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Cultivation of chicory under nutrient solutions prepared in brackish waters and applied at different temperatures[1]

Cultivo do almeirão sob soluções nutritivas preparadas em águas salobras e aplicadas em diferentes temperaturas

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HIGHLIGHTS:

Salinity affected leaf characteristics, but to a lesser degree under nutrient solution in a temperature range of 25 to 30 °C.
Damage caused by salinity on cell membranes was attenuated by cooling the nutrient solution.
Cooling the nutrient solution (25-30 °C) increased by 32.61% the production of chicory compared to the ambient temperature.

ABSTRACT: The cooling of nutrient solutions prepared in brackish water can have several implications for plants grown in hydroponics. In this context, the present study aimed to evaluate the effects of temperature and salinity stresses in the root zone on the growth, water status, production, and leaf characteristics of chicory cultivar Folha Larga, exposed to four values of electrical conductivity of nutrient solution - ECns (1.7, 3.2, 4.7, and 6.2 dS m^{-1}), applied at two temperatures (ambient temperature and controlled in the range between 25-30 °C). The randomized block design arranged in a 4 × 2 factorial scheme with four replications was used. Cooling nutrient solution mitigated effects of salinity on stem height and diameter, number of leaves, and leaf area of chicory; provided greater production and water consumption, stability into root-shoot relationships, and membrane integrity within the saline range studied (1.7 to 6.2 dS m^{-1}).

Key words: *Cichorium intybus* L., soilless cultivation, salinity, cooling

RESUMO: O resfriamento de soluções nutritivas preparadas em águas salobras pode ter diversas implicações sobre as plantas cultivadas em hidroponia. Nesse contexto, o presente estudo teve como objetivo de avaliar os efeitos dos estresses de temperatura e salinidade na zona radicular sobre o crescimento, estado hídrico, produção e características foliares do almeirão, cultivar Folha Larga, exposto a quatro valores de condutividade elétrica da solução nutritiva - CEsn (1,7; 3,2; 4,7 e 6,2 dS m^{-1}), aplicado em duas temperaturas (ambiente e controlada na faixa entre 25-30 °C). Foi adotado o esquema fatorial 4 × 2 em blocos casualizados, com quatro repetições. O resfriamento da solução nutritiva mitigou os efeitos da salinidade sobre a altura e diâmetro do caule, número de folhas e área foliar do almeirão; proporcionou maior produção e consumo hídrico, estabilidade na relação raiz parte aérea e integridade da membrana, no intervalo salino estudado (1,7 a 6,2 dS m^{-1}).

Palavras-chave: *Cichorium intybus* L., cultivo sem solo, salinidade, resfriamento

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Introduction

Hydroponic crops have been considered a solution for regions with low availability of fresh water because it requires a low volume of water (Santos et al., 2021). In this cultivation system, the use of brackish water implies less damage to plants when comparing the same plants exposed to the same salinity conditions, however, grown in soil (Atzori et al., 2019; Freitas et al., 2019).

Minimization of matrix potential due to the absence of soil favors the absorption of water by plants, which becomes predominantly affected by the osmotic potential of nutrient solution (Santos Júnior et al., 2016; Campos Júnior et al., 2018).

Several studies have already shown the technical viability of using brackish water to prepare nutrient solutions for cultivating different plant species; for example, arugula (Campos Júnior et al., 2018), cauliflower (Cruz et al., 2018), lettuce (Soares et al., 2019), coriander (Silva et al., 2020b), chicory (Alves et al., 2019; Silva et al., 2020a), among others.

On the other hand, to achieve satisfactory plant growth, it has been reported that nutrient solution temperatures should not exceed 30 °C (Sun et al., 2016; Nguyen et al., 2020). In this context, control/cooling can act as a mitigating agent for saline damage, especially in crops located in regions where high air temperatures are recorded for most of the year (Silva et al., 2020b).

This study aimed to evaluate the effects of temperature and salinity stresses in the root zone on the growth, water status, production, and leaf characteristics of the chicory cultivar Folha Larga.

Material and Methods

The experiment was conducted between December 2021 and February 2022 in a protected environment - arch type, belonging to the Fertigation and Salinity Station of Agricultural Engineering Department of Federal Rural University of Pernambuco (DEAGRI/UFRPE), Recife-PE (8°01’07” S, 34°56’53” W, and an altitude of 6.5 m).

During the experimental period, the average air temperature was 33.7 °C, and the average relative air humidity was 54% (Figure 1), recorded using a Digitech meteorological station model XC0348 installed inside the protected environment.

The experimental design was in randomized blocks arranged in a 4 × 2 factorial scheme with four replicates and nine plants per plot. The treatments consisted of four values of electrical conductivity of nutrient solutions (ECns = 1.7 – control, 3.2, 4.7, and 6.2 dS m^{-1}) that were applied in ambient temperature and a range temperature of 25 and 30 °C (Cometti et al., 2013; Martins et al., 2019; Silva et al., 2020b).

Each experimental unit was composed of a hydroponic system constituted by a hydroponic channel (PVC tube), a reservoir for the nutrient solution, and an electric pump (34 W) to circulate the nutrient solution in the system.

Each hydroponic channel was designed to be 2 m long and 0.10 m in diameter, with circular holes 0.06 m in diameter - spaced equidistantly every 0.14 m. The channels and reservoirs where the cooled nutrient solution was used were lined with an aluminized thermal blanket.

Adapters of the same diameter were attached to the ends of the tubes and connected to a valve for the water outlet. These valves induced a constant value of 0.04 m of nutrient solution

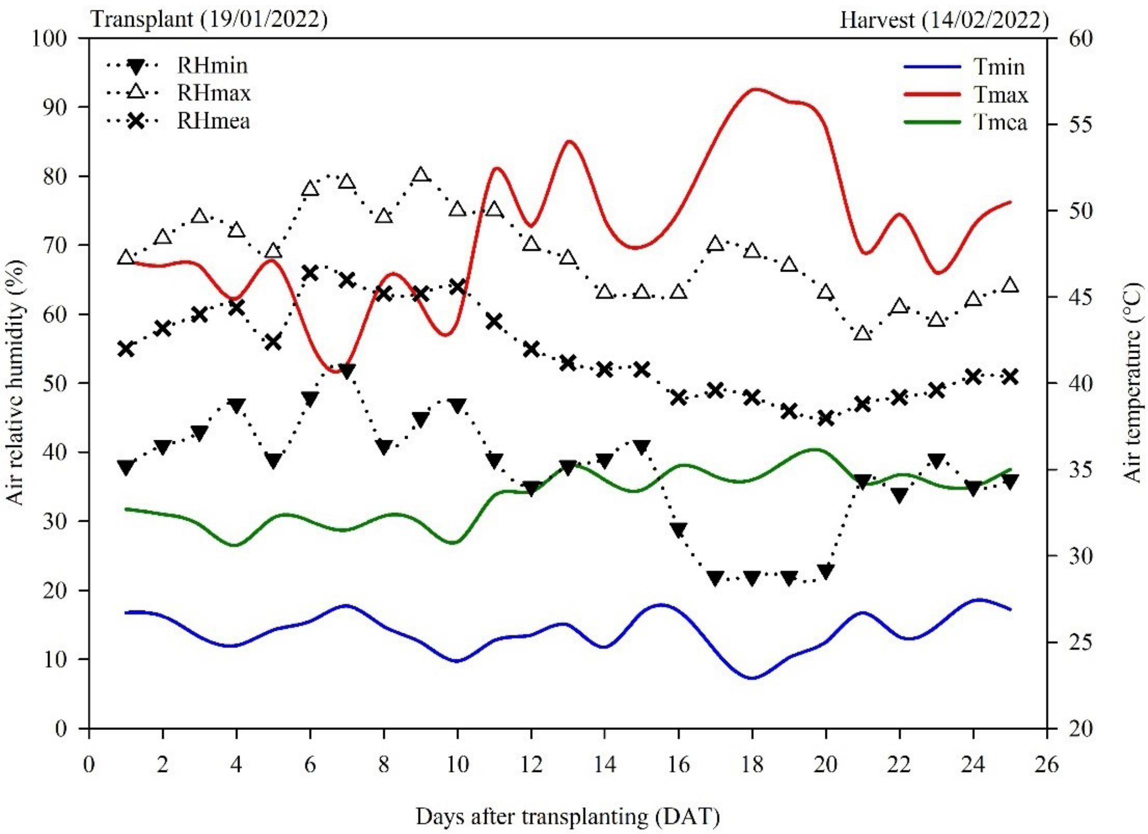


Figure 1. Minimum (Tmin), maximum (Tmax), and average (Tmea) air temperature and minimum (RHmin), maximum (RHmax), and average (RHmea) relative air humidity inside of protected environment during the experimental period

inside each tube, equitably making the solution available to all plants. The channels were horizontally arranged and leveled in a vertical wooden structure, similar to what was described by Santos Júnior et al. (2016).

An analog timer controlled the activation of the electric pump. In addition, it was used recirculation of nutrient solutions programmed to alternate intervals of 15 minutes (15 minutes running and 15 minutes in the rest) from 9:00 am to 6:00 pm. At other times of the day, there was no nutrient solution recirculation.

At the beginning of the experiment, nutrient solutions were prepared only once using local water supplies whose electrical conductivity of water (ECw) was 0.12 dS m^{-1}. The doses of fertilizers were based on the proposal by Furlani et al. (1999) for leafy vegetables. The addition of fertilizers corresponded to the following nutrient concentrations: N 13.59, Ca 2.37, K 5.50, P 2.61, S 1.37, and Mg 1.48 mmol L^{-1}; and B 180.00, Cu 30.00, Fe 180.00, Mn 140.00, Mo 8.00, and Zn 90.00 μmol L^{-1}, which provided an increase in electrical conductivity of nutrient solution equivalent to 1.58 dS m^{-1}.

After the preparation of nutrient solutions, the volume planned for treatments of the same ECns was separated into different reservoirs. Then, as a reference of Richards equation (1954), quantities of NaCl to be solubilized were established (0, 16.43, 32.85, and 49.28 mmol L^{-1} for ECns values of 1.7, 3.2, 4.7, and 6.2 dS m^{-1}, respectively). After that, an initial volume of 17 L of the nutrient solution was added to each hydroponic plot (cultivation channel and reservoir), that is, 1.88 L of nutrient solution per plant.

Regarding the management of nutrient solutions, there was continuous reuse of them. Thus, the excess nutrient solution to level it inside the tube was returned to the reservoir via a hose, and the process was repeated for each circulation event.

Replacement of evapotranspiration value was conducted daily with respective brackish water (ECw = 0.12, 1.62, 3.12, and 4.62 dS m^{-1}) used to prepare the nutrient solution; that is, with the same initial concentrations of NaCl.

In the treatments in which the cooling of the nutrient solution was foreseen, the temperature was maintained at 25 to 30 °C from 09:00 am to 6:00 pm. In this process, part of the nutrient solution was placed in freezers. While another part, already cooled, was returned to the reservoir to circulate in repeated processes with intervals of two hours.

Daily, inside cultivation channels, the temperature of nutrient solutions (Tns) was constantly monitored by a skewer-type digital thermometer and recorded at 1 hour and 30 min intervals. At the same time, electrical conductivity (ECns), pH (pHns), and dissolved oxygen (DOns) of nutrient solutions were measured in intervals between 13 and 14 hours daily.

The sowing of the chicory (*Cichorium intybus* L.) cultivar Folha Larga (Topseed - Agristar do Brasil; Santo Antonio de Posse, SP, Brazil) was performed in seeds trays filled with coconut fiber substrate. Three seeds per cell were used. In the first seven days after sowing (DAS), substrate moisture was maintained by water spraying (ECw = 0.12 dS m^{-1}).

Between the 7th and 30th DAS, seedlings were irrigated twice a day, applying 40 mL of nutrient solution as proposed by Furlani et al. (1999) with a concentration of 50%. At 23 DAS, seedlings were transferred from trays to plastic cups with a capacity of 180 mL (perforated at the bottom and laterally for the passage of roots), containing the same type of substrate used in the trays. Transplant to the hydroponic system occurred at 30 DAS; nine plants were distributed in each cultivation channel. There were no phytosanitary problems during the experiment.

At 5, 12, and 19 days after transplant (DAT), non-destructive evaluations were performed on the same plants. It was assessed plant height (PH, cm), measured from the base of the plant to the tip of the leaf. Stem diameter (SD, mm) was obtained with a digital caliper. The number of leaves (NL) was counted from the basal leaf to the last fully expanded leaf; total leaf area (LA, dm^2), according to the equation proposed by Pereira et al. (2012): $LA = \pi / (4 \times LL \times LW)$, in which: LL - leaf length, in dm; LW - leaf width, in dm.

The plants were harvested at 26 DAT (three central plants ignoring borders), and, besides the variables already mentioned, the following variables were evaluated: leaf fresh matter (LFM, g per plant) and shoot fresh matter (SFM, g per plant). Also, electrolyte leakage (EL, %) was evaluated through EC_F/EC_T ratio, where: free electrical conductivity (EC_F, dS m^{-1}); total electrical conductivity (EC_T, dS m^{-1}), according to the methodology described by Batista et al. (2021); leaf succulence (LS, g H_2O dm^{-2}) was assessed according to the equation described by Cruz et al. (2018): LS = (LFM - LDM) / LA, where LDM - leaf dry matter; water consumption (WC, L per plant) was estimated through ratio between the evapotranspired volume of nutrient solution and the number of plants in hydroponic channel; water use efficiency was calculated based on SFM (WUE-SFM = SFM/WC, g L^{-1}) according to Martins et al. (2019).

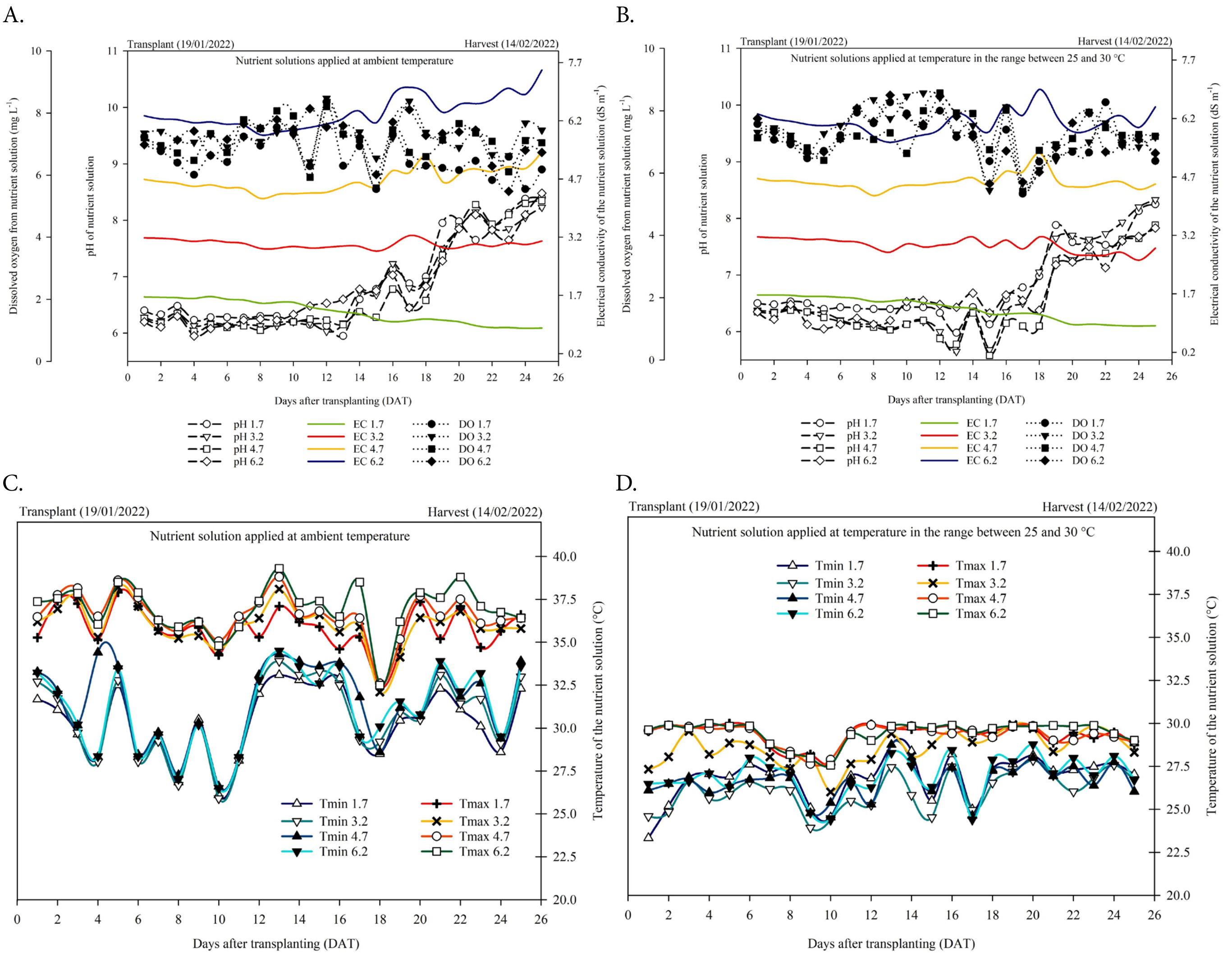
In addition, it was determined: the production of SFM (P-SFM, g SFM per plant); root-shoot relationships based on dry mass (RSR); leaf area ratio (LAR) through the relationship between LA and total dry matter (TDM); specific leaf area (SLA), LA divided by LDM; leaf mass ratio (LMR), LDM divided by TDM. The shoot dry matter (SDM), leaf dry matter (LDM), and root dry matter (RDM) were obtained after drying the fresh material in an air-forced circulation oven at 65 °C. Furthermore, TDM was obtained by adding SDM and RDM.

The data were submitted to the analysis of variance at $p \leq 0.05$. Means of ECns were submitted to regression analysis. Means of temperature of the nutrient solution were compared by the Tukey test at $p \leq 0.05$. The analyses were performed by SISVAR software (Ferreira, 2019).

Results and Discussion

Regarding variation of ECns compared to its initial value in the control treatment (1.7 dS m^{-1}), reductions of 49.41% and 48.24% were observed in nutrient solutions exposed to ambient temperature (Figure 2A) and range of 25-30 °C (Figure 2B), respectively.

This reduction, whose trend has already been verified by other authors (Alves et al., 2019; Soares et al., 2019), can be attributed to the consumption of nutrients, besides the strategy used to replace (with water of 0.12 dS m^{-1}) the level of nutrient solution reservoir that decreases, which depends on plants water consumption.



pH = pH of nutrient solution; EC = electrical conductivity of nutrient solution; DO = dissolved oxygen of nutrient solution; Tmin = minimum temperature of nutrient solution; Tmax = maximum temperature of nutrient solution; values 1.7, 3.2, 4.7 and 6.2 = values of electrical conductivity of nutrient solution in dS m^{-1}

Figure 2. Temporal variation of electrical conductivity, pH, dissolved oxygen, and temperature of nutrient solutions prepared into brackish water with the prevalence of NaCl with ambient temperature (A and C) and between 25 and 30 °C (B and D)

In both temperature conditions (ambient and range of 25-30 °C), initial ECns of 3.2 dS m^{-1} have shown the greatest variations, 11.32 and 20.08%, respectively (Figures 2A and B). Under ECns of 4.7 and 6.2 dS m^{-1}, the most pronounced increases (14.84 and 21.13%, respectively) were observed in nutrient solutions with ambient temperature (Figure 2A). This fact can be attributed to the accumulation of ions, which plants did not absorb (Campos Júnior et al., 2018; Cruz et al., 2018; Soares et al., 2019), and possibly to the nutrient solution temperature by itself.

In general, it was verified that the pH of nutrient solution – pHns was within the range between 5.50 and 7.50 in the first 18 DAT in all treatments, remaining within a range in which the pH does not negatively affect cell development of plants in hydroponic cultivations (Furlani et al., 1999). However, an upward trend was observed in the final phase of the crop cycle; thus, emphasizing a positive variation of 36.6% concerning the initial pHns, which was verified for a value of 6.2 dS m^{-1} in solution with ambient temperature (Figures 2A and B).

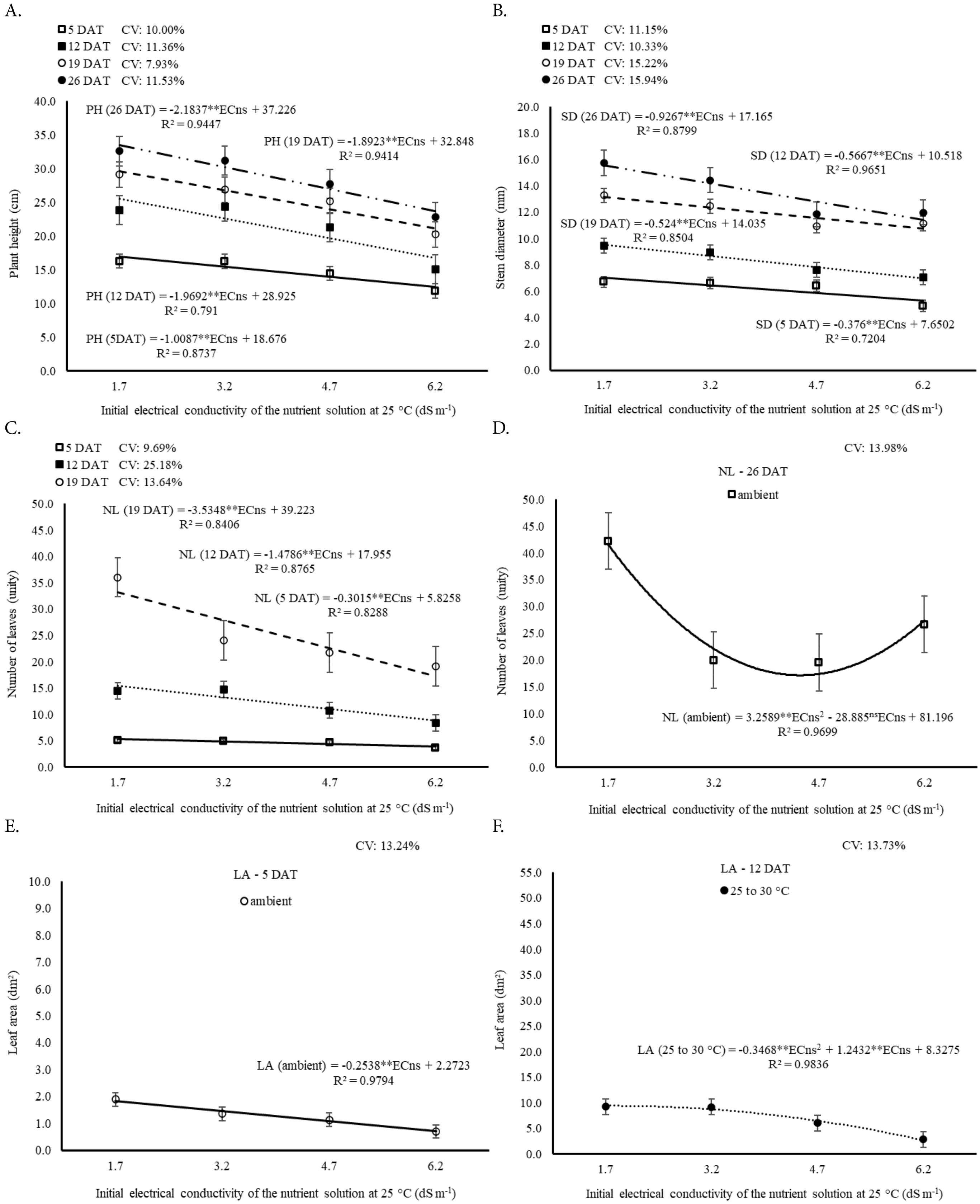
Generally, it can be observed that the concentration of dissolved oxygen in nutrient solution (DOns) ranged between 5.34 and 8.57 mg L^{-1} for all treatments (Figures 2A and B). However, DOns concentration in nutrient solution was inversely proportional to its temperature (Al-Rawahy et al., 2019). This effect was not observed in this present research, which can be attributed to the efficiency of high frequency in the recirculation of solution.

Temperature variation of nutrient solution with ambient conditions has shown the highest daily average temperature was 36.5 °C, reaching average peaks of 39.3 °C in measurements taken at 1 pm. The average temperatures of nutrient solutions when applied at ambient temperature and between 25-30 °C were 33.6 °C and 28.0 °C, respectively (Figures 2C and D).

In all evaluations (5, 12, 19, and 26 days after transplanting - DAT), there was a significant effect ($p \leq 0.01$) of electrical conductivity values of nutrient solutions (ECns) on plant height - PH (Figure 3A), stem diameter - SD (Figure 3B), number of leaves - NL (Figures 3C and D), and leaf area - LA (Figures 3E and H) of chicory. The effect of nutrient solution temperatures has shown significant ($p \leq 0.01$) influences of PH at 19 DAT, SD at 5 and 12 DAT, NL, and LA at 12, 19, and 26 DAT (Table 1). Significant interaction ($p \leq 0.01$) was observed in NL with 26 DAT (Figure 3D) and LA with 5 DAT (Figure 3E), 12 DAT (Figure 3F), and 26 DAT (Figure 3H).

Increased ECns reduced (p≤0.01) PH and SD with a rate of 1.01, 1.97, 1.89, and 2.18 cm and 0.38, 0.57, 0.52, and 0.93 mm at 5, 12, 19, and 26 DAT, respectively (Figures 3A and B); as well as the NL at 0.30, 1.48, and 3.53 leaves with 5, 12, and 19 DAT (Figure 3C) and LA in 4.28 dm^2 with 19 DAT per incremented ECns unit (Figure 3G). In addition, at harvest time, at the highest salinity value tested (6.2 dS m^{-1}), the average PH and SD were 29.32% (Figure 3A) and 26.75% (Figure 3B) lower than the control treatment, respectively.

Application of nutrient solution with temperature between 25 and 30 °C resulted in gains of 16.20% in SD at 5 DAT and 14.31 and 22.81% in SD and NL at 12 DAT, respectively.



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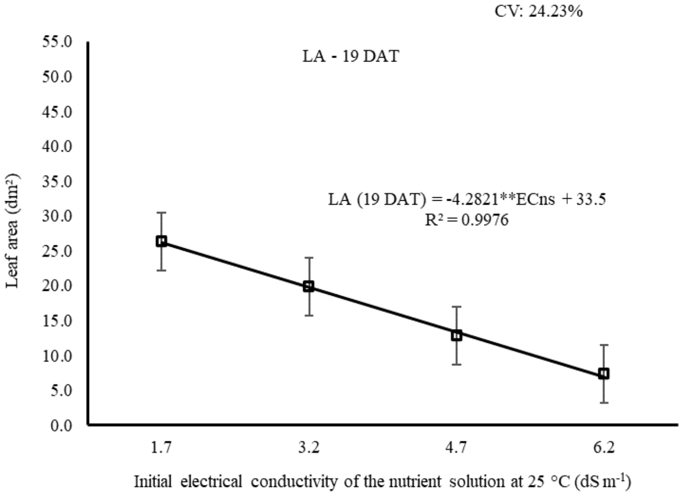

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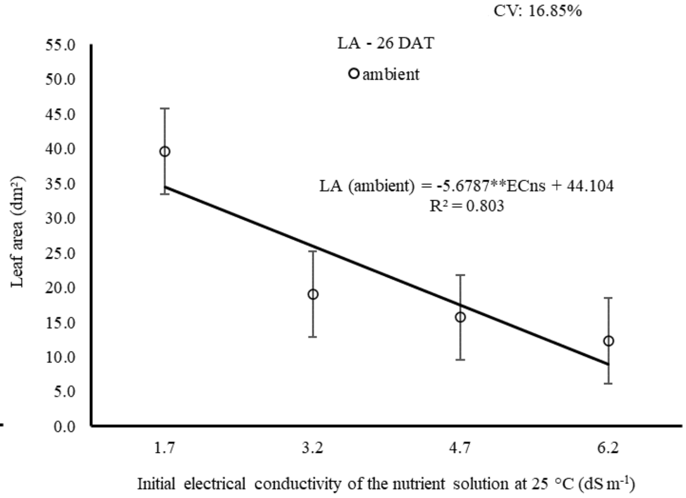


Note: Vertical bars represent the standard error of the mean (n = 4)

Figure 3. Plant height (A), stem diameter (B), number of leaves at 5, 12, and 19 days after transplant - DAT (C), number of leaves at 26 DAT (D), leaf area at 5 DAT (E), 12 DAT (F), 19 DAT (G), and 26 DAT (H) from chicory plants cultivar Folha Larga, exposed to nutrient solutions prepared in brackish water and arranged at ambient temperature and in the temperature between 25 and 30 °C

Table 1. Summary of means for plant height (PH), stem diameter (SD), number of leaves (NL), and leaf area (LA) at 5, 12, 19, and 26 days after transplant - DAT, electrolyte leakage (EL), leaf succulence (LS), water consumption (WC), water use efficiency based on shoot fresh matter (WUE-SFM), production of shoot fresh matter (P-SFM), root-shoot relationships (RSR), leaf area ratio (LAR), specific leaf area (SLA), and leaf mass ratio (LMR) at 26 days after transplant from chicory plants cultivar Folha Larga, exposed to nutrient solutions prepared in brackish water and applied at ambient temperature and between 25 and 30 °C

Temperature of nutrient solution	PH (cm)				SD (mm)			
	5 DAT	12 DAT	19 DAT	26 DAT	5 DAT	12 DAT	19 DAT	26 DAT
Ambient	14.43 a	20.44 a	24.37 b	27.57 a	5.70 b	7.73 b	11.34 a	12.92 a
25 to 30 °C	14.95 a	21.86 a	26.38 a	29.64 a	6.63 a	8.84 a	12.60 a	14.10 a
	NL (units)				LA (dm^2)			
	5 DAT	12 DAT	19 DAT	26 DAT	5 DAT	12 DAT	19 DAT	26 DAT
Ambient	4.55 a	10.87 b	19.96 b	27.11 b	1.27 a	4.36 b	13.61 b	21.67 b
25 to 30 °C	4.72 a	13.35 a	30.56 a	40.33 a	1.37 a	6.85 a	19.56 a	33.12 a

	EL (%)	LS (g dm^{-2})	WC (L per plant)	WUE-SFM (g L^{-1})	P-SFM (g per plant)	RSR (g g^{-1})	LAR (dm^2 g^{-1})	SLA (dm^2 g^{-1})	[1]LMR (g g^{-1})
Ambient	10.69 a	2.34 a	3.63 b	18.43 a	66.21 b	0.58 a	2.16 b	3.26 b	0.63 b
25 to 30 °C	10.43 a	2.47 a	4.87 a	18.99 a	87.80 a	0.44 b	2.82 a	4.08 a	0.68 a

Means followed by the same letters in the column indicate no significant differences between nutrient solution temperatures by Tukey test ($p \leq 0.05$). [1] CV = 10.19%, the coefficient of variation (CV) of the other variables was inserted in the respective figures

Moreover, the cooling of the nutrient solution increased by 8.27, 53.11, and 43.72% in PH, NL, and LA at 19 DAT, respectively, when compared to plants subjected to solutions at ambient temperature (Table 1).

When the plants were exposed to nutrient solution between 25 and 30 °C, LA at 12 DAT was maximum (9.44 dm^2) at ECns estimated at 1.79 dS m^{-1}. At the same time, NL at 26 DAT and LA at 5 and 26 DAT were not affected ($p>0.05$) by increases in ECns. On the other hand, in ambient temperature, there was no significant variation ($p>0.05$) of LA at 12 DAT, within the range of ECns already studied. Unlike NL, which was minimal (17.2 leaves) with ECns estimated at 4.43 dS m^{-1} at 26 DAT, and LA at 5 and 26 DAT, which was reduced by 0.25 and 5.68 dm^2, for each dS m^{-1} increased, respectively (Table 1).

In general, there was mitigation of saline damage on the performance of growth parameters of plants that were exposed to nutrient solutions at temperatures between 25 °C and 30 °C compared to the plants in ambient temperature. In this sense, after exposing plants of two coriander cultivars, Tabocas and Verdão, to the nutrient solution, which was prepared in brackish water and applied at a constant temperature of 30 and 32 °C, Silva et al. (2020b) suggested that plants responses to salt and heat stresses were variable in different organs and growth stages. Thus, they concluded that when low EC water was used, it was possible to produce up to 32 °C, emphasizing that increases in ECns, in those conditions increase saline damage.

When comparing the effect of Tns within each ECns on the number of leaves and leaf area, it is verified that the plants exposed to solutions between 25 to 30 °C had a higher number of leaves with 128.89 e 83.51%, at 26 DAT (Figure D), and increase in leaf area of 20.37 and 29.86%, at 5 DAT, under ECns of 3.2 and 4.7 dS m^{-1} (Figure E), respectively. Besides that, LA at 26 DAT was up to 110.92% higher (ECns de 3.2 dS m^{-1}) than plants exposed to the ambient temperature of nutrient solution (Figure 3H).

Deleterious effects of increased ECns on NL and LA have already been observed for crops such as chicory (D'Imperio et al., 2018; Silva et al., 2020a), basil (Santos et al., 2019), and lettuce (Moncada et al., 2020). This reduction can be attributed to morphological and anatomical changes to reduce transpiration. However, it also implies a reduction in the photosynthetically active area, which justifies the use of mitigation techniques based on nutrient solution management. For example, the use of solutions at 25-30 °C, as verified in this study, attenuates the effects of salinity on those parameters.

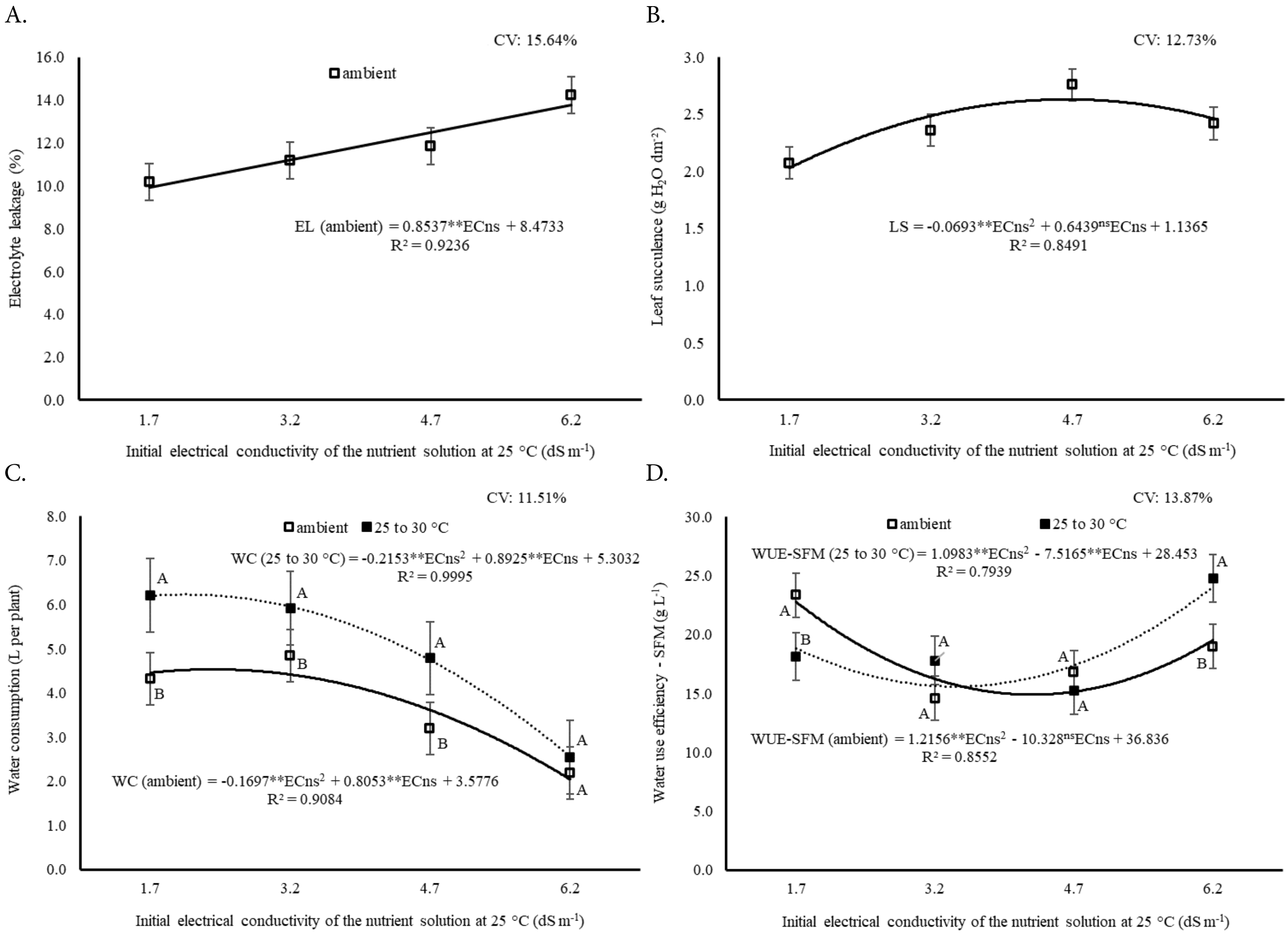
Isolated, ECns had a significant effect ($p \le 0.01$) on electrolyte leakage (EL) (Figure 4A), leaf succulence (LS) (Figure 4B), water consumption (WC) (Figure 4C), and water use efficiency in shoot fresh matter production (WUE-SFM) (Figure 4D). While Tns significantly influenced ($p \le 0.01$) only WC (Table 1). The interaction between treatments influenced ($p \le 0.01$) EL and WUE-SFM, in addition to affecting ($p \le 0.05$) the WC of plants.

Regarding the integrity of membranes, electrolytes leakage - EL was not affected ($p > 0.05$) within the ECns range studied in plants exposed to nutrient solutions between 25 and 30 °C, which an average of 10.43% (Table 1). ECns within Tns (ambient) were analyzed and verified an increase of 0.85% for each dS m^{-1}; that is, damage caused to the cell membrane of plants reached 13.77%, with ECns estimated at 6.2 dS m^{-1} (Figure 4A).

Electrolyte leakage indicates damage caused to cell membranes and is an important parameter for evaluating plant oxidative stress. Regarding salinity conditions, increased leakage has already been verified for crops such as coriander (Jamila et al., 2019), cherry tomato (Batista et al., 2021), and lettuce, where a 61% higher rate of electrolytes leakage was mentioned in plants by saline stress (40 mM NaCl) than control treatment (Freitas et al., 2019).

Leaf succulence – LS was maximum (2.63 g H_2O dm^{-2}) at ECns estimated of 4.65 dS m^{-1} and was not influenced ($p > 0.05$) by Tns (Figure 4B). According to Lema et al. (2019), it can be assumed that there was a tolerance limit to species' salinity at this point of ECns, in which LS was maximum. Until this point, the accumulation of sodium ions promotes an increase in mesophyll cells and leaf succulence, which enables additional water storage and mitigating losses (Xi et al., 2018).

Water consumption - WC of the plants was maximum (4.53 and 6.23 L per plant) under ECns estimated at 2.37 and 2.07 dS m^{-1} when submitted to the nutrient solution at ambient



Vertical bars represent the standard error of the mean (n = 4). Averages followed by the same letters indicate no significant differences between treatments by the Tukey test ($p \le 0.05$) concerning the temperature in the same electrical conductivity of the nutrient solution

Figure 4. Electrolyte leakage (A), leaf succulence (B), water consumption (C), and water use efficiency based on shoot fresh matter (D) at 26 days after transplant of chicory plants cultivar Folha Larga, exposed to nutrient solutions prepared in brackish water and arranged at ambient temperature and between 25 and 30 °C

temperature and cooled, respectively. In contrast, concerning the estimated maximum consumption, a reduction of 54.84 and 58.89% was observed in the WC of the plants exposed to the highest saline value (6.2 dS m^{-1}) when the nutrient solution was kept at ambient temperature and within the range of 25 to 30 ° C, respectively (Figure 4C). Similarly to what has been studied in this research, increases in salts concentration in nutrient solution caused a significant reduction of water consumption in rocket plants (Campos Júnior et al., 2018), parsley (Martins et al., 2019), and chicory (Alves et al., 2019; Silva et al., 2020a).

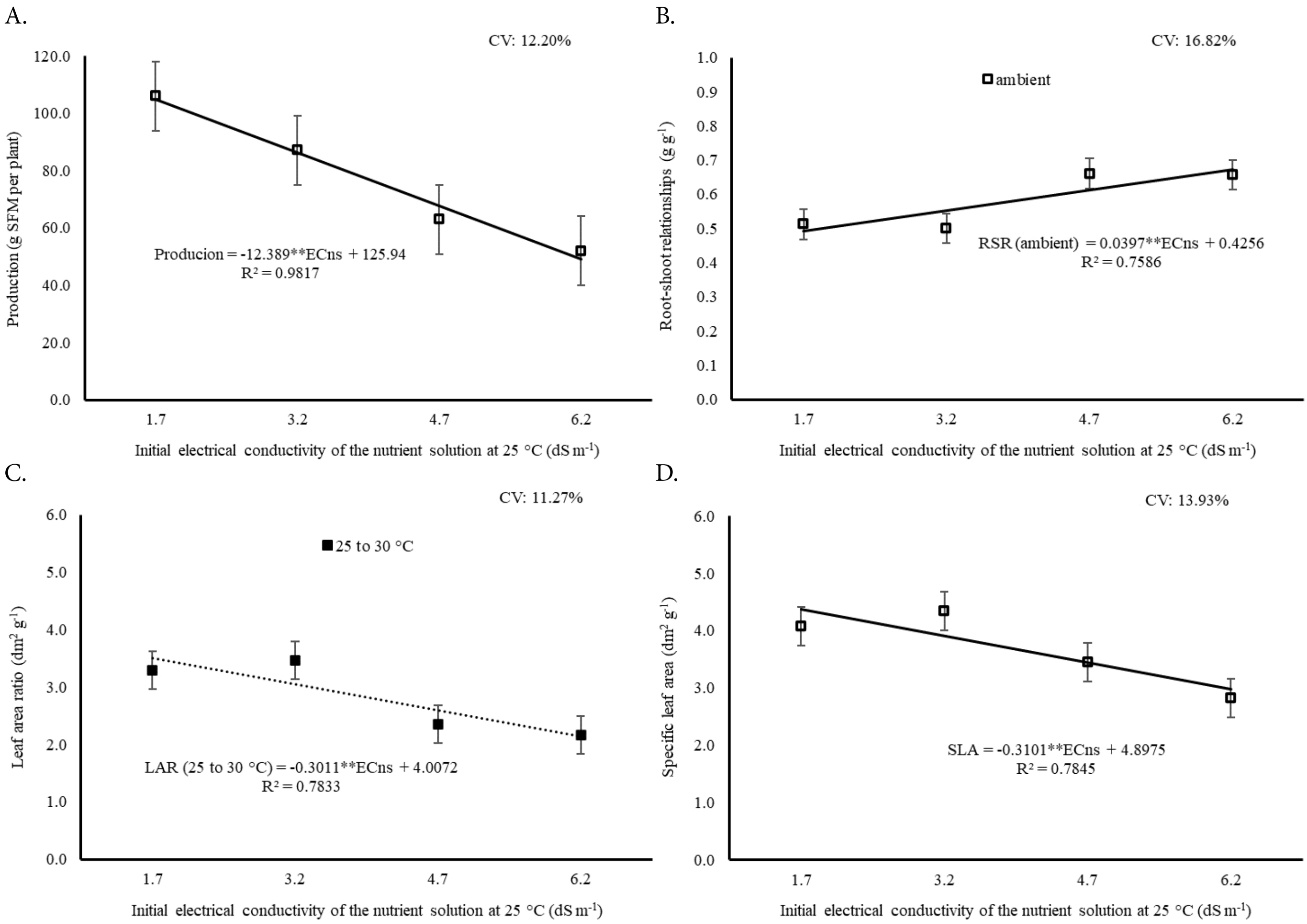
When performing an analysis of the temperature of the nutrient solution within each ECns, it was observed that, under the values of 1.7, 3.2, and 4.7 dS m^{-1}, the water consumption of chicory increased by 39.09, 34.81, and 31.22%, respectively, when plants were exposed to nutrient solutions applied at temperatures ranging from 25 to 30 °C compared to those subjected to nutrient solutions at ambient temperature (Figure 4C).

The WUE-SFM of the plants was minimal (14.90 and 15.59 g L^{-1}) at ECns estimated at 4.25 and 3.42 dS m^{-1} when the plants were exposed to nutrient solutions at ambient temperature and between 25 and 30 °C, respectively. The WUE-SFM was the same (15.60 g L^{-1}) regardless of nutrient solution temperature at an estimated ECns of 3.49 dS m^{-1}. Temperature control intervention, in turn, mitigated saline damage at the highest salinity value (6.2 dS m^{-1}). In this way, it is possible to infer that the cooling of the nutrient solution may have contributed to the reduction of evapotranspiration, which reduced the loss of water by the plant, increasing the water availability in the roots and, consequently, favoring the production of SFM per liter of water consumed at this salinity value (Figure 4D).

When growing the plants under an ECns of 1.7 dS m^{-1}, it was found that the WUE-SFM was significantly higher at ambient temperature, showing an increase of 20.92% (Figure 4D). The lower WUE-SFM verified under controlled temperature at the lowest ECns values can be attributed to the higher water consumption of plants exposed to the nutrient solution at 25 to 30 °C compared to plants grown in solution at ambient temperature.

Interaction between factors significantly influenced ($p \leq 0.01$) root-shoot relationships (RSR) (Figure 5B) and leaf area ratio (LAR) (Figure 5C). Isolated ECns influenced ($p \leq 0.01$) production of shoot fresh matter (P-SFM) (Figure 5A), LAR, and specific leaf area (SLA) (Figure 5D). Nutrient solution temperature (Tns) affected ($p \leq 0.01$) P-MFA, RSR, LAR, SLA, and leaf mass ratio (LMR) (Table 1).

In terms of production, a reduction of 12.389 g of SFM per plant was estimated for each dS m^{-1} increased within the studied ECns interval. At the lowest salinity assessed (1.7 dS m^{-1}), SFM production was 104.88 g per plant. On the other



Note: Vertical bars represent the standard error of the mean (n = 4)

Figure 5. Production of shoot fresh matter (A), root-shoot relationships (B), leaf area ratio (C), and specific leaf area (D) at 26 days after transplant from chicory plants cultivar Folha Larga, exposed to nutrient solutions prepared in brackish water and arranged at ambient temperature and between 25 and 30 °C

hand, when comparing the production of plants exposed to the highest salinity value (6.2 dS m^{-1}) with plants subjected to ECns of 1.7 dS m^{-1}, a decrease of 53.16% was observed in the production of chicory (Figure 5A).

When analyzing the isolated effect of nutrient solution temperature (Tns), it was found that SFM production of plants cultivated in nutrient solutions with a temperature between 25 and 30 °C was 32.61% higher than the production of plants exposed to solutions applied at ambient temperature. Thus, keeping the Tns in the range between 25-30 °C resulted in an average production increase of 21.59 g of SFM per plant, demonstrating the beneficial effects of cooling the nutrient solution's temperature on the production of chicory (Table 1). These results corroborate the findings of Cometti et al. (2013) in studies with hydroponic lettuce cultivation under cooled nutrient solutions with salinity conditions.

Regarding RSR, after analysis, it was found that when applied nutrient solutions in ambient temperature, there was an increase ($p \leq 0.01$) of 9.32% per unit increment of ECns, within the range of ECns studied, that is, the plant started to allocate more biomass in root than shoot. Similar results were reported by Campos Júnior et al. (2018) in arugula plants under saline conditions in hydroponic cultivation. However, in plants in nutrient solutions between 25 and 30 °C, this relationship did not change within ECns interval, maintaining an average of 0.44 g g^{-1} (Table 1).

It was worth mentioning that the highest estimated values of RSR were verified in plants cultivated with ECns of 4.7 and 6.2 dS m^{-1} (0.61 and 0.67 g g^{-1}) when solutions were applied at an ambient temperature. In this context, when analyzing Tns within each ECns, it was verified that with these ECns mentioned, the RSR of plants with the nutrient solution in an ambient temperature was 56.17 and 46.99% higher concerning the RSR verified in plants produced with cooled nutrient solution (Figure 5B).

There was a reduction in LAR (only when solutions were applied with temperature between 25 and 30 °C) and SLA with rates of 0.30 and 0.31 dm^2 g^{-1} (Figure 5C and 5D), respectively, per unit increase in ECns. It is possible to observe that, in general, as well as responses verified in growth variables, the highest average values of LAR and SLA were verified with ECns values of 1.7 and 3.2 dS m^{-1} in cooled nutrient solutions.

Likewise, for LMR, means obtained when the solution was cooled differed significantly ($p > 0.05$) from those verified in ambient temperature, with an increase of 30.45, 25.17, and 8.54% in LAR, SLA, and LMR, respectively (Table 1).

It was possible to verify with analysis of results that leaves are sensitive organs to saline stress. Thus, reduced salinity-related leaf area directly affected the LAR and SLA of chicory plants as salt concentration increased. Similar results were observed for semi-hydroponic lettuce (Guimarães et al., 2020) and hydroponic cucumber (Kaloterakis et al., 2021). This occurs partly due to investment in the production of osmoprotectors essential for plant adaptation to stress conditions. This reduction improves water use efficiency by increasing leaf thickness (Kaloterakis et al., 2021) since specific leaf area represents the inverse of leaf blade thickness. Furthermore, attenuation of salinity effects on photosynthetic aspects of chicory plants, such as an increase in LAR, SLA, and LMR verified, is related to the cooling of nutrient solutions.

Conclusions

1. Increases in electrical conductivity of nutrient solution limited plant growth in height, stem diameter, number of leaves, and leaf area. However, applying the nutrient solution with a temperature between 25 and 30 °C mitigated saline damage on the number of leaves and leaf area.

2. Up to the electrical conductivity of 4.7 dS m^{-1}, cooling the nutrient solution between 25 to 30 °C provided higher water consumption of chicory. Temperature control in this same range (25 to 30 °C) provided greater water use efficiency based on the shoot fresh matter production of the plants when cultivated at the electrical conductivity of 6.2 dS m^{-1}.

3. Damage caused to the membranes' integrity was stable in plants grown in nutrient solution with a temperature between 25 and 30 °C and increased in plants with a nutrient solution of ambient temperature.

4. The temperature maintenance of nutrient solution between 25 and 30 °C increased chicory production.

5. Root-shoot relationships of plants under nutrient solutions with temperatures between 25 and 30 °C were stable. While under nutrient solutions at ambient temperature, this relationship increased.

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