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REÚSO DE SOLUÇÕES NUTRITIVAS NO CULTIVO HIDROPÔNICO DE ALFACE: EFEITOS NA QUALIDADE PÓS-COLHEITA

PRISCILA HELENA DA SILVA MACEDO[1]; KARLA RODRIGUES BORBA[2]; MARCOS DAVID FERREIRA[3]; MARTA REGINA VERRUMA-BERNARDI[4] E CLAUDINEI FONSECA SOUZA[5]

[1] Departamento de Recursos Naturais e Proteção Ambiental, Universidade Federal de São Carlos; Brasil; priscila.silva@ufscar.br; ORCID: https://orcid.org/0000-0002-6073-2209
[2] Embrapa Instrumentação, Brasil. borbakr@gmail.com; ORCID: https://orcid.org/0000-0002-1262-9098
[3] Embrapa Instrumentação, Brasil; marcos.david@embrapa.br; ORCID: https://orcid.org/0000-0003-4544-8784
[4] Departamento de Tecnologia Agroindustrial e Socioeconomia Rural, Universidade Federal de São Carlos, Brasil; ; ORCID: https://orcid.org/0000-0003-1375-0938
[5] Departamento de Recursos Naturais e Proteção Ambiental, Universidade Federal de São Carlos, Brasil; cfsouza@ufscar.br; ORCID: https://orcid.org/0000-0001-9501-0794

1 RESUMO

A sustentabilidade dos sistemas hidropônicos depende do uso racional de recursos, incluindo o manejo adequado da solução nutritiva. O estudo avaliou os efeitos do reuso da solução, com reposição controlada de nutrientes, no pós-colheita da alface (*Lactuca sativa* L., cv. Milena) cultivada em sistema NFT. Foram testados dois tratamentos: T1 (reposição dos nutrientes consumidos, sem renovação da solução nutritiva) e T2 (renovação semanal da solução nutritiva). Avaliaram-se área foliar, índice de clorofila (SPAD), perda de massa fresca e pressão de turgescência. Os resultados mostraram que o T1 foi tão eficaz quanto o T2 em área foliar, clorofila e perda de massa, sem diferenças estatísticas. A pressão de turgescência foi significativamente maior no T2, indicando que a renovação favorece o estado hídrico foliar. Os resultados indicaram que o reuso com reposição adequada de nutrientes é uma alternativa viável, econômica e ambientalmente sustentável, com impacto mínimo sobre a qualidade pós-colheita. A turgescência foliar se destaca como indicador fisiológico sensível às variações no manejo nutricional, devendo ser considerada no monitoramento da qualidade.

Palavras-chave: hidroponia, cultivo de hortaliças, *Lactuca sativa* L., sustentabilidade.

MACEDO, P. H. S.; BORBA, K. R.; FERREIRA, M. D.; VERRUMA-BERNARDI, M. R.; SOUZA, C. F.
NUTRIENT SOLUTION REUSE IN HYDROPONIC LETTUCE CULTIVATION: EFFECTS ON POST-HARVEST QUALITY

2 ABSTRACT

The sustainability of hydroponic systems depends on the rational use of resources, including proper management of the nutrient solution. In this study, the effects of nutrient solution reuse, with controlled nutrient replenishment, on the postharvest quality of lettuce (*Lactuca sativa* L., cv. Milena) grown in an NFT system were evaluated. Two treatments were tested: T1

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(replenishment of consumed nutrients without solution renewal) and T2 (weekly nutrient solution renewal). The leaf area, chlorophyll index (SPAD), fresh mass loss, and turgor pressure were evaluated. The data revealed that T1 was as effective as T2 in terms of leaf area, chlorophyll index, and mass loss, with no significant differences. Turgor pressure was significantly greater in T2, indicating that solution renewal favors leaf water status. The results indicate that nutrient solution reuse with proper replenishment is a viable, economical, and environmentally sustainable alternative with minimal impact on postharvest quality. Leaf turgor stands out as a sensitive physiological indicator of variations in nutrient management and should be considered in quality monitoring.

Keywords: hydroponics, vegetable cultivation, *Lactuca sativa* L., sustainability.

3 INTRODUCTION

The growing global demand for food, driven by population growth and climate change, has intensified the search for more efficient and sustainable agricultural systems. Among these systems, hydroponics stands out as a soilless cultivation technique that uses nutrient solutions to provide the essential elements for plant development (RESH, 2022). However, in closed hydroponic systems, the improper disposal of nutrient solutions at the end of the growing cycle can lead to significant waste of water and fertilizers and represents a potential source of environmental pollution. The excess mineral salts released in agricultural environments, when not properly treated, are associated with the eutrophication of water bodies and the imbalance of aquatic ecosystems (GRUDA, 2019).

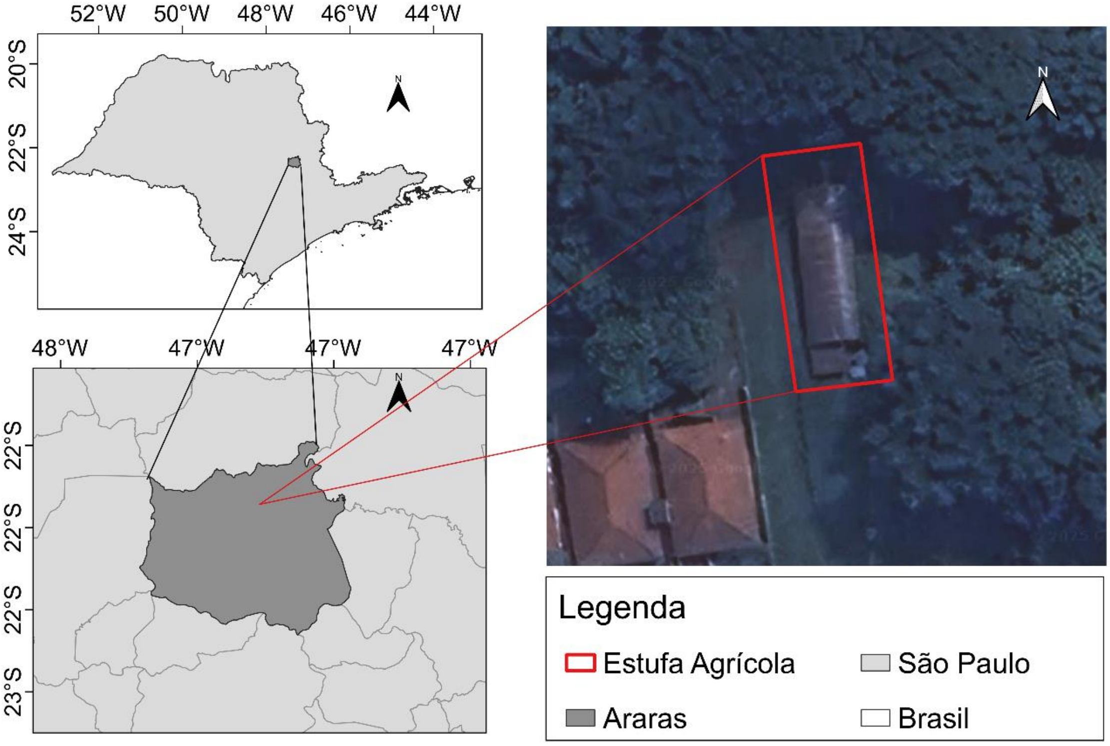
In this context, the reuse of nutrient solutions emerges as a promising strategy to increase system efficiency and minimize its environmental impacts, allowing the reuse of water and dissolved nutrients and thus reducing fertilizer consumption and the risks of contamination (SAVVAS; GRUDA, 2018). Furthermore, constant monitoring and chemical adjustment of nutrient solutions are essential for maintaining ideal nutrient levels, which favor crop productivity and quality (SANTOS JÚNIOR *et al.*, 2018).

Despite advancements, gaps remain regarding the effects of reusing nutrient solutions on the physiological and qualitative aspects of hydroponically grown plants, especially concerning postharvest characteristics, which are crucial for the commercial value of the product. Therefore, this study investigated whether reusing previously discarded nutrient solutions in hydroponic lettuce cultivation affects fundamental postharvest parameters for product quality, durability, and acceptance, such as leaf area, the chlorophyll index (SPAD), fresh weight loss, and turgor pressure.

4 MATERIALS AND METHODS

The cultivation of the Milena lettuce cultivar (curly segment) was carried out in an agricultural greenhouse at the Center for Agricultural Sciences (CCA) of the Federal University of São Carlos (UFSCar) – Araras Campus/SP, which is located at latitude 22°18'53.23" S and longitude 47°23'00.91" W (Figure 1).

Figure 1. Location and characteristics of the study area.



Source: Prepared by the authors (2026).

The greenhouse used was a Poly House model, "arched" type, with dimensions of 6.4 × 20.0 × 3.5 m (width × height), covered with transparent polyethylene film with an anti-UV additive, and the sides closed with white shade cloth. The cultivation system adopted was hydroponics, which uses the nutrient film technique (NFT).

The experimental setup consisted of eight benches, each containing four polypropylene channels with a diameter of 75 mm and a length of 3.0 m. Each bench accommodated 48 plants (12 plants per channel), with the 18 central plants considered useful.

The experiment was divided into two sequential stages. In the first stage, monitoring and data collection were carried out on the quantities of nutrients present in the nutrient solution, which was renewed weekly until 28 days after transplanting (DAT). The nutrients absorbed by the plants were quantified on the basis of the difference between the concentrations present in the initial nutrient solutions and in the solutions discarded at the end of each seven-day period.

On the basis of the data obtained in the previous stage, the second stage of the experiment was established. In this phase, two treatments were applied: treatment 1 (T1), in which the consumed nutrients were replenished without renewing the nutrient solution until 28 DAT, and treatment 2 (T2), in which the nutrient solution was completely renewed weekly, maintaining a nutritionally balanced solution every seven days until the end of the cycle, at 28 DAT. For T1, the nutrient concentration data (N, P, K, Ca, and Mg, in mg $L^{-1)}$ were converted into quantities of commercial salts (calcium nitrate, potassium nitrate, magnesium sulfate, monoammonium phosphate, and Conmicros), considering the volume of solution remaining in the reservoirs. Micronutrient replenishment was carried out on the basis of the average percentage of weekly macronutrient consumption, since these were not directly analyzed.

The experimental design for this stage was a randomized block design in which each bench was considered an experimental unit, totaling 4 repetitions per treatment.

Throughout the experiment, the pH and electrical conductivity (EC) of the nutrient solutions were monitored and adjusted as needed in accordance with the guidelines of Martinez (2002) to ensure adequate conditions for plant development. Harvesting was carried out on day 28 (DAT) in the morning. The plants were carefully packed in plastic bags and transported for analysis of the leaf area, chlorophyll index, mass loss, and turgor pressure.

Leaf area assessment was performed immediately after harvest, using four whole plants per treatment. Measurements were taken with a leaf area integrator (LI-COR 3000A, LI-COR Inc., Lincoln, Nebraska, USA), considering all the leaves from each plant. For the analyses of the total chlorophyll index, mass loss, and turgor pressure, two random plants from each treatment were used and analyzed at intervals of 1, 3, 5, and 7 days after refrigerated storage at 8°C±1°C. During storage, the plants were placed in open polyethylene bags (0.30 × 0.40 m).

Chlorophyll index readings were taken from intact leaves using a portable SPAD-502 chlorophyll meter (Minolta). With respect to the SPAD value, six measurements were performed per leaf, two cm from the margin (Camera Co., Osaka, Japan). Mass loss was determined by determining the difference between the initial and final masses of the plants every two days using a semianalytical balance (Micronal B3600), with a precision of 0.01 g, and the results are expressed in grams. Turgor pressure was measured with Wiltmeter® equipment (CALBO; FERREIRA, 2011), with readings taken in the intermediate portion of intact leaves, and the results are expressed in kgf cm^{-2} (Minolta). Camera Co., Osaka, Japan

Student's t test, with a significance level of 5%.

5 RESULTS AND DISCUSSION

The results indicate that nutrient replacement, without renewal of the nutrient solution (T1), was sufficient to meet the physiological requirements of lettuce, as evidenced by the absence of significant differences in the variables of leaf area, chlorophyll index, and mass loss between treatments (Table 1).

Table 1. Average values of the physiological and postharvest parameters of hydroponic lettuce under different nutrient solution management practices.

Treatment	Leaf area (cm^2)	Chlorophyll index (SPAD)	Mass loss (%)	Turgor pressure (kgf cm^{-2})
T1	2088.20	20.57	17.70	1.37
T2	1927.89	18.55	20.50	1.55
Detour standard	113.35	1.43	1.97	0.12
P- value	0.65	0.40	0.44	0.03

The average leaf area was 2088.20 cm² for T1 and 1927.89 cm² for T2. These results demonstrate that, even without nutrient solution renewal, controlled nutrient replenishment was effective at sustaining vegetative growth. The literature indicates that leaf morphology responds directly to nutrient availability (CID; TEIXEIRA, 2017), indicating that the management adopted in T1 provided a nutrient solution equivalent to that in T2 in terms of supplying the plant's metabolic demands.

Unlike Miller *et al*. (2020), these results indicate that controlled nutrient replenishment was sufficient to maintain the physiological balance of the plants, even without total renewal of the nutrient solution.

The average chlorophyll index was 20.57 SPAD in T1 and 18.55 SPAD in T2. Although the difference was not statistically significant, the higher value in T1 suggests that the nutrient replacement strategy favored the maintenance of photosynthetic activity. According to Miller *et al*. (2020), physiological variables such as chlorophyll content are sensitive to nutritional balance and can indicate, early on, any limitations in nutrient supply.

The mass loss was 17.7% for T1 and 20.5% for T2, with no significant difference between treatments. These results demonstrate that the reuse of the nutrient solution did not compromise the water status of the plants during storage. Considering that mass loss is strongly influenced by transpiration and respiratory metabolism (NASCIMENTO *et al*., 2017), these data indicate that reuse did not significantly alter the physiological integrity of the plant postharvest.

There was a significant difference ($p = 0.035$) in turgor pressure, with average values of 1.37 kgf cm^{-2} in T1 and 1.55 kgf cm^{-2} in T2. This indicates greater water retention in the leaf cells of plants grown with renewed solution. Leaf turgor is determined by the balance between the osmotic potential and cell pressure potential, both of which are directly influenced by the availability and management of the nutrient solution. Osmotically active nutrients, such as potassium (K^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}), play a central role in maintaining osmotic potential and, consequently, intracellular water retention (TAIZ *et al*., 2017). Postharvest fresh mass loss in vegetables is associated mainly with water loss through transpiration and is linearly correlated with a decrease in turgor pressure (BORBA; FERREIRA; CALBO, 2014). In the present study, the higher turgor pressure observed in T2 suggests that the complete renewal of the nutrient solution favored the absorption of essential cations, increasing the osmotic adjustment capacity and delaying the loss of cell pressure during storage. These results are in agreement with those of Miller *et al*. (2020), who demonstrated that nutritional deficiencies, even those with apparently adequate electrical conductivity, can reduce plant growth and water retention capacity in hydroponic systems.

6 CONCLUSIONS

Reusing the nutrient solution, with adequate nutrient replenishment, maintained the development of hydroponic lettuce in terms of the leaf area, chlorophyll index, and fresh mass loss. Turgor pressure was more sensitive to variations in nutritional management, indicating that postharvest physiological changes occurred. Reusing the nutrient solution is agronomically, environmentally, and economically viable, as it reduces water and fertilizer consumption and effluent discharge, aligning with the principles of sustainable irrigation. Management without total solution renewal is effective for crop productivity and quality, although nutritional adjustments may be necessary to preserve postharvest quality.

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