 dS m^{-1} in a potted plant experiment in a medium soil, manure, and washed sand (3:1:1).

Targino et al. (2023) found no significant effect of salinity on chlorophyll a fluorescence in papaya irrigated with saline water up to 5.0 dS m^{-1}. Similarly, Peçanha et al. (2017) found no significant differences for Fv/Fm and the leaf chlorophyll index when evaluating responses to an EC level of 3.4 dSm^{-1} for 'Sunrise Golden' or 'Uenf-Caliman 01' papaya. The Fv/Fm values found in that study were similar to results reported in the present study. Peçanha et al. (2017) also found leaf N and P contents similar to those found in the present study.

Conclusions

There were differences between irrigation with NaCl and artificial seawater for some nutrient and growth variables of papaya in an inert calcined clay medium. A significant difference between salinity sources was observed for plant height, leaf Mg and Cl contents and root Mg and Na contents. Thus, it appears that under these conditions, artificial seawater may be a better salt source for simulating responses of papaya to increased salinity expected from saltwater intrusion inland. However, this study evaluated only one cultivar in one type of medium. Therefore, additional cultivars in different soil types should be evaluated to more definitively determine if artificial seawater is a better alternative to NaCl for testing responses of papaya plants to increased salinity as expected from sea level rise and saltwater intrusion.

Abbreviations

Fv/Fm	Ratio of variable to maximum chlorophyll fluorescence
LCI	Leaf chlorophyll index
EL	Electrolyte leakage
RWC	Relative water content
Ψw	Leaf water potential
Ψo	Leaf osmotic potential
A	Net CO_2 assimilation
gs	Stomatal conductance
Tr	Transpiration
EC	Electrical conductivity
TDS	Total dissolved solids
EC_F	Free electrical conductivity
EC_T	Total electrical conductivity
PPT	Parts per thousand

Acknowledgements

The first author is grateful by the research productivity scholarship from CNPq (Grant number: 305136/2021-6). The authors are grateful to Mrs. Pamela Moon (biological scientist III, TREC-UF) and Mrs. Thais Emanuelle Monteiro dos Santos Souza (Professor UFPE – Brazil) for providing helpful supporting during the experiment.

Author contributions

Conceptualization: ERS and BS.; methodology-investigation: ERS, BS and AIV; writing—original draft preparation: ERS, BS; writing—review and editing: ERS, BS, AIV, ACS and EAGR.; funding acquisition: ERS. All authors have read and agreed to the published version of the manuscript.

Funding

This research was funded by the National Council for the Improvement of Higher Education (CAPES) for granting scholarship to first author (Number: 88887.568938/2020-00; CAPES/PRINT/UFRPE) during his sabbatical (2021–2022) in the Tropical Research and Education Center—University of Florida—USA.

Data availability
If required we can provide the data.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

Received: 22 July 2023 Accepted: 15 January 2024
Published: 2 February 2024

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