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VARIÁVEIS BIOMÉTRICAS E PÓS-COLHEITA DA ALFACE HIDROPÔNICA TRATADA COM PULSOS ELÉTRICOS DE BAIXA FREQUÊNCIA

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1 RESUMO

Hortaliças folhosas são destaque comercial graças à implementação de tecnologias que incrementam sua produtividade. Produtos que podem ser consumidos *in natura* como a alface ganham relevância comercial. Técnica de produção como a hidropônica gera bons resultados, mas ainda pode ser aprimorada. Existem relatos que indicam que o tratamento da água de irrigação com pulsos elétricos de baixa frequência pode potencializar a produtividade das culturas, pelo qual gera a demanda para o desenvolvimento de estudos detalhados. Neste sentido, o objetivo do presente trabalho foi analisar o desenvolvimento das variáveis biométricas e de pós-colheita da alface hidropônica com solução nutritiva tratada com pulsos elétricos de baixa frequência. Utilizou-se o delineamento inteiramente randomizado, em esquema fatorial, com parcelas subsubdivididas 3 x 2 x 3, com quatro repetições. Os fatores foram a frequência de aplicação dos pulsos elétricos (constante, intermitente e sem uso), dois concentrações de solução nutritiva e três ciclos de produção. O desenvolvimento e a pós-colheita da alface submetida a pulsos elétricos de baixa frequência, independentemente da solução nutritiva, apresentou comportamento similar ao das plantas não tratadas, mostrando baixa influência da tecnologia sobre o desenvolvimento.

Palavras-chave: Clorofila, perda de massa, tecnologia, inovação.

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BIOMETRIC AND POST-HARVEST VARIABLES OF HYDROPONIC LETTUCE TREATED WITH LOW-FREQUENCY ELECTRICAL PULSES

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2 ABSTRACT

Leafy vegetables are commercially important because of the implementation of technologies that increase their productivity. Products that can be consumed fresh to gain commercial importance. Production techniques such as hydroponic methods generate good results but can still be refined. Reports indicate that the treatment of irrigation water with low-frequency electrical pulses can increase the productivity of crops, increasing the demand for the development of detailed studies. In this sense, the objective of the present work was to analyze the development of biometric and postharvest variables of hydroponic lettuce with nutrient solution treated with low-frequency electrical pulses. An entirely randomized design with a factorial scheme was used, with 3 × 2 × 3 subsubdivid installments and four repetitions. The factors were the frequency of application of electrical pulses (constant, intermittent and unused), two concentrations of nutrient solution and three production cycles. The development and postharvest performance of lettuce subjected to low-frequency electrical pulses, regardless of the nutrient mixture, were similar to those of untreated plants, indicating a low influence on development technology.

Keywords: Chlorophyll, mass loss, technology, innovation.

3 INTRODUCTION

Technology has increased agricultural productivity, ensuring its supply in large metropolises in populous countries such as Brazil (MARTINEZ; MARTINS; FEIDEN, 2016; INSTITUTO D E ECONOMIA AGRÍCOLA, 2020). Leafy crops such as lettuce gain commercial importance in Brazil and around the world, being largely consumed fresh, and a large part of their production is carried out by small producers, with economic and social importance (MITOVA *et al.*, 2017; CONAB, 2020). Its consumption has health benefits at the gastrointestinal level and regulates blood sugar, as it contains low fat, caloric and sodium contents and is an important source of fiber, iron, folate, vitamin C and several other bioactive compounds (KIM *et al.).* , 2016).

Hydroponic production has allowed high productivity with good health quality, surpassing conventional production (AL-TAWAHA *et al.*, 2018). Depending on the type of hydroponic system, factors such as flow rate, nutrient mixture, planting density, water temperature and climate can generate differences in the quality of lettuce plants, in addition to exposure to temperatures outside the range of 15–25°C. Bolting (MAGALHÃES *et al.*, 2010; XAVIER *et al.*, 2021) and flow rates above 4 liters per minute generate root stress in hydroponic systems (AL-TAWAHA *et al.*, 2018).

The hydroponic system has different techniques to implement, such as the nutrient film technique (NFT), the deep flow technique (DFT), the dynamic root fluctuation technique (DRFT) and substrate culture; however, the most recommended technique for the cultivation of hardwoods is NFT (KAISER; ERNST, 2012; KOOHAKAN; JEANAKSORN; NUNTAGIJ, 2008). Because it requires little space, the hydroponic technique has expanded around urban centers, reducing the amount of water needed for production by up to 70% compared with the conventional system (SANTOS *et al.*, 2013; AL-OGAIDI *et al.*, 2017; AL-TAWAHA *et al.*, 2018).

New techniques are constantly being tested to determine the genetic potential of crops, both in the soil and in hydroponic systems, such as the reuse of wastewater (LEROY *et al.*, 2022), magnetism, and electromagnetism (CHIBOWSKI; SZCZES, 2018; PUTTI *et al.). ,* 2023a, 2023b) to low-frequency electrical pulses in irrigation water (OLAYA TELLEZ, *et al.*, 2023). There are reports that suggest microbial control and reduction in algae formation (MERCIER *et al.*, 2016), in addition to improvements in productivity when using electronic anti-fouling system treatment, which consists of applying low-frequency electrical pulses (3–32 kHz) in the water flow, altering the crystallization process of calcium and other compounds, and reducing their ability to attach to surfaces, which can be used by plants (PIYADASA *et al.*, 2017, 2018; CHIBOWSKI; SZCZES, 2018; XIAO *et al.*, 2020).

The hydroponic system in a greenhouse has excellent characteristics for evaluating the impacts of applying low-frequency electrical pulses on crop development, as it allows more precise control over the variables that affect plant development to be obtained.

In studies involving leafy vegetables for fresh consumption, the monitoring of biometric variables and chlorophyll throughout their vegetative cycle needs to be as detailed as the monitoring carried out during their "shelf life". The monitoring of biometric variables and chlorophyll throughout the vegetative cycle needs to be as detailed as the shelf-life in regard to leafy vegetables for fresh consumption (SCHVAMBACH *et al.*, 2020).

In this sense, the present work aimed to evaluate, through biometric and postharvest monitoring, the development of lettuce grown in a hydroponic system fed water treated with low-frequency electrical pulses.

4 MATERIALS AND METHODS

4.1 Location of the experimental area

The experiment was conducted in the experimental area of the Department of Forestry, Soil and Environmental Science of the Faculty of Agricultural Sciences, Universidade Estadual Paulista “Júlio de Mesquita Filho” (Unesp), municipality of Botucatu-SP, located at coordinates 22° 51' 03" South latitude and 48° 25' 37" West longitude. According to the Köppen classification, the climate is a type Cfa-hot temperate (mesothermal) humid climate, with the average temperature of the hottest month exceeding 25°C and an average altitude of 780 m. The average annual rainfall is 945.15 mm (CUNHA; MARTINS, 2009).

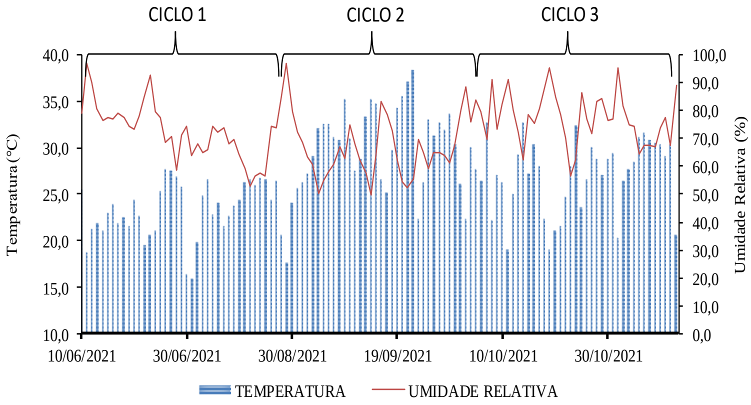
4.2 Experimental design

A randomized design was used in a factorial scheme with subsubdivided plots 3 × 2 × 3, with four replications. The factors evaluated were the frequency of use of the electronic anti-scaling system (constant, intermittent and without use), two concentrations of solution (100% and 80% of the recommendation by Furlani *et al.* (1999)) and three production cycles.

4.3 Hydroponic system

The greenhouse used is 24 m long by 7 m wide, with a ceiling height of 2.5 m and a height of 3.8 m at the highest part. A 150-micron plastic cover with two upper windows was used. The temperature and relative humidity (RH%) inside the greenhouse were constantly monitored throughout the study. Their values are presented in Figure 1.

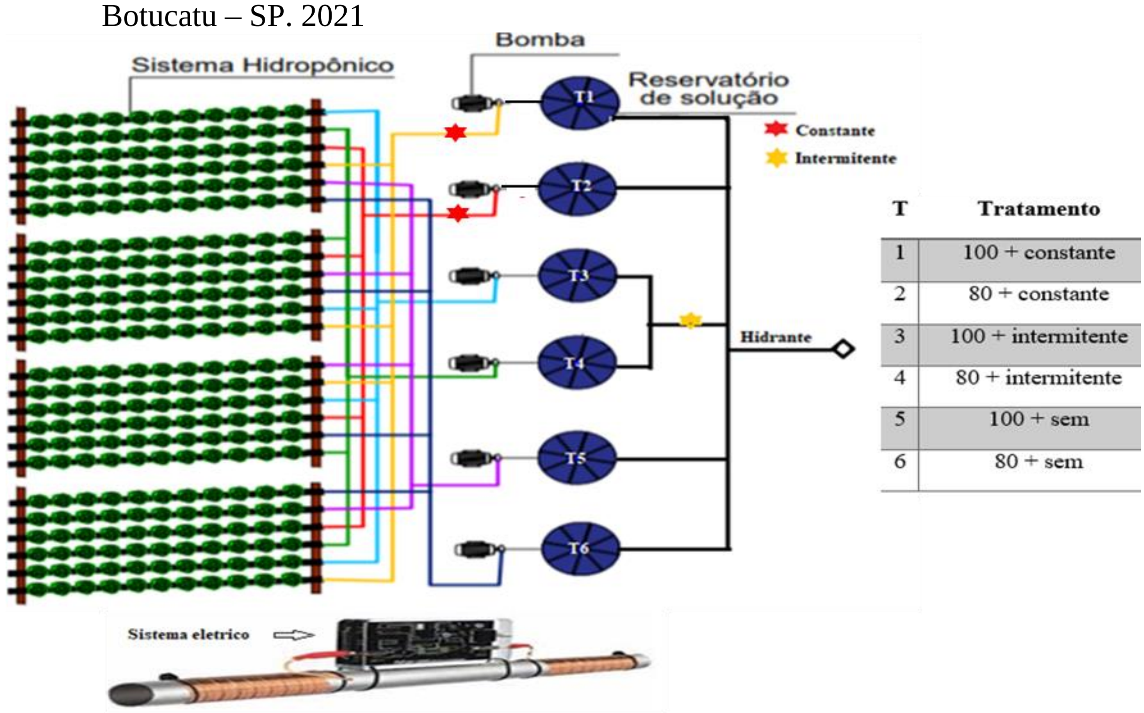
Figure 1. Behavior of the relative humidity and temperature over three experimental cycles. Botucatu - SP, 2021.



Source: Authors (2023)

The NFT hydroponic system has four benches (repetition) with a 5% slope. Each bench is 1.2 meters wide and spaced 0.7 meters apart, and the six hydroponic profiles (treatments) are 6 meters long and spaced 0.2 meters apart. Each profile has the capacity for 24 plants. The scheme of the system used is shown in Figure 2.

Figure 2. Design of the hydroponic system used in the development of lettuce cultivation. Botucatu – SP. 2021



Source: Olaya Tellez *et al.* (2023)

The nutrient solution used in each treatment was stored in 500-L reservoirs. The irrigation of each profile was carried out via 25 mm polypropylene tubing. Each treatment had its individual return of the nutrient solution to its respective reservoir. The nutrient solution pumping system was carried out with the aid of a 0.5 hp Ferrari peripheral motorpump in each reservoir, controlled by an electromechanical timer programmed to turn on the system every 15 minutes, from 6:00 am to 6:00 pm, and for 15 minutes every hour, from 6:00 pm to 6:00 am, with flow rates varying between 1.5 and 2.0 liters per minute.

The nutrient mixture used was based on Furlani's recommendation *et al.* (1999), which includes 187 N, 72P, 220K, 143Ca, 38 mg, 52S, 0.45B, 0.45 Cu, 1.81 Fe, 0.45 Mn, 0.18 Zn and 0.09 Mo at dosages of 80% and 100%, now called solutions 80 and 100. When the temperature exceeded 25°C, the solution was diluted 20%, and the proportions were maintained. The exposure of the nutrient solution to the electronic antiscaling system or low-frequency electrical pulses was constant and intermittent. The constant maintained water exposure throughout the crop cycle at all times, and the intermittent maintained the exposure of irrigation water during the period of filling the reservoirs with each solution change every 8 days. The other treatments had no exposure to the system, and the nutrient solutions were maintained.

The lettuce seedlings were grown in phenolic foam for 30 days in a protected environment, and when they reached 5 to 7 true leaves, they were selected and transplanted into the hydroponic profiles.

4.4 Reviews

At 0, 8, 16 and 24 days after transplanting (DAT), 4 (four) plants were collected from each plot, and they were duly identified. To avoid border effects, plants located at the beginning and end of each bench were eliminated as a collection option. In this way, the following four plants were harvested in planting order, alternating the end of the bench with each new collection.

The number of leaves was determined manually, and the fresh mass of the aerial part was determined with the aid of a precision scale (0.01 g). The dry mass of the aerial part was obtained after the material was dried in a forced air circulation oven at 65°C until it reached a constant weight after approximately 72 hours, with measurements on a precision scale (0.01 g).

Chlorophyll was measured between 7 and 10 am in the leaf with the highest photosynthetic activity via two different methods. The first was a portable electronic plant green color intensity meter (SPAD), model Digital SPAD 502 (Minolta Camera Co. Ltda). Four (4) measurements were taken with the device on each leaf, two on the left side and two on the right side of the leaf blade. Afterwards, the average of these measurements was calculated. The second was a portable CM1000 chlorophyll meter (Spectra Technologies, Inc.). Four measurements were also made on the crown of each plant, with the lasers located on the leaves 1 (one) meter away between the plant and the device, avoiding regions with secondary veins. The average was subsequently calculated.

The variables soluble solids, hydrogen potential and titratable acidity were determined at 0, 4 and 7 days after harvest.

Soluble solids (SS) were measured with the aid of an ATAGO PR-101 digital refractometer, with a measurement scale of 0 to 45 ° Brix, with subdivision into a decimal scale (ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTRY, 1992).

The hydrogen potential (pH) was calculated via a digital pHmeter model DMPH-2 Digimed with a glass membrane and measured with buffer solutions of pH 7 and 4, according to the Association of Official Analytical Chemistry (1992).

The titratable acidity (TA) was calculated by diluting 2.0 ml of the sap in 40 ml of distilled water. Titration was then carried out with NaOH (0.02 N) until a pH of 8.7 was reached. The procedure was carried out with the aid of a titrator automatic digital potentiometer with a Mettler DL12 glass membrane model. The results were expressed in citric acid.

Postharvest mass loss was monitored in 3 (three) plants collected and placed in plastic bags, which were duly identified, after 24 DAT. Seven consecutive days were always weighed at 10 am on a precision scale (0.01 g).

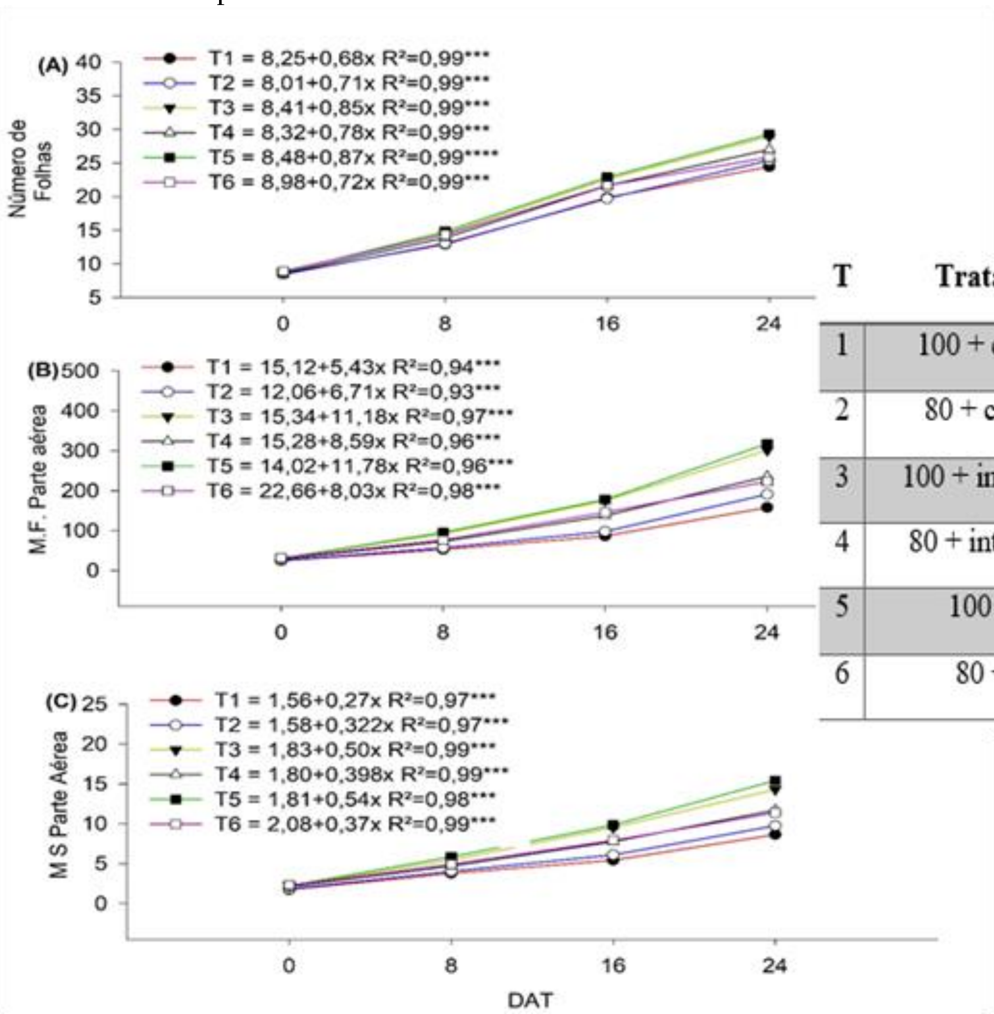
4.5 Statistical analysis

The data were subjected to the Anderson–Darling normality test, homoscedasticity test (homogeneity of variances), Hartley test, and analysis of variance, with significance levels of 5% probability of error. When significant, the means were subjected to the Tukey test at 5% significance and regression analysis via the statistical *software* R (version 4.1.2). The graphs were produced via the SigmaPlot program (version 14.0).

5 RESULTS AND DISCUSSION

The variables of the number of leaves and the fresh and dry masses of the aerial parts of the plants treated with and without low-frequency electrical pulses presented a pattern of linear variation, as shown in Figure 3 and in graphs A, B and C. The ^{R2} ^{values} for all the treatments were between 93% and 99%, and the linear coefficient was significant according to the Tukey test, indicating that the model adequately fit the data.

Figure 3. Trend in the development of biometric variables over 24 days after transplanting (DAT) of lettuce crops in a hydroponic system fed water treated with low-frequency electrical pulses



T	Tratamento
1	100 + constante
2	80 + constante
3	100 + intermitente
4	80 + intermitente
5	100 + sem
6	80 + sem

DAT: Days after transplanting; MF: Fresh pasta; MS: Dry pasta
Source: Authors, (2023)

The number of leaves continuously increased throughout the cycle at 24 DAT in the 100 + intermittent frequency (T3) and 100 + no frequency (T5) solutions. The fresh and dry masses of the aerial parts increased, with less accumulation from 8 DAT in solutions 100 and 80 + constant frequency (T1 and T2), followed by the 80 + solution with and without intermittent frequency (T4 and T6) and finally the 100 + solution with and without intermittent frequency (T3 and T5).

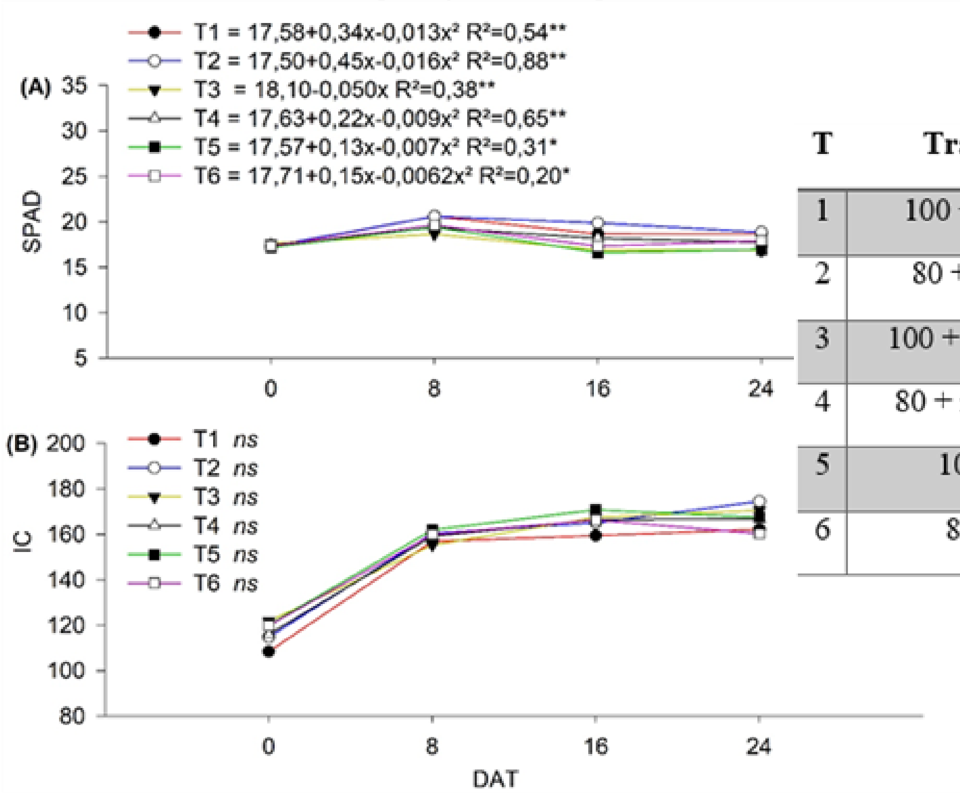
Compared with the other treatments, the 80 + solution with and without intermittent frequency (T4 and T6) had increases of 7%, 27% and 23%, respectively, in terms of the number of leaves, fresh mass and dry mass of the aerial parts. Treatments with solution 100 resulted in greater effects derived from high temperatures, which possibly generated an increase in the concentration of salts favorable for nutritional disorders (XAVIER *et al.*, 2021).

Factors such as electrical conductivity above 2.5 dSm-1 lead to an imbalance in osmotic adjustment, reducing plant development (XAVIER *et al.*, 2021). The presence of chlorine in the nutrient solution can obstruct the absorption of Ca and K, directly impacting the accumulation of dry mass and fresh mass (COVA *et al.*, 2017).

Superior results throughout the cycles were observed in the treatments with solution 80, but no significant effects were observed with the use of low-frequency electrical pulses. Lima (2021) obtained benefits in growing beans in soil via a similar electromagnetic system, a technology with a certain similarity. The implementation of nutritional solutions that are less concentrated than that recommended by Furlani *et al.* (1999) performed adequately in *Coriandrum sativum* and *Artemisia absinthium* (VASCONCELOS *et al.*, 2014; LUZ *et al.*, 2018).

The results of chlorophyll measurements via SPAD for lettuce plants grown in a hydroponic system fed with treated and untreated water via low-frequency electrical pulses were fitted with a linear model with an R^2 of 38% in the 100 + solution. intermittent frequency (T3), whereas in the other treatments, the adjusted model was quadratic, which presented a quadratic coefficient of variation with R^2 between 31% and 88%. The coefficient was significant but had a low representation in the 100 and 80 + solutions without frequency (T5 and T6, respectively), indicating that the model did not adequately fit the data (Figure 4 A). The measurements of the chlorophyll index (IC) via the CM1000 did not significantly differ from or adjust to any model (Figure 4 B).

Figure 4. Chlorophyll trend over 24 DAT in lettuce grown in a hydroponic system with water treated with low-frequency electrical pulses



T	Tratamento
1	100 + constante
2	80 + constante
3	100 + intermitente
4	80 + intermitente
5	100 + sem
6	80 + sem

IC: chlorophyll index; DAT: days after transplanting; ns: not significant
Source: Authors, (2023)

The SPAD and IC indices consistently increased until 8 DAT, with better performance for the 80 + constant-frequency solution (T2) and lower SPAD indices for the 100 + no-frequency solution (T5). From 8 to 24 DAT, SPAD and CI, in all the treatments, remained stable.

Ciriello *et al.* (2021) reported maximum values of 27 SPAD units in hydroponic lettuce cultivation during the three weeks of cultivation considered, whereas Aragão *et al.* (2020) reported 26 SPAD units at the end of the cultivation cycle 30 days after transplanting. Silva *et al.* (2020) reported 14 to 16 SPAD units in lettuce subjected to salt stress. Correct monitoring of chlorophyll via SPAD and CM1000 has a strong correlation with the nutritional status of plants and can be used in agronomic management (MAHAJAN *et al.*, 2014; ESHKABILOV *et al.*, 2021). The chlorophyll content monitored by SPAD and CM1000 increased proportionally throughout the lettuce crop cycle.

The titratable acidity responded differently to the cycle and solution factors, as shown in Table 1.

Table 1. Summary of the analysis of variance for the variables, ° Brix, pH and titratable acidity of the lettuce crop grown in a hydroponic system fed with water treated with low-frequency electrical pulses

Source of variation	Freq.	Solution	Cycle	Freq. X Solution	Freq. X Cycle	Solution X Cycle	Solution X Cycle X Freq.
				Mean square ($p < 0.05$)			
Brix	0.210	0.11	0.659	0.106	0.138	0.74	0.194
pH	0.133	0.01	0.632	0.14	0.637	0.152	0.174
To	0.003	0.102	0.0001	0.833	0.82	0.172	0.14

Brix: ° Brix; pH: Hydrogen potential; Att: Titratable acidity; $p < 0.05$ indicates differences between them according to the Tukey test at 5% significance; Freq. : Frequency of use of electrical pulses.

The average values of the postharvest variables °Brix, hydrogen potential and titratable acidity on the effects of low-frequency electrical pulses with two nutrient solutions and two hydroponic lettuce production cycles are presented in Table 2.

Table 2. Mean values and standard deviations of postharvest variables of lettuce grown in a hydroponic system fed water treated with low-frequency electrical pulses

Source of variation		Brix	pH	Att
Freq.	Constant	2.72±0.6	6.09±0.45	0.14±0.05
	Intermittent	2.49±0.5	6±0.22	0.14±0.04
	without	2.48±0.6	6.08±0.36	0.14±0.05
Dose	80	2.69±0.4	5.96±0.24b	0.15±0.05
	100	2.43±0.68	6.16±0.41a	0.13±0.04
Cycle	2	2.53±0.49	6.04±0.2	0.1±0.02b
	3	2.6±0.65	6.08±0.46	0.18±0.03a

Averages followed by the same letter or without a letter in the columns do not differ from each other; Brix: ° Brix; pH: hydrogen potential; Att: titratable acidity; Freq. : Frequency of use of electrical pulses.

The pH was greater in the 100% solution than in the 80% solution, whereas the titratable acidity decreased in cycle 2 compared with cycle 3 throughout the postharvest period. The differences found were approximately 4% in favor of solution

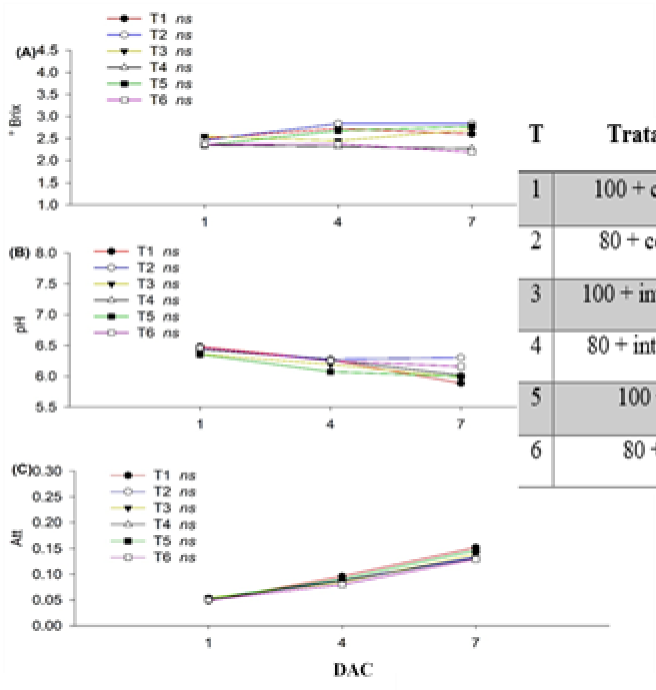
100 and 34% in favor of cycle 2. The use of low-frequency electrical pulses did not have a significant effect on these variables (Table 2).

In the work of Silva *et al.* (2011), the total soluble solids content was similar in the conventional system and higher than that in the hydroponic system. In the research of Fontana *et al.* (2018), the variables pH, ° Brix and titratable acidity for lettuce grown in conventional, hydroponic and organic systems did not significantly differ, with values ranging from 2.4--5.9 and higher titratable acidity in the hydroponic system. Similar values were found in the present work.

The use of different lettuce production systems influences size, weight and consumer purchase perception (FONTANA *et al.*, 2018). Conventional and hydroponic systems have longer postharvest shelf-life (SILVA *et al.*, 2011; REIS *et al.*, 2014). Lima (2021), in studies on common beans, did not find conclusive results in the use of electromagnetism.

The behavior of the variables soluble solids, pH and titratable acidity over the 7 days of lettuce postharvest for the different treatments carried out in the hydroponic system are shown in Figure 5.

Figure 5. Trend in the development of variables over 7 days postharvest (DAC) for a lettuce crop grown in a hydroponic system fed water treated with low-frequency electrical pulses



T	Tratamento
1	100 + constante
2	80 + constante
3	100 + intermitente
4	80 + intermitente
5	100 + sem
6	80 + sem

DAC: days after harvest; Att: titratable acidity
Source: Authors (2023)

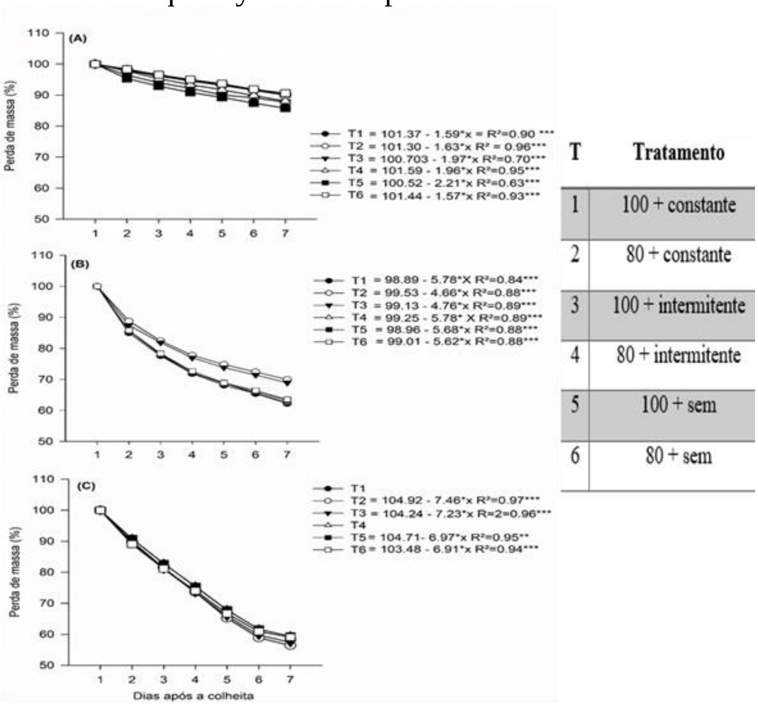
No variation pattern was found that significantly adjusted the behavior of the variables soluble solids, pH and titratable acidity over 7 days postharvest, as shown in Figure 5, graphs A, B and C.

The soluble solids fluctuated less after harvest, especially in the 80 + constant-frequency solution (T2). The pH generally decreased from the first day of postharvest, with the 100% solution + intermittent frequency (T3) treatment resulting in the greatest reduction. The titratable acidity of the plants tended to increase from 1 to 7 DAC, which was inversely proportional to pH. Simulation results were reported by Reis *et al.* (2014) on the behavior of soluble solids, pH and titratable acidity in postharvest lettuce in different cultivation systems. According to Fontana *et al.* (2018), conventional and hydroponic systems are better accepted by consumers and present values similar to those reported in the present work, indicating that the use of low-frequency electrical pulses did not significantly change the variables analyzed in lettuce postharvest.

The behavior of the hydrogen potential is correlated with the consumption of organic acids in the respiratory process; thus, in postharvest lettuce, an inverse relationship can be observed between pH and titratable acidity, factors such as the type of packaging and the storage environment. storage are correlated (GOMES *et al.*, 2021).

The mass loss in lettuce over 7 days postharvest fit a linear model with a pattern of decreasing variation across all cycles (Figure 6). The correlation coefficient R ^{2} was significant, ranging between 63% and 96% in cycle 1 and between 88% and 95% in cycles 2 and 3.

Figure 6. Mass loss over 7 days postharvest of lettuce grown in a hydroponic system with water treated with low-frequency electrical pulses



A. Cycle 1; B: Cycle 2: C; Cycle 3
Source: Authors (2023)

The environmental conditions influenced mass loss on the order of 12, 35 and 40% in cycles 1, 2 and 3, respectively, which was greater under high-temperature conditions. Andrade (2019) and Soares *et al.* (2020) also reported limitations in the development of lettuce at temperatures above 25°C, influencing postharvest quality and reducing shelf life.

Results similar to those reported in the present work were reported by Fontana *et al.* (2018), who reported that the use of a modified atmosphere interferes with the loss of fresh mass and maintains the relative water content, improving storage quality. According to Reis *et al.* (2014), the use of packaging provides a lower vapor pressure gradient between the internal atmosphere and the plant surface, increasing postharvest shelf-life.

The implementation of low-frequency electrical pulses of 3–32 kHz did not interfere with mass loss in cycles 1 and 3 in any of the treatments, whereas in cycle 2, less mass loss was observed in the 80 + constant frequency solution (T2) and 100 + intermittent frequency solution (T3). According to Putti *et al.* (2015, 2018, 2023b), the use of magnetically treated water has positive effects on the productivity of lettuce and carrot plants, which may be related to their postharvest quality. Liu *et al.* (2019) reported positive results when using electromagnetism throughout plant development. On the other hand, Olaya Tellez *et al.* (2023) reported similar results between hydroponic lettuce plants irrigated with water treated with low-frequency electrical pulses and those that did not receive treatment.

6 CONCLUSIONS

The development of lettuce grown in a hydroponic system with water treated with low-frequency electrical pulses, regardless of the nutrient solution, exhibited the same behavior as that of untreated plants, indicating the low influence of the implemented technology. The use of low-frequency electrical pulses did not cause differences in pH, titratable acidity, °Brix or mass loss in postharvest hydroponic lettuce.

7 THANKS

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