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ORIGINAL ARTICLE

Lettuce growing in different hydroponic systems and nutrient concentrations of the nutrient solution[1]

Cultivo de alface em diferentes sistemas hidropônicos e concentrações de nutrientes na solução nutritiva

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HIGHLIGHTS:
Cultivation systems and nutrient solutions influence lettuce plants.
NFT system provides greater plant biomass in a less dilute solution.
Diluted nutrient solution with lower EC (1.6 dS m⁻¹) is sufficient for lettuce production and quality.

ABSTRACT: Alternative techniques for cultivation without soil are widespread; however, studies comparing hydroponic systems still need to be studied, mainly in semi-arid regions. The present study aimed to evaluate the effect of hydroponic systems on the yield and quality of lettuce cultivars subjected to different electrical conductivities of the nutrient solution. The research was conducted in a greenhouse, adopting a completely randomized design in a 2 × 2 × 3 factorial scheme, being two lettuce cultivars (Cinderela and Rubinela), two electrical conductivities (2.90 and 1.6 dS m^{-1}), and three hydroponics systems (NFT, semi-hydroponic, and floating), with three replications. The number of leaves, leaf succulence, specific leaf area, leaf fresh mass, total dry mass, leaf area, titratable acidity, vitamin C, and soluble solids were evaluated. Cinderela cultivar showed the highest average leaf fresh mass, total dry mass, leaf area, and vitamin C values. The NFT and floating systems provided the highest leaf yield and quality, especially in the solution of 1.60 dS m^{-1}. The semi-hydroponic system provided greater development of the plants with a more concentrated nutrient solution (2.90 dS m^{-1}).

Key words: electrical conductivity, vegetables, *Lactuca sativa*

RESUMO: Técnicas alternativas de cultivo sem solo são difundidas; no entanto, estudos comparando os sistemas hidropônicos ainda precisam ser estudados, principalmente em regiões semiáridas. O presente estudo teve como objetivo avaliar a efeito de sistemas hidropônicos na produtividade e qualidade de cultivares de alface submetidas a diferentes condutividades elétricas da solução nutritiva. A pesquisa foi conduzida em casa de vegetação, adotando delineamento inteiramente casualizado. em esquema fatorial 2 × 2 × 3, sendo duas cultivares de alface (Cinderela e Rubinela), duas condutividades elétricas (2,90 e 1,6 dS m^{-1}), e três sistemas hidropônicos (NFT, semi-hidropônico e floating), com três repetições. Foram avaliados número de folhas, suculência foliar, área foliar específica, massa fresca foliar, massa seca total, área foliar, acidez titulável, vitamina C e sólidos solúveis. A cultivar Cinderela apresentou maior massa fresca de folhas, massa seca total, área foliar, acidez titulável e vitamina C e sólidos solúveis. Os sistemas NFT e floating proporcionaram maior produtividade e qualidade foliar, especialmente na solução de 1,60 dS m^{-1}. O sistema semi-hidropônico proporcionou maior desenvolvimento das plantas com solução nutritiva mais concentrada (2,90 dS m^{-1}).

Palavras-chave: condutividade elétrica, hortaliças, *Lactuca sativa*

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Introduction

Lettuce (*Lactuca sativa* L.) stands out for its significant economic importance among leafy vegetables, occupying a significant production area of around 86,900 hectares, with the State of São Paulo being the main producer. In the 2023/24 summer harvest, the area should still grow 7.5% compared to 2022/23, given the greater investment in genetic material resistant to the probable hot climate with more frequent rain (Anuário Brasileiro de Horti&Fruit, 2023).

Lettuce is the most cultivated crop in hydroponic systems (Abbey et al., 2019). Among the hydroponic cultivation techniques, the static aeration system (floating), cultivation on substrates (semi-hydroponic), and the nutrient film technique (NFT) stand out (Mouroutoglou et al., 2021). Among these systems, NFT is the most used in producing leafy vegetables (Martinez, 2021).

Due to its characteristics, each system has peculiarities that provide advantages and limitations. The NFT system highly depends on electrical energy, while the floating system requires an efficient oxygenation system (Martinez, 2021). The semi-hydroponic or substrate system provides considerable savings in electrical energy and a satisfactory balance between aeration and water availability for the plants (Schafer & Lerner, 2022).

Another key factor in hydroponic cultivation is the adequate electrical conductivity (EC) of nutrient solution, considering that low EC can imply a shortage of nutrients (Savvas & Gruda, 2018). On the other hand, under high EC, osmotic stress can occur, resulting in more energy expenditure by plants to absorb water and nutrients, causing a decrease in crop productivity (Conversa et al., 2021a).

Given the above, the present study was conducted to evaluate the effect of hydroponic systems on the yield and quality of lettuce cultivars subjected to different electrical conductivities of the nutrient solution.

Material and Methods

The experiment was conducted from October to December 2019 in a protected environment (greenhouse) in the experimental area of the Department of Agricultural and Forestry Sciences - DCAF of the Federal Rural University of the Semi-Arid Region – UFERSA, Mossoró, RN. The greenhouse is located at 5º 12' 48" S, 37º 18' 44" W, and 18 m of altitude, with a structure with a galvanized steel arch roof measuring 3.5 m in ceiling height, 7 m wide and 18 m long, covered with low-density polyethylene film, flanked with black mesh with 50% shading.

The experimental design was completely randomized in a 2×2×3 factorial scheme with three replications. The treatments were obtained by combining two lettuce cultivars (Cinderela and Rubinela), two electrical conductivities - EC (2.90 and 1.60 dS m^{-1}), equivalent to 100 and 50% strength, respectively, concerning the recommendation by Furlani et al. (1999); and three hydroponic cultivation systems (NFT, semi-hydroponic, and floating). The experimental plot was represented by five plants for all systems.

The water source used in the preparation of the nutritional solutions comes from the municipal supply, where its chemical characterization was: pH = 7.57; EC = 0.54 dS m^{-1}, Ca^{2+} = 0.83, Mg^{2+} = 1.20, K^+ = 0.31, Na^+ = 3.79, Cl^- = 2.40, HCO_3^- = 3.20, CO_3^{2-} = 0.60 $mmol_c\ L^{-1}$, and RAS = 4.90 $(mmol\ L^{-1})^{0.5}$.

The nutrient solution with EC 2.90 dS m^{-1} contained the concentrations of fertilizers as recommended by Furlani et al. (1999): $Ca(NO_3)_2$ = 750.0 g 1000L^{-1}; KNO_3 = 500.0 g 1000L^{-1}; MAP = 150.0 g 1000L^{-1}; $MgSO_4$ = 400.0 g 1000L^{-1}. To supply micronutrients, Rexolin® BRA was used (30 g 1000L^{-1}), with the following concentration: 11.6% potassium oxide (K_2O), 1.28% sulfur, 0.86% magnesium, 2.1% boron, 2.66% iron, 0.36% copper, 2.48% manganese, 0.036% molybdenum, and 3.38% zinc. The nutrient solution with EC 1.6 dS m^{-1} (50% strength) was obtained by diluting the previous nutrient solution.

The NFT system (Nutrient Laminar Flow Technique) comprised six benches, each consisting of four hydroponic profiles 2.0 m long and seven holes spaced 0.25 m apart. Each bench contained two replications (one for each cultivar), containing two profiles with seven plants, and the profiles of the lateral ends of each bench, as well as the first and last plants of each profile, were not considered for the evaluations.

The profiles were installed on sawn wood beams at a height of 1.0 m from the ground in the highest part and 0.9 m in the lowest part, with a slope of 5%. A 0.20 m spacing was left between profiles, and a 0.6 m wide corridor was left between the benches to facilitate traffic and operability.

Control of nutrient solution circulation was conducted using an analog timer, adopting a 15-minute circulation schedule interspersed every 15 minutes from 5:00 a.m. to 6:00 p.m. During the night, the interval between circulations was two hours, with each event lasting 15 minutes (Martinez, 2021).

Semi-hydroponic cultivation (using substrate) was installed using plastic trays (14 × 37 × 60 cm, for height, width, and length, respectively), with a capacity of 20 L. The trays were placed on a wooden bench 0.5 m high, using a spacing of 0.10 m between trays.

The substrate was prepared by mixing coconut fiber and washed fine sand in a 2:1 (v/v) ratio. Each tray represented an experimental plot in which five lettuce seedlings of the same cultivar were placed; one plant was distributed in the center of the tray, and the others were located close to each end so that 0.25 m remained between plants.

A drainage system was installed in each tray, consisting of a PVC sink drain, a 2.0 cm thick layer of gravel, and a textile blanket. The trays of each nutrient solution were connected through a system composed of PVC tubes and connections (40 mm) to collect and reuse the drained solution, which returned to the individual nutrient solution reservoir (bottle-type) so that the system worked as a closed recirculating system.

Control of nutrient solution circulation was conducted using a digital timer, adopting a schedule of seven daily events, starting at 6:00 a.m. with a 2-hour interval lasting 10 minutes each (Pessoa et al., 2023).

The floating system (Deep Film Technique, DFT) was installed using structures similar to cultivation on a mixed substrate, plus a Styrofoam plate (10 mm) measuring 35 × 58 cm in width and length, respectively. Five holes three centimeters in diameter were drilled in each Styrofoam plate, to which 50 mL disposable bodies were attached, containing two holes at the bottom of the cup to allow root growth (Martinez et al., 2021).

To maintain the level of nutrient solutions in the trays, a PVC sink drain was installed to which a 12 cm long PVC tube was attached to maintain a constant 12 cm water depth. To promote oxygenation of the nutrient solutions, an air compressor with a flow rate of 100 L min^{-1} (ACO -008 120W 220v) was installed, using air dividers and microtubes to distribute oxygen to the trays.

To replace the volume consumed in the trays, the nutrient solution recirculated automatically with a digital timer at intervals of 2 hours between applications of nutrient solution, lasting 10 minutes.

The plant material used was lettuce seedlings (*Lactuca sativa* L.), Cinderela and Rubinela cultivars, produced in expanded polystyrene trays with 200 cells, using coconut fiber as substrate. Sowing was conducted on October 11, 2019, placing four seeds in each cell at a depth of 0.5 cm. Thinning was performed five days after emergence (DAE), leaving one seedling in each cell. On this date, fertigation began using the floating system with the solution diluted to 50%. Transplanting was conducted on November 5, 2019, when the seedlings had 4-5 definitive leaves, using five plants for observation per plot for hydroponic systems.

An independent pumping system was used for each nutrient solution, cultivar, and cultivation system. It contained an electric pump to pump the nutrient solution from a lower reservoir (30 L) to the profiles and trays, distributing it through 5 mm diameter microtubes.

The nutrient solutions were monitored daily, replacing the volume of water consumed and adjusting the nutrient solutions when a 10% reduction in initial electrical conductivities was detected. As it was necessary to replace the nutrient solution, the pH values were adjusted (range 5.5 to 6.5) by adding NaOH (1M) or HCl (1M)

At the end of the experiment (25 days after transplanting), the plants were collected and evaluated for the following variables:

Number of leaves, counting all leaves, considering commercial only those larger than 3.0 cm;

Leaf area, determined by the leaf disc method using a volumetric stainless-steel ring with an internal diameter of 5 cm, collecting ten leaf discs per plant (Souza et al., 2012);

Specific leaf area, determined by the ratio between the leaf area and its respective dry mass (Benincasa, 2004);

Leaf fresh mass, determined immediately after collection, using a precision digital scale;

Total dry mass, obtained after drying the plants in a forced air circulation oven at 65 ± 1 °C until they reached constant weight;

Leaf succulence is determined by the relationship between the mass of water in the leaf and the leaf area (Mantovani, 1999). They were then weighed on a precision digital scale (0.01 g).

In addition, post-harvest quality analysis was conducted, with the following variables being analyzed: Titratable acidity (%), vitamin C (mg asc. ac. per 100mL), and soluble solids (°Brix), where the samples were ground in a domestic blender, following which the quantities required for each analysis were withdrawn.

The titratable acidity was determined using the titration method with 10 g of pulp diluted in 100 mL of distilled water titrated with 0.02 N sodium hydroxide (NaOH) and 3-4 drops of phenolphthalein until the color turned slightly pink (IAL, 2008).

The vitamin C content was determined using a 10 g sample of the ground material diluted in 100 mL of oxalic acid; then, a 5 mL aliquot was taken to which 45 mL of water was added. Titration was performed with DFI (0.094 mg mL^{-1}) until the solution turned pink (IAL, 2008).

The soluble solid content was determined using a digital refractometer (model PR - 100, Palette, Atago Co., Ltd., Japan), and the results were expressed in °Brix (IAL, 2008).

The data obtained were subjected to the Shapiro-Wilk normality test, and variance analysis was applied after meeting the normality assumption. The factors were split when there was a significant response to the interaction between the factors. The effect of treatments was analyzed using the Tukey test at a 0.05 probability level. Statistical analyses were conducted using the Sisvar statistical software (Ferreira, 2019).

Results and Discussion

There was no significant influence of the interaction among cultivars (C), hydroponic systems (S), and electrical conductivities (EC) on number of leaves (LN), leaf succulence (LS), and specific leaf area (SLA) variables. There was a significant effect of the hydroponic systems (S) on the LN and SLA ($p \leq 0.01$). It was found that the interaction among cultivars (C), hydroponic systems (S), and electrical conductivities (EC) significantly affected leaf fresh mass (LFM) and total dry mass (TDM) at a 0.05 probability, as well as leaf area (LA) at the 0.01 probability (Table 1).

For the leaf number, the highest values were found for the Cinderela cultivar, grown in the semi-hydroponic system, using the nutrient solution of 1.6 dS m^{-1} (Table 2). The number of lettuce leaves of the cultivars used in the present study ranges according to the literature, depending on several factors, such as cultivation system and environmental conditions. In this context, for the Rubinela cultivar, the number of leaves varied from 11.0 (Machado et al., 2023) to 18.1 (Almeida et al., 2022). For the Cinderella cultivar, a variation can be found from 12.8 (Aquino et al., 2017) to 17.8 leaves (Pereira et al., 2023).

The lower number of leaves observed in the electrical conductivity of 2.90 dS m^{-1} can be attributed to its higher electrical conductivity, confirming the results presented by Conversa et al. (2021b), who also observed a reduction in leaf emission in plants subjected to higher EC (3.5 dS m^{-1}) when studying lettuce in different hydroponic systems and electrical conductivities.

A nutrient solution with a very high EC can make it difficult for plants to absorb water due to the osmotic effect. Plants subjected to water deficit conditions adopt a strategy to adapt to unfavorable conditions to reduce water loss through transpiration, resulting in morphological and anatomical

Table 1. Summary of analysis of variance for number of leaves (LN), leaf succulence (LS), specific leaf area (SLA), leaf fresh mass (LFM), total dry mass (TDM), and leaf area (LA) of lettuce cultivars grown in different hydroponic systems and electrical conductivities

Source of variation	DF	Mean squares					
		LN	LS	SLA	LFM	TDM	LA
Cultivar (C)	1	109.55**	268.98ns	9261.60ns	205.74ns	0.57ns	709335.82ns
System (S)	2	69.53**	114.63ns	120542.75**	3700.29**	1.64ns	11693060.53**
Electrical conductivities (EC)	1	30.25*	85.39ns	9.49ns	651.39*	3.95*	210489.36ns
C × S	2	19.67ns	17.97ns	6915.34ns	137.66ns	3.40**	68943.85ns
C × EC	1	1.13ns	137.50ns	797.79ns	44.50ns	0.17ns	5511.70ns
S × EC	2	1.89ns	3.84ns	1825.25ns	2371.57**	9.05**	1732572.33**
C × S × EC	2	1.69ns	22.27ns	2086.61ns	651.85*	2.85*	1467030.89**
Residue	24	6.21	112.77	5727.27ns	119.04	0.58	185119.00
CV (%)		22.76	20.95	23.76	18.75	21.48	23.50

nsNon-significant; * - significant at $p \leq 0.05$; ** - significant at $p \leq 0.01$; DF – Degree of freedom; CV - Coefficient of variance

Table 2. Number of leaves (LN), leaf succulence (LS), and specific leaf area (SLA) in lettuce cultivars grown in different hydroponic systems and electrical conductivities

Systems	LN	LS ($g\ H_2O\ cm^2$)	SLA ($cm^2\ g$ LDM)
NFT	10.27 b	50.15 a	275.97 b
Semi-hydroponic	13. 62 a	50.00 a	432.99 a
Floating	8.96 b	47. 89 a	246.58 b
Cultivars			
Cinderela	12.69 a	47.95 a	334.55 a
Rubinela	9.21 b	53. 42 a	302.47 a
Electrical conductivities			
1.60 dS m^{-1}	10.03 b	49.14 a	319.02 a
2.90 dS m^{-1}	11.87 a	52. 22 a	318.00 a
Average	10.95	49.14	318.51

Means followed by the same letters in the column for cultivars, hydroponic systems, and electrical conductivities do not differ from each other using the Tukey test ($p \leq 0.05$)

changes in plants, especially in the reduction in leaf emission, leaf size, and thickness (Li et al., 2023).

The cultivars, hydroponic systems, and electrical conductivities did not influence the leaf succulence (LS), obtaining an average LS of 49.14 mg H_2O cm^2 of the leaf (Table 2).

In other studies, such as the one conducted by Targino et al. (2019), with an increase in the electrical conductivity of the nutrient solution, the authors observed an increase in LS, indicating the osmotic adjustment of the plants. The divergences between the results presented by Targino et al. (2019) and the present study can be attributed, in part, to the salts used. In the present study, the salinity of the nutrient solution increased with the concentration of nutrients. In contrast, in the study of these authors, sodium chloride was used, which is toxic to plants.

The plants grown in the semi-hydroponic system showed a specific leaf area (SLA), 56.9 and 75.6% higher than those obtained in the NFT and floating systems, respectively. On the other hand, in the NFT and floating systems, plants had thicker leaf blades due to lower water availability (Table 2).

These results indicate that semi-hydroponic cultivation provided greater water availability, which caused lower stomatal density and leaf blade thickness (Guimarães et al., 2020). According to Roman et al. (2021), reducing SLA under conditions of low water availability is a morphological strategy of plants for adaptation, with less leaf expansion and thicker leaves, seeking to reduce the total surface available for evapotranspiration.

The analysis of leaf fresh mass (LFM) accumulation (Figure 1A) in plants of Cinderela cultivar grown in the semi-hydroponic system showed higher LFM (96.71 g per plant) when using the higher electrical conductivity (2.9 dS m^{-1}), followed by the NFT system (76.99 g plant) with electrical conductivity of 1.6 dS m^{-1}.

For the Rubinela cultivar, there was an effect of electrical conductivity only in the floating system, in which EC 1.6 dS m^{-1} provided greater LFM (60.53 g per plant), with an increase of 135.71% in LFM concerning EC 2.9 dS m^{-1}. Furthermore, the hydroponic systems influence the LFM of plants of the Cinderela cultivar when using the nutrient solution with EC 1.6 dS m^{-1}. The cultivars differed in LFM accumulation only when grown in the NFT system with the nutrient solution of EC 1.6 dS m^{-1}, where the Cinderela cultivar was superior to the Rubinela cultivar (Figure 1A).

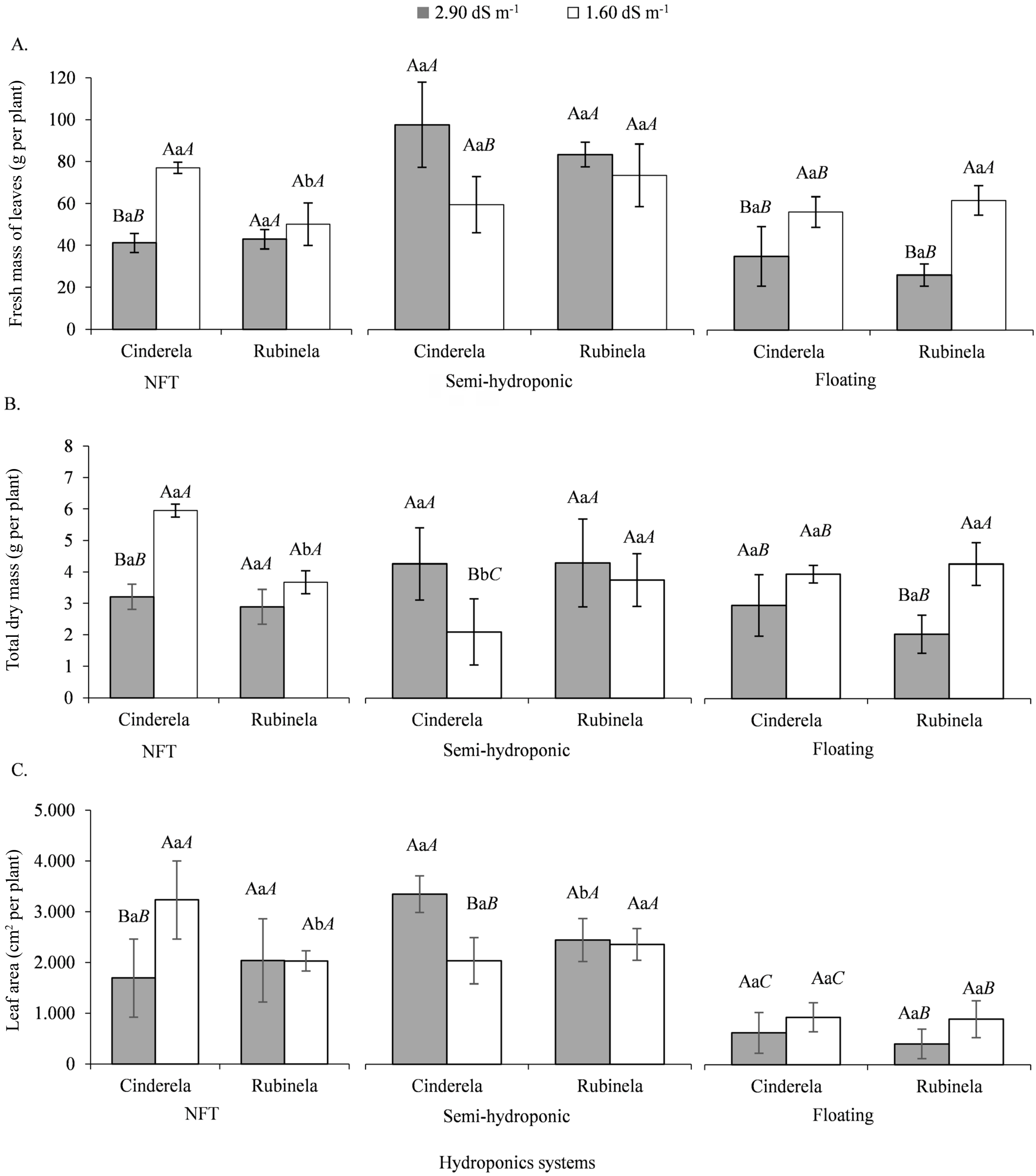
In the literature, few studies analyze hydroponic cultivation systems for lettuce. In a study analyzing the efficiency of different systems, Frasetya et al. (2021) found that the NFT system provided greater efficiency in lettuce production.

Other authors also observed that the cultivation system directly interferes with production. When studying parsley, Nunes et al. (2020) observed greater growth in plants grown in substrate than in the NFT system. Mouroutoglou et al. (2021), working with Greek sweet onion (*Allium cepa* L.), comparing floating (FL), aeroponic (AER), and NFT systems and substrate cultivation also observed that substrate cultivation provided greater plant development than the NFT system.

These results demonstrate that the interaction between the electrical conductivities and the cultivation system adopted is important for choosing the combination of factors that enable cultivars to express their greatest potential.

From the LFM data, it was verified that the cultivation of lettuce in the semi-hydroponic system requires a more concentrated nutrient solution than NFT and floating systems to achieve high production, considering that in these systems, the solution with EC 1.6 dS m^{-1} was sufficient to provide greater plant growth. These results confirm those found by other authors; a reduction in the electrical conductivity by 50% allows nutrient savings without reducing crop yield (Conversa et al., 2021a).

The total dry mass (TDM) variable showed a significant difference between the cultivars only when a nutrient solution with an EC of 1.6 dS m^{-1} was used, in which the Cinderela cultivar was superior in the NFT system, while the Rubinela



*Means followed by the same uppercase letters between electrical conductivities, lowercase letters between cultivars, and uppercase and italic letters between hydroponic systems do not differ by the Tukey test ($p < 0.05$)

Figure 1. Leaf fresh mass (A), leaf dry mass (B), and leaf area (C) of lettuce cultivars grown in different hydroponic systems and electrical conductivities

cultivar was superior in the semi-hydroponic system. The cultivars did not differ in the floating system (Figure 1B).

The cultivation systems differed in terms of TDM for both electrical conductivities. The semi-hydroponic system was superior to floating for the EC 2.90 dS m^{-1} nutrient solution in both cultivars. The NFT system was superior to the others for the electrical conductivity of 1.6 dS m^{-1} in the Cinderela cultivar. There was no significant difference between the cultivation systems for the Rubinela cultivar with the electrical conductivity of 1.6 dS m^{-1} (Figure 1B).

Analyzing the effect of the electrical conductivity on TDM, a significant and varied response was observed according to the cultivation system and the cultivar analyzed. For the Cinderela cultivar, the highest values occurred in nutrient solutions with ECs of 1.6 and 2.9 dS m^{-1} for the NFT and semi-hydroponic systems, respectively. For the Rubinela cultivar, there was a difference between the electrical conductivities in the floating system, with the highest TDM observed in the solution with EC of 1.6 dS m^{-1} (Figure 1B).

These results demonstrate that the effect observed on LFM is also reflected in TDM. Furthermore, the lower dry mass obtained in the more concentrated solution in the NFT system is due to the osmotic effect caused by an increase in the electrical conductivity of the nutrient solution (Soares et al., 2020).

The performance of cultivars in terms of leaf area (LA) was found to be superior in the Cinderela cultivar compared to the Rubinela cultivar in the semi-hydroponic system for the nutrient solution with EC of 2.9 dS m^{-1} and in the NFT system for EC of 1.6 dS m^{-1} (Figure 1C).

Generally, the lowest leaf area (LA) values occurred in the floating system for both cultivars. For EC of 1.6 dS m^{-1}, the NFT system favored greater development of LA in the Cinderela cultivar (3,228.98 cm^2 per plant), while plants grown in the floating system showed lower LA (918.62 cm^2 per plant). In the Rubinela cultivar, the highest LA values were obtained in the NFT (2,037.23 cm^2 per plant) and semi-hydroponic (2,442.45 cm^2 per plant) systems (Figure 1C).

Analyzing the effect of nutrient solutions on LA, the EC of 2.9 dS m^{-1} provided greater leaf development only in the Cinderela cultivar (3,341.35 cm^2 per plant) grown in the semi-hydroponic system. In the NFT system, the EC of 1.6 dS m^{-1} provided higher LA in the Cinderela cultivar (3,228.98 cm^2 per plant) (Figure 1C).

The LA is one of the variables most affected by variation in the EC of irrigation water or nutrient solution (Pessoa et al., 2023; Oliveira et al., 2024). The reduction in LA due to the increase in the EC of the nutrient solution is associated with a reduction in leaf emission and the expansion of the leaf blade due to osmotic stress resulting from lower water potential (Conversa et al., 2021b).

The effect of the interaction between cultivar and hydroponic system (C × S) and cultivar and electrical conductivity (C × EC) was identified for the titratable acidity ($p \leq 0.05$). Vitamin C (VIT C) content was affected by the interaction between cultivars and hydroponic systems (C × S) ($p \leq 0.05$). The significant effect of the interaction between hydroponic systems and electrical conductivities (S × EC) was observed for the variable soluble solids (SS) at 1% significance (Table 3).

Table 3. Summary of the analysis of variance for titratable acidity (TA), vitamin C (VIT C), and soluble solids (SS) in lettuce cultivars grown in different hydroponic systems and electrical conductivities

Source of variation	DF	Mean squares		
		TA	VIT C	SS
Cultivar (C)	1	0.0004^{ns}	48.78^{**}	18.20^{**}
System (S)	2	0.0001^{ns}	14.60^{ns}	11.41^{**}
Electrical conductivities (EC)	1	0.0001^{ns}	17.03^{ns}	6.76^{**}
C × S	2	0.007^{*}	26.69^{*}	1.28^{ns}
C × EC	1	0.009^{*}	8.90^{ns}	1.60^{ns}
S × EC	2	0.003^{ns}	9.99^{ns}	7.24^{**}
C × S × EC	2	0.001^{ns}	8.22^{ns}	0.13^{ns}
Residue	24	0.002	5.98	0.57
CV (%)		39.42	22.56	13.25

^{ns} Non-significant; $^{*}p \leq 0.05$; $^{**}p \leq 0.01$; DF – Degree of freedom; CV – Coefficient of variance

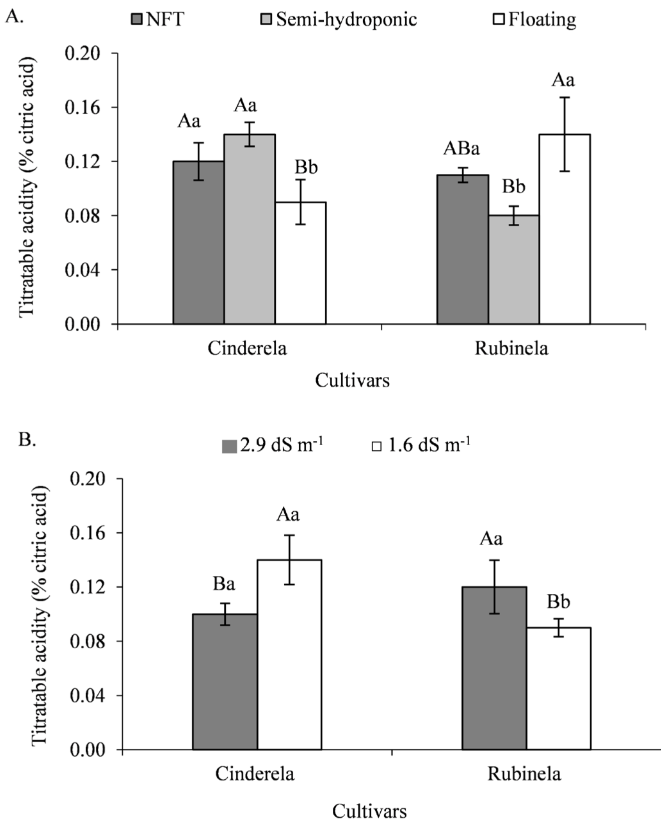
The titratable acidity (TA) differed between cultivars according to the cultivation system. The Cinderela cultivar was 42.8% higher than the Rubinela cultivar in the semi-hydroponic system. However, the Rubinela cultivar was 55.5% higher in cultivation in a floating system. There was no difference between cultivars in the NFT system (Figure 2A). The semi-hydroponic system provided greater TA in the Cinderela cultivar, while the floating system was superior in the Rubinela cultivar (Figure 2A).

It is also verified that for the Cinderela cultivar, the NFT and semi-hydroponic systems provided the highest TA; however, for the Rubinela cultivar, the floating system provided the highest TA value (Figure 2).

The Cinderela and Rubinela cultivars showed different behaviors concerning the nutrient solutions used. The Cinderela cultivar had higher TA in plants grown with EC of 2.9 dS m^{-1}, while the Rubinela cultivar had higher TA with EC of 1.6 dS m^{-1} (Figure 2B). Furthermore, there was an effect of nutrient solutions on TA for both cultivars. The increase in EC caused a 40% increase in TA for the Cinderela cultivar but reduced it by 25% in the Rubinela cultivar.

Changes in titratable acidity due to the concentration of nutrients in the nutrient solution occur due to the direct effect of electrical conductivity, as observed by Oliveira et al. (2024) working with kohlrabi.

For vitamin C (VIT C) content, the cultivars differed when grown in the NFT system, in which the Rubinela cultivar



For Figure A, means followed by the same letters, uppercase for hydroponic systems and lowercase for cultivars, do not differ from each other using the Tukey test ($p \leq 0.05$). For Figure B, means followed by the same uppercase letters for electrical conductivities and lowercase letters for cultivars do not differ by the Tukey test ($p \leq 0.05$)

Figure 2. Titratable acidity in leaf tissue of lettuce cultivars grown in different hydroponic systems and electrical conductivities

presented 13.56 mg asc. ac. per 100 mL, 63% higher than the VIT C content obtained in the Cinderela cultivar (8.30 mg asc. ac. per 100 mL). Concerning the cultivation systems, the higher vitamin C values occurred in the semi-hydroponic (10.04 mg asc. ac. per 100mL) and floating (10.67 mg asc. ac. per 100 mL) systems for the Cinderela cultivar. For the Rubinela cultivar, the NFT and floating systems provided the higher levels of vitamin C, obtaining 13.56 and 13.11 mg asc. ac. per 100mL, respectively (Figure 3).

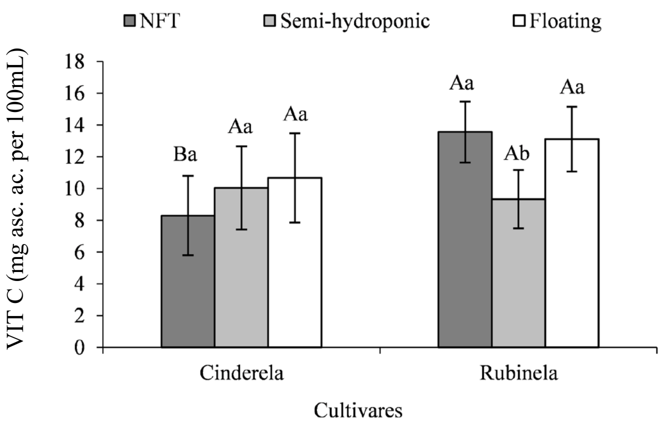
The vitamin C content was not affected by the electrical conductivity of the nutrient solution, in line with the results presented by Quy et al. (2018), who also found no significant changes in the vitamin C content in lettuce subjected to a nutrient solution with EC ranging from 1.5 to 2.5 dS m^{-1}.

The content of ascorbic acid, the precursor of vitamin C, is normally increased in salt-stressed plants, especially in NaCl-rich medium, to protect plant cells from salt-induced oxidative stress resulting from increased formation of reactive oxygen species (Zandi & Schnug, 2022). However, in the present study, the increase in the EC of the nutrient solution was provided by the increase in the concentration of fertilizers so that no toxicity stress occurred.

Regarding the soluble solids (SS) content, a significant response was found only for hydroponic systems and electrical conductivities. There was no effect of cultivation systems on SS in plants subjected to EC of 2.9 dS m^{-1}, obtaining an average SS of 5.24 °Brix. For the electrical conductivities of 1.6 dS m^{-1}, the NFT system presented the highest SS value (7.97 °Brix), while the lowest value occurred in the semi-hydroponic system (4.53 °Brix) (Figure 4).

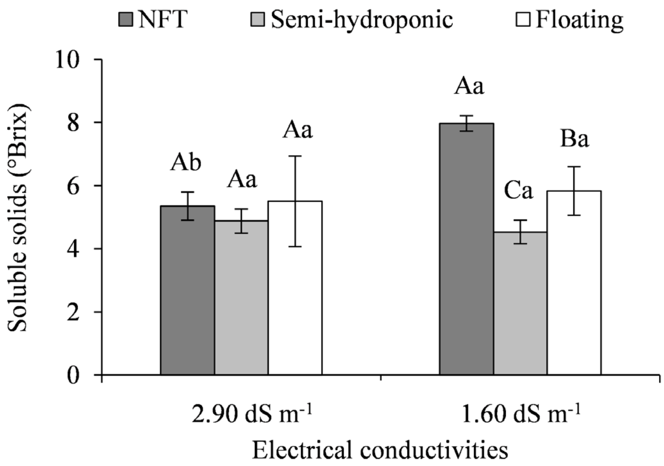
Regarding nutrient solutions, it was found the effect of EC on SS only in the NFT system, in which there was a variation from 5.35 to 7.12 °Brix for ECs of 1.6 and 2.9 dS m^{-1}, respectively, with an increase of 33.1% in SS with an increase in EC (Figure 4).

An increase in the content of soluble solids, especially sugars, in lettuce subjected to saline stress has been observed by other authors (Carillo et al., 2021; Babaousmail et al., 2022). This increase in the content of soluble solids in response to



Means followed by the same uppercase letters for hydroponic systems and lowercase letters for cultivars do not differ by the Tukey test ($p \leq 0.05$)

Figure 3. Vitamin C content in leaf tissue of lettuce cultivars grown in different hydroponic systems and electrical conductivities



Means followed by the same uppercase letters for hydroponic systems and lowercase letters for electrical conductivities do not differ by the Tukey test ($p \leq 0.05$)

Figure 4. Soluble solids content in leaf tissue of lettuce cultivars grown in different hydroponic systems and electrical conductivities

saline stress occurred because plants accumulate soluble sugars to make osmotic adjustments, helping to maintain turgor and stabilize the quaternary structure of proteins (Munir et al., 2021). According to Bres et al. (2022), under saline stress, plants accumulate sugars as a strategy to protect their biomolecules and membranes.

Conclusions

1. The electrical conductivity of the nutrient solution of 1.60 dS m^{-1} provided the highest values for most growth and quality variables and was sufficient to promote adequate cultivation conditions for lettuce cultivars in the NFT and floating systems.

2. The NFT and floating systems presented the highest values for the variables related to growth, quality, and nutrients when the solution of 50% strength was used (1.60 dS m^{-1}).

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