Comunicata Scientiae
Horticultural Journal

ORIGINAL ARTICLE
published: 06 June 2022
https://doi.org/10.14295/CS.v13.3725

Production of *Talisia esculenta* seedlings under irrigation with saline water in substrate with hydrogel

Francisco Thiago Coelho Bezerra*, Marlene Alexandrina Ferreira Bezerra, Walter Esfrain Pereira, Carlos Jardel Andrade de Oliveira, Gleyse Lopes Fernandes de Souza, Ana Paula Pereira do Nascimento

Federal University of Paraíba, Areia, Brazil
*Corresponding author, e-mail: bezerra_ftc@yahoo.com.br

Abstract

Salinity is one of the factors that compromise the formation of seedlings, so it is necessary to associate measures that mitigate its effects. The objective of this study was to evaluate the effects of irrigation frequencies, water salinity, polymer and container volume on the growth and quality of *Talisia esculenta* (A. St.-Hil.)Radlk seedlings. The treatments were obtained from the combination of polymer concentrations (0.0; 0.2; 0.6; 1.0 and 1.2 g dm^{-3}), electrical conductivities of water (0.3; 1.1; 2.7; 4.3 and 5.0 dS m^{-1}) and irrigation frequencies (daily and alternate) plus two additional treatments to evaluate container volume. The growth and quality of seedlings were analyzed at 100 days after sowing. Reduction in irrigation frequency from daily to alternate days reduced the growth, biomass accumulation, and quality of the seedlings. Overall, salinity hampered the formation of the seedlings while the polymer had positive effects. *T. esculenta* seedlings are considered to be sensitive to salinity and should be irrigated using water with conductivity of up to 0.7 dS m^{-1} at a daily frequency of application. The polymer can be incorporated up to 1.2 g dm^{-3} and containers with higher volumetric capacity (0.75 *vs* 1.30 dm^3) are indicated for the production of *T. esculenta* seedlings.

Keywords: Pitomba, seedling quality, salt stress, polymer, container volume

Introduction

The species *Talisia esculenta* (A. St.-Hil.) Radlk, belonging to the Sapindaceae family, is native to the Western Amazon and is locally known as 'pitomba', 'pitombeira', 'olho de boi', among others, with different uses for its fruits, bark, leaves and wood, besides being indicated for planting in degraded areas (Guarim Neto et al., 2003). In Brazil, it is found in the North (Amazonas, Pará), Northeast (Bahia, Ceará, Maranhão, Paraíba, Pernambuco), Midwest (Mato Grosso, Minas Gerais, Goiás), Southeast (Rio de Janeiro) and South (Paraná) regions. However, in the Brazilian Northeast, particularly in the semi-arid region, the cultivation of fruit crops faces limitations, especially regarding the irregularity of rainfall and the quality of the waters, due mainly to the excess of salts.

Salt stress reduces from the emergence of seeds (Bezerra et al., 2022) to the growth and quality of seedlings, as observed in *Passiflora edulis* (Bezerra et al., 2014, 2019), *Artocarpus heterophyllus* (Oliveira et al., 2017), *Annona squamosa* (Silva et al., 2018a, b), *Tamarindus indica* (Lima Neto et al., 2018), *Carica papaya* (Nascimento Neto et al., 2020), as well as *T. esculenta* (Melo Filho et al., 2017), which is considered sensitive to salinity (Bezerra et al., 2022). This is because excess salts have the effect of reducing water potential, hindering water absorption, in addition to the specific toxicity of each ion (Taiz et al., 2017), resulting in physiological and metabolic changes (Bezerra et al., 2022). Since each species has a limit of salinity tolerance, it is necessary to check the limit and, mainly, associate measures that mitigate salt stress to enable the use of water that is restrictive for agriculture.

Recently, studies with water-absorbing polymer have contributed to the production of seedlings of *P. edulis* (Carvalho et al., 2013; Fagundes et al., 2015), *Eucalyptus dunnii* (Navroski et al., 2015, 2016) and *C.*

Received: 10 April 2021
Accepted: 24 January 2022

papaya (Nascimento Neto et al., 2020). Among the effects of this input, it is possible to mention the increase in water storage capacity (Felippe et al., 2016) and the reductions in nutrient leaching (Fagundes et al., 2015), water demand (Navroski et al., 2015), irrigation frequency (Carvalho et al., 2013; Felippe et al., 2020) and, consequently, salts as there is the possibility of reducing the water depth.

However, not only the depth, but also the frequency of irrigation can affect the performance of seedlings (Silva et al., 2018a, b; Nascimento Neto et al., 2020). When the depth is excessive, water is wasted and it can contribute to nutrient leaching, while lower irrigation frequency can cause greater variation in water availability and result in water deficit, in addition to the economic consequences through the waste of energy and/or labor (Carvalho et al., 2013). The adequacy of the volume of containers is also a relevant factor, as it can interfere in the production of seedlings (Barbosa et al., 2013; Silva et al., 2018a, b; Nascimento Neto et al., 2020), so it is necessary to determine the smallest volume that does not compromise the formation and quality of seedlings, thus reducing production and transportation costs.

Thereby, this study was conducted to evaluate the effects of irrigation frequency, electrical conductivity of irrigation water, water-absorbing polymer and volume of containers on the growth and quality of *T. esculenta* seedlings.

Material and Methods

Experimental site

The experiment was carried out in a screened shelter (6° 58' 10.9" South; 35° 42' 59.1" West and; 536 m elevation) of the Department of Soils and Rural Engineering, at the Center for Agrarian Sciences of the Federal University of Paraíba, municipality of Areia, state of Paraíba, Brazil.

Treatments and design

The treatments were obtained from the arrangement between doses of the polymer Hydroplan-EB/HyA (0.0; 0.2; 0.6; 1.0 and 1.2 g dm^{-3}) and electrical conductivities of irrigation water (0.3; 1.1; 2.7; 4.3 and 5.0 dS m^{-1}), following the $2^2 + 2 \times 2 + 1$ scheme of the Box's Central Composite matrix (Montgomery, 2013), combined factorially with two irrigation frequencies (daily and alternate), plus two additional treatments (1.30 and 0.75 dm^3) to observe the effect of container volume (Table 1). The experimental design used was randomized blocks with four replications and the experimental unit consisted of four containers.

Table 1. Scheme between the levels of the factors (HyA - polymer; ECiw - electrical conductivity of irrigation water; IrrigF - irrigation frequency and; ConV - container volume) used in the experiment.

Treat.[1]	Levels[2]		Doses/Concentrations		IrrigF	ConV (dm^3)
	HyA	ECiw	HyA (g dm^{-3})	ECiw (dS m^{-1})		
1	-1	-1	0.2	1.1	Daily	1.30
2	-1	1	0.2	4.3	Daily	1.30
3	1	-1	1.0	1.1	Daily	1.30
4	1	1	1.0	4.3	Daily	1.30
5	-1.41 (-a)[2]	0	0.0	2.7	Daily	1.30
6	1.41 (a)	0	1.2	2.7	Daily	1.30
7	0	-1.41 (-a)	0.6	0.3	Daily	1.30
8	0	1.41 (a)	0.6	5.0	Daily	1.30
9	0	0	0.6	2.7	Daily	1.30
10	-1	-1	0.2	1.1	Alternate	1.30
11	-1	1	0.2	4.3	Alternate	1.30
12	1	-1	1.0	1.1	Alternate	1.30
13	1	1	1.0	4.3	Alternate	1.30
14	-1.41 (-a)	0	0.0	2.7	Alternate	1.30
15	1.41 (a)	0	1.2	2.7	Alternate	1.30
16	0	-1.41 (-a)	0.6	0.3	Alternate	1.30
17	0	1.41 (a)	0.6	5.0	Alternate	1.30
18	0	0	0.6	2.7	Alternate	1.30
19	0	0	0.6	2.7	Daily	0.75
20	0	0	0.6	2.7	Alternate	0.75

[1]Number of treatments for each arrangement between doses of polymers and electrical conductivity of irrigation water = $2^k + 2k + 1$ (k = 2, nº of factors) ∴ $2^2 + 2 \times 2 + 1 = 9$; [2]Levels established according to the Box's Central Composite matrix; [3]a = √1.41.

Substrate preparation

The substrate used consisted of the mixture between the material of a soil, sand and aged bovine manure in the proportion of 3:2:1, respectively. The soil material was collected from the 0–20 cm layer of the profile of a *Latossolo Vermelho-Amarelo* (Oxisol) in the municipality of Areia-PB. The aged bovine manure was obtained in a stable in the rural area of Areia-PB. Each component of the substrate, after being properly air dried in the shade, was passed through a 4-mm-mesh sieve and then homogenized.

A sample of the substrate was collected and analyzed, showing the following fertility attributes: pH - 5.9; Na^+, K^+, Ca^{2+}, Mg^{2+}, sum of bases, H^++Al^{3+} and cation exchange capacity - 0.23, 0.88, 1.74, 1.28, 4.13, 9.47 and 13.60 $cmol_c$ dm^{-3}, respectively; base saturation - 30.3%; phosphorus - 45 mg dm^{-3}; organic matter - 2.43 %; and electrical conductivity in soil-water suspension - 0.46 dS m^{-1}. The saturation paste extract showed pH of 5.90; electrical conductivity of 1.97 dS m^{-1}; Cl^{-1}, CO_3^{2-}, HCO_3^-, Ca^{2+}, Mg^{2+}, K^+ and Na^+ of 15.25, 0.00, 2.80, 4.62, 8.88, 5.46 and 5.13, $mmol_c$ L^{-1}, respectively; and sodium adsorption ratio of 1.97 (mmol L^{-1})$^{0.5}$. The values found for texture were 68.67% of sand, 18.17% of silt and 13.16% of clay, with bulk and particle densities of 1.35 and 2.64 g cm^{-3}, respectively, porosity of 48.86%, and moisture contents of 15.81 and 8.22% under the respective tensions of 0.033 and 1.5 MPa.

In the preparation of the substrate, phosphorus and nitrogen contents were raised to 300 and 100 mg kg^{-1} (Novais et al., 1991), respectively, and at 60 and 85 days after sowing, 200 mg dm^{-3} of nitrogen was applied. The sources of mineral fertilizers were urea (45% N) and monoammonium phosphate - MAP (52% P_2O_5, 11% N). The polymer was incorporated into the dry substrate, prior to filling the containers, according to the applied treatments (Table 1). Before mixing, each 1 g of dry polymer was hydrated with 49 g of water. After filling the containers, irrigation was carried out to moisten the substrate, so that the substrate particles could settle, for sowing.

Obtaining the seeds and conducting the experiment

T. esculenta fruits were acquired in the local market, and the seeds were extracted from the fruits manually, kept in water for 24 hours for fermentation of the pulp and then washed in running water to remove the remaining pulp. After pulping, the seeds were dried in the shade for 24 hours and then sown directly in the containers.

Sowing was performed by placing two seeds per container at a depth of approximately 2.5 cm. Irrigation water was prepared by adding ions of sodium (Na^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}) in the proportion of 5:2:1 on a mass basis (Silva Júnior et al., 1999), respectively, in the form of chloride, to the public-supply water (0.3 dS m^{-1}). The concentrations of these ions were determined according to each level of electrical conductivity verified in the irrigation water. In irrigation with alternate frequency, started after thinning, performed at 42 days after sowing, the equivalent to 70% of the volume applied daily was applied. The daily water depth was applied to keep the substrate close to field capacity, checking the beginning of drainage.

Variables analyzed

At 100 days after sowing, the following variables were analyzed: seedling height, in cm, as the distance between the collar and the apex measured with a millimeter ruler; stem diameter at ground level (DGL), in mm, measured with digital caliper in the collar; height/diameter ratio, in cm mm^{-1}; number of leaves; shoot dry matter mass (SDMM), root dry matter mass (RDMM), SDMM/RDMM ratio and total dry matter mass (TDMM), in g, after drying in an air circulation oven kept at 65 °C; root density (RD), in g kg^{-1}, through the ratio between root dry matter mass and substrate mass; leaf mass ratio (LMR), in g g^{-1}, from the ratio between leaf dry mass and total dry matter mass (Hunt, 1990) and; Dickson quality index (DQI) according to Dickson (1960).

$$DQI = \frac{TDMM\ (g)}{\frac{H\ (cm)}{DGL\ (mm)} + \frac{SDMM\ (g)}{RDMM\ (g)}}$$

Statistical analyses

The data were subjected to normality analysis by the Kolmogorov-Smirnov test ($p \leq 0.05$), being transformed into log (y + 10) when they did not follow normal distribution. Then, analysis of variance was performed. The effects of polymer and electrical conductivity of water were fitted by polynomial regression using the F test ($p \leq 0.10$). Irrigation frequency and the effects of container sizes were tested by orthogonal contrasts, using the F test ($p \leq 0.05$). Principal component analysis (PCA) and cluster analysis were also performed based on treatment scores (Husson et al.,2017). The criterion used to classify the variable in the components was based on the relationship 0.5($\lambda^{-0.5}$), where λ is the eigenvalue of the component (Ovalles & Collins, 1988). The analyses were performed in the software programs SAS® University Edition and R® version 4.0.2 (R Core Team).

Results

The summary of ANOVA for the effects of the factors applied on growth and quality variables can be seen in Table 2. Except for the shoot dry matter mass to root dry matter mass ratio and leaf mass ratio, the effects of the electrical conductivity of water and polymer were presented for the two irrigation frequencies because they were significant and/or the interaction with the Box's Central Composite was significant.

Table 2. Summary of the analysis of variance and contrasts (Mean Square) for height (H), stem diameter at ground level (DGL), H/DGL ratio, number of leaves (NL), shoot dry matter mass (SDMM), root dry matter mass (RDMM), SDMM/RDMM ratio, total dry matter mass (TDMM), root density (RD), leaf mass ratio (LMR) and Dickson quality index (DQI) in *T. esculenta* seedlings at 100 days after sowing under the factors electrical conductivity of irrigation water (ECiw), polymer (P), irrigation frequency (F) and container volume (Y).

SV	DF	H[1]	DGL	H/DGL	NL[2]	SDMM	RDMM
Block	3	0.0003^{ns}	0.1347*	0.2729^{ns}	0.1487*	0.0364^{ns}	0.0412^{ns}
Treatment	(19)	0.0028**	0.0959*	0.5435**	0.2304**	0.6555**	0.1092**
F	1	0.0181**	1.0559**	0.8993*	1.1020**	2.8691**	0.5079**
BCC[3]	8	0.0031**	0.0537^{ns}	0.7857**	0.2747**	0.8269**	0.1184**
BCC x F	8	0.0003^{ns}	0.0188^{ns}	0.2337^{ns}	0.1465**	0.2129*	0.0308^{ns}
Y_1[4]	1	0.0020*	0.0422^{ns}	0.2605^{ns}	0.3176*	0.0377^{ns}	0.0034^{ns}
Y_2[4]	1	0.0014^{ns}	0.0623^{ns}	0.0568^{ns}	0.0991^{ns}	0.8171**	0.0374^{ns}
Residual	57	0.0004	0.0445	0.1751	0.0487	0.0788	0.0345
CV (%)		1.49	7.28	8.69	6.40	16.54	17.28

SV	DF	SDMM/RDMM[1]	TDMM	RD	LMR	DQI
Block	3	0.0001^{ns}	0.1180^{ns}	0.0372^{ns}	0.0008^{ns}	0.0065^{ns}
Treatment	(19)	0.0003^{ns}	1.1891**	0.2089**	0.0035^{ns}	0.0160**
F	1	0.0005^{ns}	5.7912**	0.4954**	0.0036^{ns}	0.0744**
BCC[3]	8	0.0003^{ns}	1.4875**	0.1155**	0.0034^{ns}	0.0162**
BCC x F	8	0.0003^{ns}	0.2130^{ns}	0.0300^{ns}	0.0058^{ns}	0.0053^{ns}
Y_1[4]	1	0.0000^{ns}	0.0638^{ns}	0.4526**	0.0012^{ns}	0.0000^{ns}
Y_2[4]	1	0.0007^{ns}	1.2040**	0.4229**	0.0018^{ns}	0.0150^{ns}
Residual	57	0.0002	0.1170	0.0320	0.0044	0.0039
CV (%)		1.34	12.34	17.47	15.52	14.47

[1] and [2] Data transformed to log (x + 10) and root (x) for not following normal distribution according to the Kolmogorov-Smirnov test (p > 0.05), respectively; [3]Combinations between the electrical conductivity of irrigation water and polymer doses, using the Box's Central Composite (BCC); [4]Effect of container volume (1.30 vs 0.75 dm^3) at daily (Y_1) and alternate (Y_2) irrigation frequencies evaluated by contrasts; ^{ns}, * and **: not significant and significant at 5 and 1% probability levels by the F test, respectively.

Effects of irrigation frequency

For the shoot dry matter mass to root dry matter mass ratio as well as leaf mass ratio of *T. esculenta* seedlings, there was no effect of irrigation frequency (Table 2). Conversely, the reduction in irrigation frequency from daily to alternate days reduced height from 14.98 to 13.18 cm, -12% (Figure 1A), stem diameter from 3.03 to 2.79 mm, -8% (Figure 1B), height to stem diameter ratio from 4.96 to 4.73 cm mm^{-1}, -5% (Figure 1C), number of leaves from 13 to 11, -15% (Figure 1D), shoot dry matter mass from 1.94 to 1.54 g, -21% (Figure 1E), root dry matter mass from 1.18 to 1.01 g, -14% (Figure 1F), total dry matter mass from 3.12 to 2.55 g, -18% (Figure 1G), root density from 1.16 to 1.00 g kg^{-1}, -14% (Figure 1H) and the Dickson Quality Index from 0.47 to 0.41, -13% (Figure 1I), respectively.

Effects of water salinity and polymer

The linear interaction between the electrical conductivity of irrigation water and polymer doses was not significant ($F \leq 1.53$; $p > 0.10$) for the variables. The growth in height of *T. esculenta* seedlings under daily irrigation frequency decreased from 16.30 to 13.92 cm (-15%), at a unit rate of 0.51 cm or 3%, between electrical conductivity levels of 0.3 and 5.0 dS m^{-1}, respectively (Figure 2A). On the other hand, when irrigating on alternate days, the reduction due to the unit increase in salinity was 0.36 cm (-2%), but heights of 14.04 and 12.36 cm (-12%) were obtained under the respective conductivities of 0.3 and 5.0 dS m^{-1}. The increment of the polymer in the substrate, when irrigated daily, promoted a gain from 13.74 to 16.34 cm (+19%) from the absence to 1.20 g dm^{-3} (Figure 2B). However, no functional relationship was established with irrigation on alternate days ($F \leq 1.73$; $p > 0.10$).

The diameter of *T. esculenta* seedlings had its growth reduced due to the electrical conductivity of the irrigation water, applied on alternate days (Figure 2C). The mean loss was equal to 0.03 mm (1%) per unit increase in salinity, from 2.86 to 2.71 mm (-5%) at conductivity levels from 0.3 to 5.0 dS m^{-1}, respectively. The effects of salinity under daily irrigation (Figure 2B) and polymer (Figure 2C), when irrigating both daily and on alternate days, were not described by the regression ($F \leq 1.40$; $p > 0.10$).

The height to stem diameter ratio of the seedlings was altered as a function of salinity and polymer, but only when plants were irrigated daily. The increase in the electrical conductivity of irrigation water from 0.3 to 5.0 dS m^{-1} reduced this ratio from 5.26 to 4.61 cm mm^{-1} (-12%), respectively (Figure 2E). Conversely, the polymer increased the height to stem diameter ratio from 4.54, without polymer, to 5.50 cm mm^{-1} at a dose of 1.20 g dm^{-3}, which represents an increase of 21% (Figure 2F).

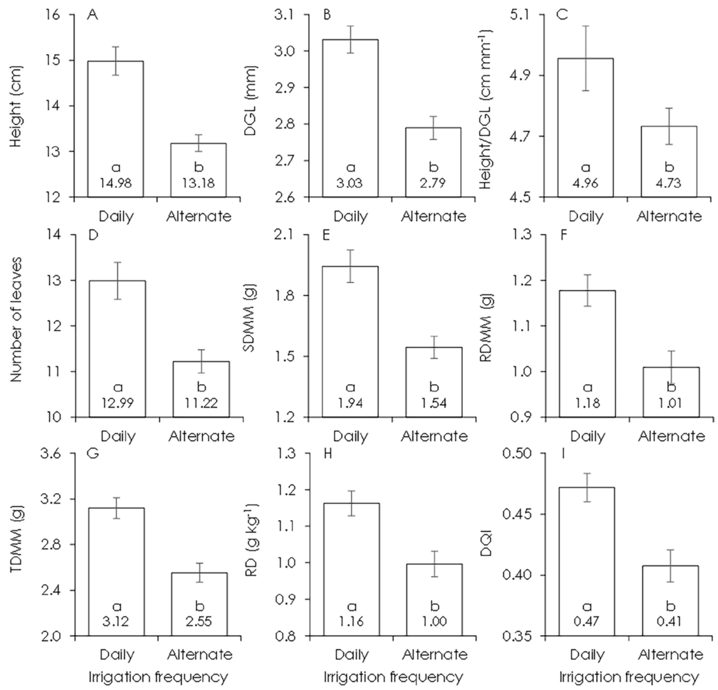

Figure 1. Mean values ± standard error for height (A), stem diameter at ground level - DGL (B), Height/DGL ratio (C), number of leaves (D), shoot dry matter mass - SDMM (E), root dry matter mass - RDMM (F) and total dry matter mass - TDMM (G), root density - RD (H) and Dickson quality index - DQI (I) in *T. esculenta* seedlings at 100 days after sowing as a function of irrigation frequency. Means followed by the same letter do not differ from each other by the F test (p ≤ 0.05).

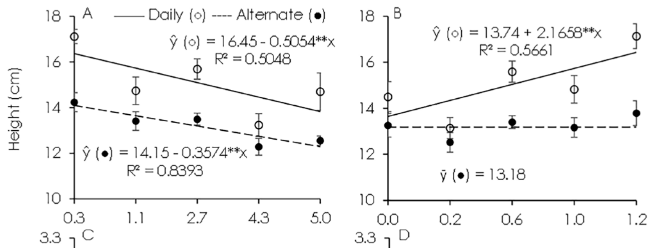

Figure 2. Height, stem diameter at ground level – DGL, height/DGL ratio and number of leaves in *T. esculenta* seedlings at 100 days after sowing, at daily (○) and/or alternate (●) irrigation frequencies, as a function of the electrical conductivity of irrigation water - ECiw (A, C, E, G) and polymer doses (B, D, F, H). °, * and **: significant at 10, 5 and 1% probability levels by F test, respectively.

Leaf production in *T. esculenta* seedlings as a function of the electrical conductivity of irrigation water reduced both under daily irrigation, from 15 to 11 leaves (-27%), and under irrigation on alternate days, from 12 to 10 (-17%), at the electrical conductivities of 0.3 and 5.0 dS m^{-1}, respectively (Figure 2G). Regarding polymer doses, the number of leaves increased up to the dose of 0.8 g dm^{-3}, an increase of 3 leaves (+27%) compared to the 11 leaves obtained in the substrate without polymer and irrigated daily (Figure 2H). However, under irrigation on alternate days, the regression of this variable as a function of polymer doses was non-significant ($F \leq 0.32$; $p > 0.10$).

The shoot dry matter mass of *T. esculenta* seedlings decreased with increasing electrical conductivity of irrigation water (Figure 3A). Under daily irrigation, the maximum dry mass (2.77 g) was obtained under conductivity of 0.3 dS m^{-1}, while the lowest value was 1.60 g, obtained under 3.7 dS m^{-1}, a loss of 42%. When irrigating on alternate days, the shoot dry matter mass decreased from 1.89 to 1.24 g, a reduction of 34%, under the conductivities of 0.3 and 5.0 dS m^{-1}. Conversely, the increase in polymer doses, under daily irrigation frequency, stimulated the accumulation of shoot dry matter mass from 1.67 g, without polymer, to 2.06 g, with the polymer dose of 0.9 g dm^{-3} (Figure 3B). For the irrigation on alternate days, there was no fit of this variable as a function of polymer doses ($F \leq 1.77$; $p > 0.10$).

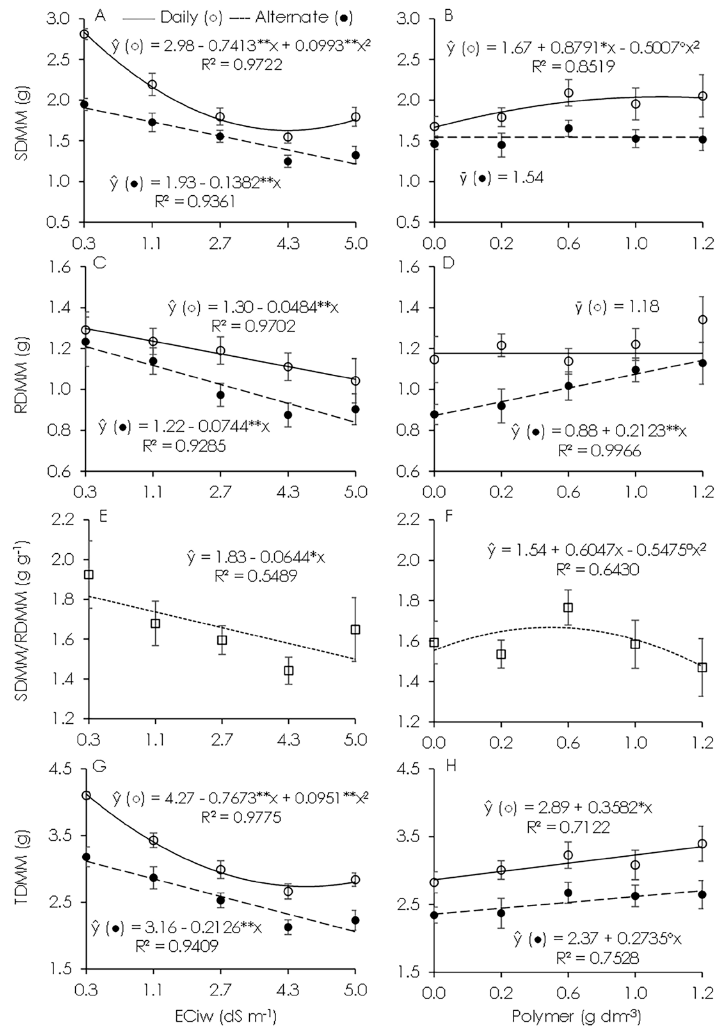

Figure 3. Shoot dry matter mass - SDMM, root dry matter mass - RDMM, SDMM/RDMM ratio and total dry matter mass - TDMM in *T. esculenta* seedlings at 100 days after sowing, under daily (○) and/or alternate (●) irrigation frequencies, as a function of the electrical conductivity of irrigation water - ECiw (A, C, E, G) and polymer doses (B, D, F, H). °, * and **: significant at 10, 5 and 1% probability levels by F test, respectively.

The root dry matter mass of *T. esculenta* seedlings also decreased with the increment in the electrical conductivity of irrigation water from 0.3 to 5.0 dS m^{-1}, respectively from 1.29 to 1.06 g (-18%), under daily irrigation, and from 1.19 to 0.85 g (-29%), under frequency of alternate days (Figure 3C). For the polymer, there was no fit in the regression under daily irrigation ($F \leq 1.53$; $p > 0.10$); however, with irrigation on alternate days, root dry matter mass increased from 0.88 to 1.13 g (+28%) without polymer and with 1.2 g dm^{-3} of polymer, respectively (Figure 3D).

The shoot dry matter mass to root dry matter mass ratio decreased from 1.81 to 1.51 g g^{-1} (-17%) under irrigation with water of 0.3 and 5.0 dS m^{-1}, respectively (Figure 3E). Conversely, the increase in polymer doses increased this ratio from 1.54 to 1.71 g g^{-1}, with a reduction to 1.49 g g^{-1} under the respective doses of 0.0, 0.6 and 1.2 g dm^{-3} (Figure 3F).

The total dry matter mass of *T. esculenta* seedlings decreased with increasing electrical conductivity of irrigation water (Figure 3G). With daily irrigation, the decrease in biomass was from 4.05 to 2.72 g (-33%) under the respective conductivities of 0.3 and 4.0 dS m^{-1}, and from 3.10 to 2.10 g (-32%) when irrigated on alternate days using water with electrical conductivities of 0.3 and 4.0 dS m^{-1}, respectively. However, the increase in polymer doses from 0.0 to 1.20 g dm^{-3} increased the total dry matter mass of the seedlings from 2.89 to 3.32 g (+15%), under daily irrigation, and from 2.37 to 2.70 g (+14%), under the irrigation frequency of alternate days, respectively (Figure 3H).

The root density of *T. esculenta* seedlings decreased by 47.8 and 73.5 mg kg^{-1} at the daily and alternate irrigation frequencies, with the unit increase in the electrical conductivity of irrigation water (Figure 4A). For the daily irrigation, the loss was from 1.28 to 1.05 g kg^{-1} (-18%) under the electrical conductivities of 0.3 and 5.0 dS m^{-1}, respectively, while for irrigation on alternate days with the respective waters the reduction was from 1.19 to 0.84 g kg^{-1} (-29%). However, for the polymer, the regression did not fit under daily irrigation ($F \leq 1.61$; $p > 0.10$); however, under irrigation on alternate days, root density increased from 0.87 to 1.12 g (+29%) without polymer and with 1.2 g dm^{-3} of polymer, respectively (Figure 4B).

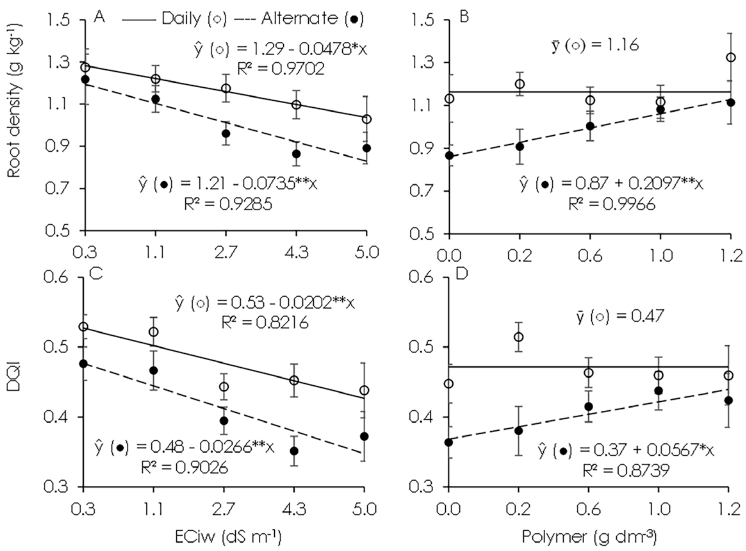

Figure 4. Root density and Dickson quality index – DQI in *T. esculenta* seedlings at 100 days after sowing, under daily (○) and/or alternate (●) irrigation frequencies, as a function of the electrical conductivity of irrigation water - ECiw (A, C) and polymer doses (B, D). * and ** significant at 5 and 1% probability levels by F test, respectively.

The quality of the seedlings, evaluated by the Dickson quality index, was lower under higher levels of water salinity (Figure 4C). Under daily irrigation, the reduction was from 0.52 to 0.43 (-17%), while under irrigation on alternate days the reduction was from 0.47 to 0.35 (-26%), at the electrical conductivities of irrigation water of 0.3 and 5.0 dS m^{-1}, respectively. For polymer doses, no functional relationship was established with Dickson quality index ($F \leq 0.76$; $p > 0.10$); however, under irrigation on alternate days, this index increased from 0.37 to 0.44 (+19%) without polymer and with 1.2 g dm^{-3} of polymer, respectively (Figure 4B).

From these data, two principal components were formed, representing 82% of the total variance (Table 3). In component one, with 64.47% of the total variability, all variables except for leaf mass ratio were retained.

The total dry matter mass had the highest contribution (13.7%), followed by shoot dry matter mass (13.1%), height (11.5%), root dry matter mass (10.6%), root density (10.6%), Dickson quality index (10.2%), stem diameter at ground level (8.8%), number of leaves (8.5%), height to stem diameter ratio (6.6%) and shoot dry matter mass to root dry matter mass ratio (5.5%). Thus, it indicates that dry mass accumulation is associated with seedling growth and quality. In the second component, with 17.6% of the total variability, the variables leaf mass ratio and shoot to root mass ratio were retained, with their respective contributions of 39 and 28%, that is, the higher supply of dry mass in the leaves alters the allocation of dry mass between shoots and roots.

Table 3. Eigenvalues and eigenvectors for the principal components (PC) of the growth and quality variables of *T. esculenta* seedlings.

	PC1	PC2
Eigenvalues (λ)	7.08	1.94
Explained variance (%)	64.4	17.6
Accumulated variance (%)	64.4	82.0
	Eigenvectors[1]	
H	**0.3385**	0.0802
DGL	**0.2981**	-0.0241
H/DGL	**0.2574**	0.1033
NL	**0.2911**	0.0960
SDMM	**0.3618**	0.1295
RDMM	**0.3260**	-0.3445
SDMM/RDMM	**0.2356**	**0.5252**
TDMM	**0.3707**	-0.0065
RD	**0.3260**	-0.3444
LMR	0.0874	**0.6253**
DQI	**0.3187**	-0.2283

[1]Representative variables of the component based on the modulus of the ratio $0.5(\lambda^{-0.5})$, highlighted in bold (Ovalles & Collins, 1988).

In the separation of treatments, three groups were formed (Figure 5). Groups one and two contain mostly treatments under daily irrigation, with the direction of the vectors of the variables associated with these groups. On the other hand, group three contains mostly the irrigation frequency of alternate days, which resulted in a reduction in the growth and quality of *T. esculenta* seedlings.

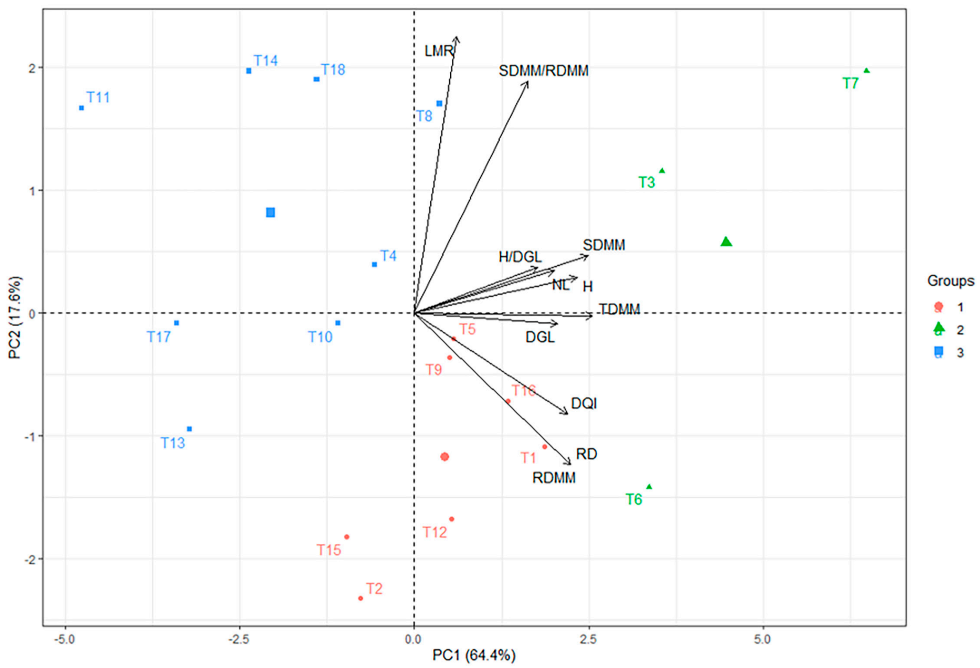

Figure 5. Dispersion of growth and quality variables of *T. esculenta* seedlings and groups of treatments (Table 1) based on the scores of the first and second principal components (PC).

Effects of container volume

The effects of container volumes for daily and alternate irrigation frequencies were not significant on stem diameter at ground level, height to stem diameter ratio, root dry matter mass, shoot dry matter mass to root dry matter mass ratio, leaf mass ratio and Dickson quality index of *T. esculenta* seedlings (Table 4). Conversely, under daily irrigation frequency, the reduction in container volume from 1.30 to 0.75 dm^3 caused an increase of 0.84 dS m^{-1} (49%) in the electrical conductivity of the substrate and losses of 1.76 cm (12%) in height, 2.88 leaves (14%) and 0.48 g kg^{-1} (45%) in root density; for the container of larger volume, the values were 1.70 dS m^{-1}, 14.96 cm, 14.40 leaves and 1.07 g kg^{-1}, respectively. For the alternate irrigation frequency, the reduction in the volume of the containers caused an increase of 1.30 dS m^{-1} (65%) in the electrical conductivity of the substrate and reductions of 0.64 g (38%) in shoot dry matter mass, 0.78 g (30%) in total dry matter mass, and 0.46 g kg^{-1} (51%) in root density; in the container of 1.30 dm^3, the values were 1.99 dS m^{-1}, 1.69 g, 2.60 g and 0.90 g kg^{-1}, respectively.

Table 4. Mean values ± standard error of height (H), stem diameter at ground level (DGL), H/DGL ratio, number of leaves (NL), shoot dry matter mass (SDMM), root dry matter mass (RDMM), SDMM/RDMM ratio and total dry matter mass (TDMM), root density (RD), leaf mass ratio (LMR) and Dickson quality index (DQI) in *T. esculenta* seedlings at 100 days after sowing as a function of container volume under daily and alternate irrigation frequencies.

	Daily irrigation			Irrigation on alternate days		
	1.30 dm^3	0.75 dm^3	EC	1.30 dm^3	0.75 dm^3	EC
H	14.96 ± 0.66	13.19 ± 0.31	-1.76*	13.42 ± 0.41	12.04 ± 0.53	-1.38^{ns}
DGL	3.03 ± 0.17	2.88 ± 0.12	-0.15^{ns}	2.85 ± 0.08	2.67 ± 0.17	-0.18^{ns}
H/DGL	4.95 ± 0.06	4.59 ± 0.10	-0.36^{ns}	4.71 ± 0.10	4.54 ± 0.27	-0.17^{ns}
NL	14.40 ± 1.19	11.52 ± 0.95	-2.88*	11.44 ± 0.58	10.04 ± 1.05	-1.40^{ns}
SDMM	1.66 ± 0.10	1.52 ± 0.05	-0.14^{ns}	1.69 ± 0.17	1.05 ± 0.15	-0.64**
RDMM	1.08 ± 0.11	1.04 ± 0.11	-0.04^{ns}	0.91 ± 0.10	0.78 ± 0.04	-0.14^{ns}
SDMM/RDMM	1.59 ± 0.19	1.50 ± 0.13	-0.08^{ns}	1.86 ± 0.14	1.38 ± 0.28	-0.48^{ns}
TDMM	2.74 ± 0.14	2.57 ± 0.13	-0.18^{ns}	2.60 ± 0.25	1.82 ± 0.12	-0.78**
RD	1.07 ± 0.11	0.59 ± 0.06	-0.48**	0.90 ± 0.10	0.44 ± 0.02	-0.46**
LMR	0.40 ± 0.04	0.42 ± 0.01	0.02^{ns}	0.45 ± 0.02	0.42 ± 0.07	-0.03^{ns}
DQI	0.42 ± 0.03	0.42 ± 0.03	0.00^{ns}	0.40 ± 0.04	0.31 ± 0.02	-0.09^{ns}

EC – estimated contrast between container volumes of 1.30 vs 0.75 dm^3; ^{ns}, * and **: not significant and significant at 5 and 1% probability levels by the F test, respectively.

Discussion

Effects of irrigation frequency

The reduction in irrigation frequency resulted in a reduction in growth, biomass accumulation and quality not only in seedlings of *T. esculenta* (Melo Filho et al., 2017) but also in seedlings of *P. edulis* (Carvalho et al., 2013), *A. squamosa* (Silva et al., 2018a, b), *E. dunnii* (Felippe et al., 2020), among others. The reduction in irrigation frequency reduces the availability of water to the seedlings (Felippe et al., 2020) and can lead to water stress.

Under water restriction, caused by the lower frequency of irrigation, biochemical and physiological processes in plants are altered (Moura et al., 2016; Felippe et al., 2020; Bezerra et al., 2022) in order to adjust to the conditions of the environment. Growth is partly governed by cell turgor pressure (Taiz et al., 2017) and, therefore, water limitation reduces both the synthesis and the growth of new cells, consequently altering morphology. In *T. esculenta* seedlings, the primary growth (height) and secondary growth (stem diameter) were reduced as the daily irrigation changed to alternate days, with greater intensity for height (Figure 1C), reflecting the limitation to growth to the detriment of development, as also observed in *C. papaya* (Nascimento Neto et al., 2020).

Another aspect that is limiting to growth, due to water limitation, refers to the reduction in the number of leaves, caused by the lower synthesis of new leaves (Carvalho et al., 2013; Silva et al., 2018a), as well as the reduction in their size (Nascimento Neto et al., 2020) and thickness (Carvalho et al., 2013), and consequently in the leaf area (Carvalho et al., 2013; Felippe et al., 2020), in addition to lower net photosynthetic rate (Bezerra et al., 2022). There is also restriction/adjustment in the root system, reducing its length and biomass accumulation (Carvalho et al., 2013), causing less exploration of the substrate (Figure 1H).

Reductions in root system and leaves under water limitation also cause lower biomass accumulation in seedlings of *T. esculenta* (Figure 1G), *P. edulis* (Carvalho et al., 2013), *A. squamosa* (Silva et al., 2018b) and *E. dunnii* (Felippe et al., 2020). Under lower water availability, larger leaf area is required to sustain the same rate of biomass accumulation, as observed in seedlings of *P. edulis*, which obtained the highest leaf area ratio when the irrigation frequency was reduced from daily to alternate days or every two days (Carvalho et al., 2013). In addition, water restriction, caused by the lower frequency of irrigation, in addition to compromising growth and biomass accumulation, also reduces the quality of *T. esculenta* seedlings (Figure 1), as also observed in *A. squamosa* seedlings (Silva et al., 2018a, b).

Effects of water salinity and polymer

There is a direct relationship between the increase in the electrical conductivity of irrigation water and of the substrate (Bezerra et al., 2014; Silva et al., 2018a), because there is an increase in soluble salts, leading to salinization (Sá et al., 2015). This salinity reduces growth and quality not only in seedlings of *T. esculenta* (Melo Filho et. Al., 2017), but also in other species such as *A. heterophyllus* (Oliveira et al., 2017), *A. squamosa* (Sá et al., 2015; Silva et al., 2018a, b) and *P. edulis* (Bezerra et al., 2014, 2019), affecting both physiological aspects (Nascimento et al., 2015; Bezerra et al., 2022) and morphological aspects in seedlings (Nascimento Neto et al., 2020). There is a direct relationship between the parameters of growth, dry mass accumulation and quality of *T. esculenta* seedlings (Table 3, Figure 5).

The increase in the concentration of soluble salts, besides hindering water absorption, because there is a reduction in water potential, also causes specific toxic effect of ions (Taiz et al., 2017). There was an increase in the concentrations of sodium and chloride, and a reduction in nutrients such as phosphorus, potassium, calcium, magnesium, sulfur and iron in shoots and roots (Nascimento et al., 2015; Rahneshan et al., 2018) as there is competition for absorption sites. Under salt stress, osmotic adjustment may occur, as observed in *Hymenaea courbaril* seedlings (Nascimento et al., 2015), through the synthesis of organic solutes (Nascimento et al., 2015; Rahneshan et al., 2018). This is a strategy that plants can use to tolerate salinity, allocating energy and carbon skeleton for the synthesis of solutes to the detriment of growth and biomass accumulation.

The polymer favored the growth and quality of *T. esculenta seedlings* (Figures 2, 3, 4). Fagundes et al. (2015), for seedlings of *P. edulis*, recommended to incorporate into the substrate the dose of 2 g L^{-1} of polymer. For seedlings of *E. dunnii*, the recommendation was 3 g L^{-1} (Navroski et al., 2015), but with better quality of seedlings of this species under the dose of 3.3 g L^{-1} (Navroski et al., 2016). The effect of the polymer is mainly related to changes in water dynamics in the substrate, as the polymer also contributes to increasing water holding capacity in the substrate (Felippe et al., 2016; Navroski et al., 2016), reducing the negative consequences of high fluctuations in water availability, reducing nutrient losses by leaching (Fagundes et al., 2015).

Reduction in water requirement has also been found for *E. dunnii* seedlings (Navroski et al., 2015). These authors observed that the water requirement was 12 mm per day, a reduction of up to 40%, when using 3 g L^{-1}. There is also the effect on the decrease in irrigation frequency (Carvalho et al., 2013; Felippe et al., 2020). Carvalho et al. (2015) observed no significant loss in the growth of *P. edulis* seedlings between daily and alternate day irrigations, when 3 g L^{-1} of polymer was incorporated.

Effects of container volume

The effect of the reduction in container volume is closely related to the species (Barbosa et al., 2013) and, mainly, to the period necessary for the production of seedlings (Campany et al., 2017; Cabreira et al., 2021), since seedlings produced in larger containers may show better vegetative performance after transplantation, as observed in *Inga laurina* (Cabreira et al., 2021). However, the effect of container volume is tied to other factors such as irrigation frequency (Ouma, 2007; Espinoza et al., 2017; Silva et al., 2018a, b; Nascimento Neto et al., 2020), as observed in the present study, with more negative effects of the reduction in container volume on the growth of *T. esculenta* seedlings irrigated on alternate days (Table 4).

In line with this, Ouma (2007) observed that *Mangifera indica* seedlings obtained higher growth and biomass accumulation when produced in larger containers and under higher irrigation frequency. *Quillaja saponaria* seedlings were also affected by the interaction between container volume and water availability (Espinoza et al., 2017). Among the consequences in reducing the volume of the container with the potential to negatively affect the production of seedlings is the greater salinization of the substrate, because the increment of salts in the substrate was inversely correlated (Pearson = -0.27; t = 2.45; p = 0.0163) with root density in *T. esculenta* seedlings, that is, smaller volume of substrate proportionally explored in smaller containers. The restriction to root growth, caused by the reduction in container volume, can reduce the growth, biomass accumulation, composition and leaf gas exchange of seedlings (Campany et al., 2017).

Conclusions

In the production of *T. esculenta seedlings*, instead of irrigating on alternate days, daily irrigation is recommended for promoting greater growth and quality;

T. esculenta seedlings are sensitive to salinity and should be irrigated using water with electrical conductivity of up to 0.7 dS m^{-1}, as it causes reduction of less than 10% in growth and quality;

Up to 1.2 g dm^{-3} of polymer can be incorporated into the substrate for the production of *T. esculenta* seedlings;

Containers with higher volumetric capacity (0.75 *vs* 1.30 dm^3) are indicated in the production of *T. esculenta* seedlings.

Acknowledgments

This study was conducted with support from the Coordination for the Improvement of Higher Education Personnel (CAPES) and the National Council for Scientific and Technological Development (CNPq), through the granting of scholarships. We also thank Hydroplan-EB® for providing the polymer.

References

Barbosa, T.C., Rodrigues, R.R., Couto, H.T.Z. 2013. Tamanhos de recipientes e o uso de hidrogel no estabelecimento de mudas de espécies florestais nativas. *Hoehnea* 40: 537–556.

Bezerra, F.T.C.; Bezerra, M.A.F.; Nascimento, R.R.A.; Pereira, W.E.; Oliveira, C.J.A.; Souza, G.L.F.; Ribeiro, J.E.S. 2022. Physiology in *Talisia esculenta* seedlings under irrigation with saline water on substrate with hydrogel. *Semina: Ciências Agrárias* 43: 751–774.

Bezerra, M.A.F., Pereira, W.E., Bezerra, F.T.C., Cavalcante, L.F., Medeiros, S.A.S. 2014. Água salina e nitrogênio na emergência e biomassa de mudas de maracujazeiro amarelo. *Agropecuária Técnica* 35: 150–160.

Bezerra, M.A.F., Pereira, W.E., Bezerra, F.T.C., Cavalcante, L.F.C., Medeiros, S.A.S. 2019. Nitrogen as a mitigator of salt stress in yellow passion fruit seedlings. *Semina: ciências agrárias* 40: 611–622.

Cabreira, G.V., Leles, P.S.S., Alonso, J.M., Resende, A.S., Cabreira, W.V., Sousa, T.J.S. 2021. Controlled-release fertilizer and container volume to produce *Inga laurina* seedlings. *Floresta e Ambiente* 28: e20190057.

Campany, C.E., Medlyn, B.E., Duursma, R.A. 2017. Reduced growth due to belowground sink limitation is not fully explained by reduced photosynthesis. *Tree Physiology* 37: 1042–1054.

Carvalho, R.P., Cruz, M.C.M., Martins, L.M. 2013. Frequência de irrigação utilizando polímero hidroabsorvente na produção de mudas de maracujazeiro-amarelo. *Revista Brasileira de Fruticultura* 35: 518–526.

Dickson, A., Leaf, A.L., Hosner, J.F. 1960. Quality appraisal of white spruce and white pine seedling stock in nurseries. *The Forestry Chronicle* 36: 10–13.

Espinoza, S.E., Santelices, R.E., Cabrera. A.M., Magni, C.R. 2017. Interactive effects of water stress, container size and fertilizer on survival, gas exchange and morphological traits of *Quillaja saponaria* seedlings. *Bosque* 38: 409–414.

Fagundes, D.A., Araujo, M.M.V., Camili, E.C. 2015. Crescimento de plântulas de maracujazeiro-amarelo sob diferentes lâminas de irrigação e uso de hidrogel. *Revista de Agricultura* 90: 229–236.

Felippe, D., Navroski, M.C., Aguiar, N.S., Pereira, M.de.O., Moraes, C., Amaral, M. 2020. Crescimento, sobrevivência e trocas gasosas de mudas de *Eucalyptus dunnii* Maiden submetidas a regimes de irrigação e aplicação de hidrogel. *Revista Forestal Mesoamericana Kurú* 17: 11–20.

Felippe, D., Navroski, M.C., Sampietro, J.A., Frigotto, T., Albuquerque, J.A., Mota, C.S., Pereira, M.O. 2016. Efeito do hidrogel no crescimento de mudas de *Eucalyptus benthamii* submetidas a diferentes frequências de irrigação. *Floresta* 46: 215–225.

Guarim Neto, G., Guarim V.L.M.S., Nascimento, N.P.O. 2003. Repertório botânico da "pitombeira" (*Talisia esculenta* (A. St.-Hil.) Radlk. - Sapindaceae). *Acta Amazonica* 33: 237–242.

Hunt, R. 1990. Basic growth analysis: plant growth analysis for beginners. *Unwin Hyman*, London, UK. 112 p.

Husson, F., Lê, S., Pagès, J. 2017. *Exploratory multivariate analysis by example using R*. Taylor and Francis Group, Boca Raton, USA. 262 p.

Lima Neto, A.J.., Cavalcante, L.F., Nunes, J.C., Souto, A.G.L., Bezerra, F.T.C., Cavalcante, A.G. 2018. Biometric variables and photosynthetic pigments in tamarind seedlings irrigated with saline water and biofertilizers. *Semina: Ciências Agrárias* 39: 1909-1920.

Melo Filho, J.S., Véras, M.L.M., Alves, L.S., Silva, T.I., Gonçalves, A.C.M., Dias, T.J. 2017. Salinidade hídrica, biofertilizante bovino e cobertura vegetal morta na produção de mudas de pitombeira (*Talisia esculenta*). *Revista Scientia Agraria* 19: 131-145.

Montgomery, D. G. 2013. *Design and analysis of experiments*. John Wiley & Sons, New Jersey, EUA. 724 p.

Moura, A.R., Nogueira, R.J.M.C., Silva, J.A.A., Lima, T.V. 2016. Relações hídricas e solutos orgânicos em plantas jovens de *Jatropha curcas* L. sob diferentes regimes hídricos. *Ciência Florestal* 26: 345–354.

Nascimento Neto, E.C, Bezerra, F.T.C., Bezerra, M.A.F., Pereira, W.E., Cavalcante, L.F., Oliveira, F.F.O. 2020. Allometry and morphophysiology of papaya seedlings in a substrate with polymer under irrigation with saline water. *Comunicata Scientiae* 11: e3339.

Nascimento, H.H.C., Santos, C.A., Freira, C.S., Silva, M.A., Nogueira, R.J.M.C. 2015. Ajustamento osmótico em mudas de jatobá submetidas à salinidade em meio hidropônico. *Revista Árvore* 39:641–653.

Navroski, M. C., Araujo, M.M., Fior, C.S., Cunha, F.S., Berghetti, A.L.P., Pereira, M.O. 2015. Uso de hidrogel possibilita redução da irrigação e melhora o crescimento inicial de mudas de *Eucalyptus dunnii* Maiden. *Scientia Forestalis* 43: 467–476.

Navroski, M.C., Araujo, M.M., Reiniger, L.R.S., Fior, C.S., Scharfer, G., Pereira, M.O. 2016. Initial growth of seedlings of *Eucalyptus dunnii* maiden as influenced by the addition of natural polymer and farming substrates. *Revista Árvore* 40: 627–637.

Novais, R.F., Neves, J.C.L., Barros, N. F. 1991. Ensaio em ambiente controlado. In: Oliveira, A.J., Garrido, W.E., Araújo, J.D., Lourenço, S. (eds.). *Métodos de pesquisa em fertilidade do solo* Brasília. EMBRAPA Informação Tecnológica, Brasília, Brazil. p. 189-253.

Oliveira, F.I.F., Souto, A.G.L., Cavalcante, L.F., Medeiros, W.J.F., Bezerra, F.T.C., Bezerra, M.A.F. 2017. Quality of jackfruit seedlings under saline water stress and nitrogen fertilisation. *Semina: Ciências Agrárias* 38: 2337–2350.

Ouma, G. 2007. Effect of different container sizes and irrigation frequency on the morphological and physiological characteristics of mango (*Mangifera indica*) rootstock seedlings. *International Journal of Botany* 3: 260–268.

Ovalles, F.A., Collins, M.E. 1988. Variability of northwest Florida soils by principal component analysis. *Soil Science Society of America Journal* 5:1430–1435.

Rahneshana. Z., Nasibi, F., Moghadam, A.A. 2018. Effects of salinity stress on some growth, physiological, biochemical parameters and nutrients in two pistachio (*Pistacia vera* L.) rootstocks. *Journal of Plant Interactions* 13:73–82.

Sá, F.V.S., Brito, M.E.B., Ferreira, I.B., Antônio Neto, P., Silva, L.A., Costa, F.B. 2015. Balanço de sais e crescimento inicial de mudas de pinheira (*Annona squamosa* L.) sob substratos irrigados com água salina. *Irriga* 20: 544–556.

Silva Júnior, L.G.A., Gheyi, H.R., Medeiros, J.F. 1999. Composição química de águas do cristalino do Nordeste Brasileiro. *Revista Brasileira de Engenharia Agrícola e Ambiental* 3: 11–17.

Silva, A.R., Bezerra, F.T.C., Cavalcante, L.F., Pereira, W.E., Araújo, L.M., Bezerra, M.A.F. 2018a. Frequency of irrigation with saline water in sugar-apple seedlings produced on substrate with polymer. *Revista Brasileira de Engenharia Agrícola e Ambiental* 22: 825–830.

Silva, A.R., Bezerra, F.T.C., Cavalcante, L.F., Pereira, W.E., Araújo, L.M., Bezerra, M.A.F. 2018b. Biomass of sugarapple seedlings under saline water irrigation in substrate with polymer. *Revista Brasileira de Engenharia Agrícola e Ambiental* 22: 610–615.

Taiz, L., Zeiger, E., Møller, I. M., Murphy, A. 2017. *Fisiologia e desenvolvimento vegetal*. Artmed, Porto Alegre, Brasil. 858 p.

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.