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Pretreated Agro-Industrial Effluents as a Source of Nutrients for Tomatoes Grown in a Dual Function Hydroponic System: Tomato Quality Assessment

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Abstract: In a zero-waste approach for the agro-industrial sector, this study aimed to evaluate the reuse of cheese whey wastewater (chemical oxygen demand = 2.1 g L^{-1}) pretreated by immediate one-step lime precipitation followed by natural carbonation as a nutritive solution for tomato production in hydroponic systems. Pretreated effluent, diluted with groundwater (1:6) and supplemented with nutrients, was utilized to irrigate different hydroponic systems designed to assess the influence of tomato rooting type (free/confined−setup_A) and the feed's solution level (with/without water deep−setup_B). Plants and fruit development, fruit physicochemical characteristics and sensory analysis, and effluent quality after reuse were analyzed. Good quality tomato production with high crop yield was obtained. The highest marketable tomato weight per plant (682 g) was observed in setup_B with a deep-bed system, but setup_A, with free or confined rooting, presented similar values. The type of rooting, within setup_A or water deep within setup_B, did not significantly influence plant and fruit characteristics. The highest maturity and flavor indexes were observed for setup_A with free rooting. Regarding sensory analysis, setup_A often scored the highest in terms of overall appreciation with free or confined rooting. The reuse of cheese whey wastewater in hydroponics reduced freshwater consumption for crop production, allowed for a treated final effluent and prevented soil degradation in a sustainable circular economy methodology.

Keywords: cheese whey wastewater; hydroponic system; nutrients; sustainable development; tomato

1. Introduction

Due to climate change and anthropogenic causes, the scarcity of water, fertile soils, and food is becoming a growing problem [1,2]. In a study conducted by Xue et al. [3], it was found that climate change influences vegetation growth and photosynthesis and alters the phenology, directly affecting vegetation productivity. According to the authors, the earlier start of the photosynthetic period caused by climate change increases soil water loss, leading to summer drought stress and decreased productivity. A possible answer to this developing issue may rely on hydroponic crops, a type of cultivation without soil developed in greenhouse systems. Although hydroponic cultivation presents some drawbacks, such as the investment in equipment/system, energy consumption, and need for qualified labor, it presents several advantages for both producers and consumers, namely: (i) quality products with less water consumption and without soil degradation; (ii) replacement of conventional agriculture in areas with low agricultural quality soils; (iii) increased production yields, due to the high number of plants per area, faster plant growth, shelter from the outside environment and the weather, and pest control; (iv) reduction in the use of fertilizers; and (v) the possibility of reusing treated wastewaters as nutritive solutions according to the UN Sustainable Development Goals [4–6].

There is a wide variety of hydroponic systems, including those with or without a solid substrate to support the roots, with flow or drip irrigation, with or without recirculation of the nutritive solution, cultivation in horizontal tubes or vertical pipes, etc. The choice of an optimal hydroponic system will depend on the type of cultivar, environmental conditions and other factors [7]. The use of a nutritive solution to provide the plant with all the essential nutrients required for its healthy development is transversal to all types of hydroponic systems. Inorganic fertilizers that are usually primarily composed of commercial inorganic salts are used as nutrient sources, although in recent years, more sustainable formulations have been proposed [7]. The use of ashes from plant biomass (rich in calcium, potassium and phosphorus), algae extract, or even mine minerals, among others, have been proposed in the literature for the sustainable production of fertilizers [8]. Additionally, being the plant/fruit characteristics directly affected by the uptake of nutrients during their growth, the development of fertilizers targeted to enhance specific product properties has emerged. In a study performed by Luo et al. [9], a new organic-inorganic compound fertilizer was specifically developed to increase the growth of fragrant rice, its yield formation, and the biosynthesis of the 2-acetyl-1-pyrroline grain, responsible for the unique aroma of the fragrant rice under study.

Using different wastewater streams as sources of nutrients and water in hydroponic systems has been widely studied in a sustainable agriculture approach. Besides addressing the water scarcity crisis and reducing the use of fertilizers, it leads to wastewater purification while producing economically valuable goods [10]. In particular, the use of agro-industrial wastewater has received particular attention since it can be a source of nitrogen, phosphorus, potassium, organic matter and micronutrients for plant growth [11]. A good example of an effluent with such properties is cheese whey wastewater (CWW), whose use for crop cultivation in the soil is documented in the literature [12]. CWW richness in nitrogen (0.01–1.7 g L^{-1}) and total phosphorus (0.006–0.5 g L^{-1}) and its high abundance worldwide make it a good candidate for hydroponic production. However, no studies were found reporting its direct use as nutritive solution in hydroponic systems, which is likely due to its high organic load (0.8–102 g L^{-1} of chemical oxygen demand (COD)) despite it being considered biodegradable (biochemical oxygen demand (BOD_5)/COD > 0.5), and its high content of suspended solids (0.1–22.0 g L^{-1}), oils and fats (0.075–3.76 g L^{-1}) [13]. Thus, before its utilization in crop irrigation, CWW should be subjected to a pretreatment that may involve high costs that small producers cannot afford [14]. Immediate one-step lime precipitation (IOSL), a simple and economical treatment process based on the pollutants removal by precipitation with lime, has been applied to pretreat CWW, attaining high removal efficiencies in organic matter, oils and fats, suspended solids, as well as in total phenols and turbidity [15]. Prazeres et al. [15] reported a removal above 90% in suspended solids, oils, and fats when applying IOSLP to treat CWW. However, this process leads to an increase in the electrical conductivity (EC) and pH of the effluent, having proposed a subsequent natural carbonation (CB) process with atmospheric CO_2 mitigation to decrease the pH and remove the calcium from the effluent [15]. The sludge produced during the treatment, rich in organic matter and nutrients such as Ca, Mg, P, Cl, Na and K, can be utilized as fertilizer in soil crops [16].

A wide range of fruits and vegetables can be grown through hydroponics. However, some criteria must be fulfilled, such as the root and fruit size and the harvesting time cycle, among others [7]. Considered the most important horticultural crop in the world, tomato (*Solanum lycopersicum*) is one of the most cultivated fruits through hydroponics [17]. It is grown in almost every country on the planet, ranking 350th in the world's most traded products in 2021 with a total trade of USD 10.3 billion [18,19]. This is due to the tomato's many health benefits, as it is the main dietary source of the antioxidant lycopene, known for reducing the risk of heart disease and cancer [20].

The use of agrochemicals is the major challenge in tomato production, and the tomato industry, regarded as highly advanced, globalized, and innovative, is searching for strategies that ensure the sustainable management of the value chain [20]. In that line, studies addressing the reduction of agrochemicals in tomato production have been developed, such as the replacement of fertilizers by plant growth-promoting bacteria [21] or by nutrient-rich effluents [22–27]. Effluents from aquaponic systems [22,25], brewery effluent [26], and effluent from an anaerobic baffled reactor of a decentralized wastewater treatment system [27] were already studied for the hydroponic growth of tomatoes. Although there are concerns about the possible uptake of undesirable substances by the tomato fruit, such as pharmaceuticals, hormones, and psychoactive substances, studies have shown that, when detected, the respective amounts did not endanger the health of the consumer [28].

The objective of this study was to evaluate CWW reuse after pretreatment by IOSPL + CB in the hydroponic production of cherry tomatoes (*Solanum lycopersicum* var. *cerasiforme*) as a way to reduce the need for fertilizers and potable water in agriculture. Different hydroponic systems were exploited, and the quality of the produced tomatoes was evaluated by determining their physicochemical properties and sensory characteristics. The characterization of the liquid effluent from the hydroponic systems was also assessed.

2. Materials and Methods

2.1. Agro-Industrial Wastewater

2.1.1. CWW Sampling and Pretreatment

The CWW was collected from a small industry located in the village of Serpa, in the Alentejo region of Portugal, which produces sheep and goat cheese. The sample was carried out in PVC containers with a capacity of 1000 L. The raw CWW was pretreated by IOSLP to a pH of 12.5 using a 200 g L^{-1} hydrated lime solution prepared with groundwater and commercial hydrated lime (Calcidrata Indústria de Cal, S.A., Alcanede, Portugal), followed by a carbonation step through atmospheric CO_2 for more than 90 days. To form a precipitate that allowed efficient removal of organic matter and other contaminants, 25 mL of lime solution per liter of CWW was used [29].

2.1.2. Nutritive Solution

Since the pretreated CWW presented high EC and pH and did not contain the necessary nutrients to be utilized as irrigation water in hydroponic culture, it was necessary to dilute it with groundwater (CWW:groundwater = 1:6) and supplement it with macro and micronutrients [22]: 23 mg L^{-1} of TRADECORP AZ (mixture of micronutrients chelated with EDTA), 157–364 mg L^{-1} of KNO_3, 456–504 mg L^{-1} of $MgSO_4$, 220 mg L^{-1} of KH_2PO_4, and 415 mg L^{-1} of $Ca(NO_3)_2$. Nutrient supplementation followed the literature recommendations [17,30] based on the characteristics of the pretreated CWW. According to Hochmuth and Hochmuth [31], tomato crop demand for N, K, and Mg increases as the crop grows. Thus, the supplemented N, K, and Mg concentrations were slightly adjusted throughout the development phase of the plants, according to Table S1 (Supplementary Material).

2.1.3. Analytical Methods

pH, redox potential, dissolved oxygen (DO), EC, total dissolved solids (TDS), salinity, and temperature were measured in situ using a Multiparameter Water Quality Meter—HI98194 (Hanna Instruments, Póvoa de Varzim, Portugal). Determinations of COD, BOD_5, ammonia nitrogen (AN), total Kjeldahl nitrogen (TKN), total phosphorus (P_{total}), and calcium and magnesium hardness were performed according to APHA (2017), as described elsewhere [29,32]. TKN was determined using a P-SELECTA BLOC DIGEST 6 (JP Selecta, Barcelona, Spain) for the sample digestion and a Distillation Unit B-316 (BUCHI, Barcelona, Spain). This distillation unit was also utilized for AN determination. Sodium and potassium were determined on a CORNING 410 flame photometer (Dias de Sousa S.A., Alcochete, Portugal).

All determinations were done in triplicate, and results are presented as medium values with standard deviations.

2.2. Hydroponic Systems: Experimental Design

The cherry tomato production was conducted between December 2022 and July 2023 in a greenhouse located in the "Centro Hortofrutícola" of the Polytechnic Institute of Beja (Portugal), where the temperature ranged between 13 and 25 °C, with an average of 8 h of light period per day.

Two different setups, A and B, were utilized, with each one comprising three different systems according to the schematics presented in Figure 1:

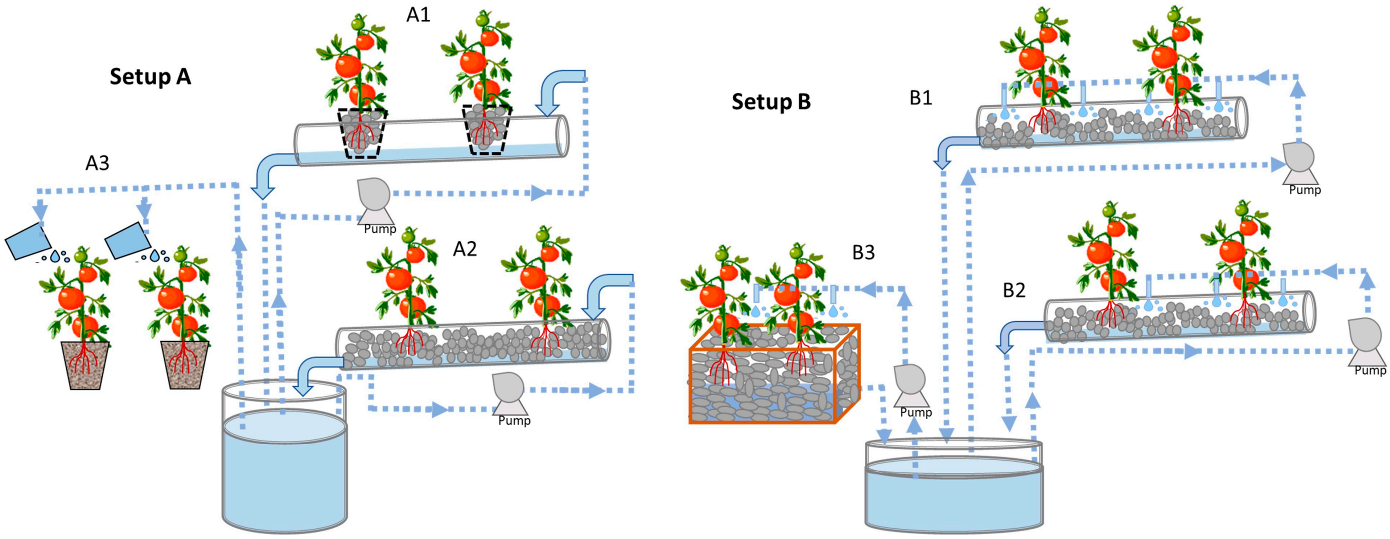


Figure 1. Diagram of the different systems used to grow the tomato plants.

A1—Hydroponic system of tomato plants with confined rooting.
A2—Hydroponic system of tomato plants with free rooting.
A3—Traditional tomato cultivation with confined rooting in pots with soil.
B1—Hydroponic system of tomato plants without water depth.
B2—Hydroponic system of tomato plants with water depth.
B3—Hydroponic system of deep-bed tomato plants.

The main characteristics of the different systems are presented in Table 1. For the systems of setup A (A1, A2 and A3), tomato seeds *Solanum lycopersicum* var. *cerasiforme* were purchased from a local store and placed in truffle cultivation trays. After 53 days, the tomato plants were transplanted into the hydroponic systems, where they remained until they were harvested. For the systems of setup B (B1, B2 and B3), tomato plants *Solanum lycopersicum* var. *cerasiforme*, with about 70 days post-seeding and an average height of 16.5 cm, were purchased from a local store and transplanted to the hydroponic systems 7 days after acquisition.

Table 1. Main characteristics of the different systems used to grow the tomato plants.

Parameter	**Setup A**			**Setup B**		
	A1	**A2**	**A3**	**B1**	**B2**	**B3**
System configuration	PVC tube [6 m (L), Ø 125 mm, 2% slope] With individual perforated pots	—	Individual pots (22)	PVC tube [0.25 m (L), Ø 90 mm]		PVC box [0.5 × 0.53 × 0.45 m]
No. lines	2	2	—	2	2	2
Support medium	Leca®NR 10/20		Soil	Leca®NR 10/20		
No. plants/line	11	11	—	11	11	6
Distance between plants (cm)	45	45	—	23	23	23
Irrigation type	Automatic channel irrigation with recirculation		Manual	Automatic drip irrigation with recirculation		
Irrigation cycle	Intermittent: 15 min ON—15 min OFF from 9 am to 5 pm		Once a day (200 mL/plant)	Intermittent: 15 min ON—30 min OFF from 8 am to 7 pm		Continuous with constant volume of 5 L
Average inflow/outflow (mL min^{-1})	505/180	206/180	—	55/30	55/30	28/13
Fruit harvesting (days after plants were transplanted)	98 [a] 157 [b]	98 [a] 157 [b]	143 [a] 161 [b]	55 [a] 161 [b]	55 [a] 161 [b]	64 [a] 193 [b]

[a] First harvest. [b] Last harvest.

All the systems were irrigated with a nutritive solution prepared from pretreated CWW (as described in Section 2.1.2). The nutritive solution was intermittently recirculated within the setups, being replaced with fresh nutritive solution every two weeks. The physicochemical characterization of the withdrawn solutions was performed according to Section 2.1.3.

2.3. Plants and Fruit Characterization

2.3.1. Crop Growth and Yield

The growth and yield of the plants were evaluated just before the fruit harvesting through the following parameters: height, stem diameter, number of leaves, number of bunches, total fruit and marketable fruit. It was considered marketable fruit for those that did not show blossom-end rot or wormhole.

Regarding the fruit, the evaluation was carried out immediately after its harvesting, through measurements of diameter and weight, being presented the results for fruit and marketable fruit. The total weight of marketable fruit per plant was also determined.

2.3.2. Tomato Physicochemical Characterization

Tomatoes were harvested at the stage of red maturation. Part of them was used for fresh sensory analysis and agronomic evaluation. The other part was crushed and homogenized with a blender, peel and seeds included, for the physicochemical characterization, which comprised the evaluation of the following parameters: pH, titratable acidity (TA), total soluble solids (TSS), maturity index (M_{index}), flavor index (F_{index}), dry matter (DM), ash content, firmness, total phenolic compounds (TPh), ferric reducing antioxidant power (FRAP), Trolox equivalent antioxidant capacity (TEAC), vitamin C, lycopene, β-carotene, chlorophyll a and b, potassium and sodium.

pH was measured with a 691-pH meter (Metrohm, Herisau, Switzerland), using 25 g of sample. For TA determination, 10 g of sample was mixed with 25 mL of distilled water and titrated potentiometrically with 0.1 N NaOH solution until it reached an endpoint of pH 8.2, being results expressed in mg of citric acid per 100 g of fresh sample [33]. TSS was determined using a digital refractometer DR103L (Bellingham and Stanley, Tunbridge Wells, UK). Samples were filtered before determination with the measurements done at a controlled temperature of 20 °C, and results were expressed in °Brix [34]. M_{index} and F_{index} were calculated using the TA and TSS values according to Equations (1) and (2), respectively [35].

$$M_{index} = \frac{TSS}{TA} \quad (1)$$

$$F_{index} = \frac{TSS}{20 \times TA} + TA \quad (2)$$

Dry matter and ash content were determined by the gravimetric method, using 10 g of a sample, and the results were expressed as a percentage [36]. For the dry matter analysis, the sample was dried at 70 °C in a vacuum oven with a pressure lower than 100 mmHg. The ash content was determined after 4 h at 550 °C. Firmness was determined through a manual penetrometer (fruit pressure tester) (Vórtice, Equipamentos Científicos Lda., Lisbon, Portugal) applied directly to the skinned fruit, with results being expressed in N [36].

TPh was determined by the Folin–Ciocalteau method [37], using standard solutions of gallic acid monohydrate. The absorbances were measured at 740 nm using a FLUOstar OPTIMA microplate spectrometer (BMG LABTECH, Ortenberg, Germany). The results were expressed in mg of the gallic acid equivalent (GAE) per 100 mg of fresh sample. FRAP and TEAC analyses comprised the preparation of a lipophilic extract [38]. For that, 0.5 g of sample was homogenized with hexane for 10 min and centrifuged at 15,000 rpm for 10 min using a Mikro 200 centrifuge (Hettich, Kirchlengern, Germany). The supernatant was discarded, and the residual hexane part was homogenized for 10 min with a mixture of acetone:water:acetic acid (70:29.5:0.5, *v*/*v*/*v*), followed by centrifugation at 15,000 rpm for 10 min. The supernatant, the hydrophilic part, was then transferred to a 10 mL flask. FRAP determination followed the procedure described by Macedo et al. [37], using standard solutions of $FeSO_4$. The absorbances were measured at 595 nm using the microplate spectrometer described above, and the results were expressed as mmol of Fe^{2+} per 100 g of fresh sample. TEAC evaluation followed the procedure described by Al-Duais et al. [39] using a standard Trolox solution. The absorbances were measured at 730 nm through the microplate spectrometer. The results were expressed as Trolox equivalent in mmol per 100 g of sample.

Vitamin C was determined according to Müller et al. [40] based on the reaction between dehydroascorbic acid and 2,4-dinitrophenylhydrazine. The previous preparation of an extract was required, which comprised the homogenization of 0.1 g of tomato with metaphosphoric acid for 10 min, followed by centrifugation at 15,000 rpm for 30 min. The supernatant was transferred to a 10 mL flask and redissolved in metaphosphoric acid. The absorbances were measured at 510 nm using the microplate spectrometer. The results were expressed in mg per 100 g of sample. The amounts of lycopene, β-carotene, and chlorophyll a and b were determined according to the procedure described by Nagata and Yamashita [41]. The pigments were extracted from 10 g of sample using 10 mL of acetone/hexane (2:3, *v*/*v*) centrifuged at 3750 rpm for 10 min. The supernatant absorbance was measured at 453 (A_{453}), 505 (A_{505}), 645 (A_{645}), and 663 (A_{663}) nm using an Evolution UV-Vis spectrophotometer (Thermo Scientific, Dreieich, Germany). Lycopene, β-carotene, and chlorophyll a and b were calculated through Equations (3) to (6), respectively, with the results expressed in mg per 100 g of sample [41].

$$\text{Lycopene} = -0.0458\ A_{663} + 0.204\ A_{645} + 0.372\ A_{505} - 0.0806\ A_{453} \quad (3)$$

$$\beta - \text{Carotene} = 0.216\ A_{663} - 1.22\ A_{645} - 0.304\ A_{505} + 0.452\ A_{453} \tag{4}$$

$$\text{Chlorophyll a} = 0.999\ A_{663} - 0.0989\ A_{645} \tag{5}$$

$$\text{Chlorophyll b} = -0.328\ A_{663} + 1.77\ A_{645} \tag{6}$$

Potassium and sodium content were determined by flame photometer using a CORNING 410 flame photometer (Dias de Sousa S.A., Alcochete, Portugal) [42]. For that, the ash content of the samples was dissolved in 3 N HCl, filtered, and the volume adjusted to 500 mL with distilled water.

All the analyses were performed in triplicate, and results are presented as medium values with standard deviations.

2.4. Sensory Analysis

A hedonic sensory study was conducted with the help of 30 volunteer consumers. A sensory laboratory, with separate testing booths, was used for the testing [43]. A random number code was used to identify the samples all at once. The intensity of each sample, in the parameters red color, smell, flavor, juiciness, texture, and overall appreciation, was scored on a five-point mixed structured hedonic scale, where 5 equals "extremely pleasant", 4 "pleasant", 3 "indifferent", 2 "unpleasant" and 1 "extremely unpleasant" [29]. The sensory rating form included questions about the tasters' sex, age, tomato-eating patterns and intent to buy.

The sensory analysis was performed in two sessions: Session 1—evaluation of fruit from systems A1 and A2; Session 2—evaluation of fruit from systems A3, B1, B2 and B3.

2.5. Statistical Analysis

Data from plants and fruit characterization and sensory study were statistically analyzed using Statistica 12.0 software. For the data from plants and fruit characterization, the statistical analysis was run separately for setups A and B (comparison between A1, A2 and A3 between B1, B2 and B3). Regarding the sensory study data, the statistical analysis was made separately for the two sensory sessions performed (comparing A1 and A2 and A3, B1, B2 and B3). A variance analysis (ANOVA) was followed, and statistically significant differences were signalized whenever the F-value was higher than critical F. For F values lower than critical F, no statistically significant difference occurred. Tukey's HDS test was used to compare the means of the results at a significance level of 0.05.

3. Results and Discussion

3.1. CWW and Nutritive Solution

Table 2 presents the physicochemical characterization of the CWW before and after the IOSLP + CB pretreatment and of the initial nutritive solution prepared with the pretreated CWW, diluted with groundwater and supplemented with nutrients. The pretreatment led to an increase in pH, EC, TDS, salinity and total hardness, which are associated with the addition of the hydrated lime. The content of some ions also increased, which could be due to contamination of the lime.

In hydroponic cultivation, nutrient absorption depends on the characteristics of the nutrient solution, namely in terms of pH and EC. In the case of tomato plant growth in a hydroponic system, the nutrient solution should have, according to the literature, a pH between 6.0–6.5 and an EC between 2.0–4.0 mS cm^{-1} to allow good plant development and fruit production [44]. To achieve these recommended pH and EC values, the pretreated CWW was diluted with groundwater. As a result, the EC decreased below the minimum value recommended while the pH was still above the optimal range. Nevertheless, this difference between the obtained values and those recommended did not inhibit the development and growth of the tomato plant and fruit.

The availability of adequate concentrations of macro and micronutrients is another key factor in plant development and fruit production [17,31]. Because pretreated CWW did not have an acceptable concentration of some nutrients, which was further accentuated by the dilution with groundwater, it was necessary to supplement the nutritive solution at this level, as described in Section 2.1.2. This supplementation led to an increase in potassium, total phosphorus, calcium, magnesium and nitrogen.

Table 2. Characterization parameters of the CWW, before and after the IOSLP + CB pretreatment, and of the initial nutritive solution (mean value ± standard deviation, $n \geq 3$).

Parameter	Raw CWW	Pretreated CWW	Initial Nutritive Solution
pH (Sorensen)	7.2 ± 0.3	10.8 ± 0.5	8.0 ± 0.5
Redox potential/mV	−540 ± 9	32 ± 2	100 ± 6
DO/mg L^{-1}	1.4 ± 0.4	4.0 ± 0.9	4.0 ± 0.7
EC/mS cm^{-1}	3.8 ± 0.9	4.8 ± 0.9	1.2 ± 0.4
TDS/g L^{-1}	1.9 ± 0.3	2.4 ± 0.4	0.6 ± 0.1
Salinity/PSU	2.0 ± 0.1	2.2 ± 0.2	0.62 ± 0.05
BOD_5/g L^{-1}	1.87 ± 0.03	–	0.051 ± 0.001
COD/g L^{-1}	2.1 ± 0.2	1.61 ± 0.05	0.24 ± 0.07
$[K^+]$/mg L^{-1}	28.1 ± 0.7	29.1 ± 0.7	219 ± 9
$[Na^+]$/mg L^{-1}	181 ± 7	196 ± 9	36.6 ± 0.9
P_{total}/mg L^{-1}	61 ± 2	0.5 ± 0.2	91 ± 1
Total hardness/mg$CaCO_3$ L^{-1}	59 ± 2	135 ± 3	274 ± 1
$[Ca^{2+}]$/mg L^{-1}	20 ± 1	54.0 ± 0.6	72.7 ± 0.6
$[Mg^{2+}]$/mg L^{-1}	2.40 ± 0.02	0	22.70 ± 0.05
AN/mg L^{-1}	65.3 ± 0.4	1.5 ± 0.1	7.2 ± 0.2
TKN/mg L^{-1}	85.9 ± 0.5	3.1 ± 0.3	21.1 ± 0.3

3.2. Morphological Characterization of Plants and Fruit

Table 3 displays the morphological characterization of the plants and fruit grown in the different systems fed with NS prepared from pretreated CWW. The maximum, minimum, and median values obtained for each of the parameters evaluated in the different systems are presented to better assess the range and trend of the results obtained. The statistical analysis of the morphological characterization data is presented as Supplementary Material (Table S2).

Regarding the tomato plants grown in Setup A, A3 presented the highest medians for height and number of leaves and bunches. However, it presented the lowest medians for stem diameter and the number of total and marketable fruit. When compared with systems A1 and A2, which do not present significant differences between them, it is observed that the culture in soil A3 is more advantageous for the development of the tomato plant, although it is less suitable for quality tomato production. As for the characterization of tomato plants in setup B, system B3 presented the highest medians for all parameters evaluated. Although systems B1 and B2 do not present significant differences between them, they are significantly different from B3, observing that B3, a system with less availability to nutritive solution and deeper rooting, is more advantageous for the development of the tomato plant. Comparing the two setups, the B3 system showed the best plant growth, indicating that the plants present a better development in a system with a lower input flow rate of nutritive solution and deeper rooting. It should be noted that the average tomato plant height obtained in this study is within those found in the literature for cherry tomato plants grown in hydroponic systems, which vary between 115 and 193 cm [45].

Analyzing the fruit results, it can be seen that for the fruit produced in setup A, system A2 presented the highest median values for all parameters evaluated. However, the differences for A1 and A3 are not significant. Growing tomatoes in the A2 system with free rooting seems more advantageous for tomato production, as 79% of the production is considered marketable. Regarding the characterization of the tomatoes produced in setup B, B2 also stands out, except for the tomato production indicator. For this parameter, the B3 system presented the best results, with 60% of marketable production. Comparing the two setups, the A2 system presents the largest fruit and the highest production yield.

However, B3 exhibits better commercial characteristics, such as a 1.6 and 2.5 cm diameter and a weight between 10 and 20 g [46]. The average results of this study in terms of tomato diameter and weight are in accordance with data reported by Coyago-Cruz et al. [47] when evaluating the quality parameters in commercial cherry tomatoes. They also compare well with the results obtained in other studies on hydroponic systems [48,49].

Table 3. Characterization of the plants and fruit grown in the different hydroponic systems fed with nutritive solution from pretreated CWW: Max—maximum; Min—minimum; MED—median ($n \geq 10$).

	Parameter	**Setup A**									**Setup B**								
		A1			**A2**			**A3**			**B1**			**B2**			**B3**		
		Max	**Min**	**MED**	**Max**	**Min**	**MED**	**Max**	**Min**	**MED**	**Max**	**Min**	**MED**	**Max**	**Min**	**MED**	**Max**	**Min**	**MED**
Plants	Height/cm	148	88	124	160	79	130	164	125	144	132	76	94	138	74	88	174	79	163
	Stem diameter/mm	15.7	7.5	10.7	16.5	8.5	13.2	10.9	9.0	10.0	13.8	9.0	10.0	12.7	8.3	9.8	12.0	9.8	10.1
	Number of leaves	12	4	10	11	5	8	22	13	16	26	17	21	25	17	21	42	32	40
	Number of bunches	5	1	4	8	3	5	8	4	6	7	1	5	7	3	5	26	5	11
	Total fruit	47	2	26	53	17	33	27	2	12	25	5	11	22	6	12	224	15	132
	Marketable fruit	38	2	15	37	2	26	13	0	3	11	2	5	14	3	8	168	5	64
Fruit	Diameter/mm	41	7	27	43	10	28	36	11	26	29	7	13	29	8	19	28	7	19
	Marketable diameter/mm	41	11	28	43	10	29	36	17	27	29	8	21	29	12	23	26	14	19
	Weight/g	36	0.3	12	41	0.5	12	23	0.9	11	14	0.3	2	13	0.3	4	12	0.3	4
	Marketable weight/g	36	1	13	41	1.1	14	23	3	13	14	1.2	7	13	1	8	11	1.9	4
	Total marketable weight (g)/plant	540	16	170	527	27	334	149	2	43	71	11	32	133	13	47	682	31	287

3.3. Tomato Physicochemical Characterization

The physicochemical characteristics of the tomatoes produced in setups A and B are presented in Table 4. Titratable acidity and pH are parameters relevant for taste, especially when combined with appropriate sugar content [50], and generally, the acid concentration in tomatoes increases during development and tends to decrease later due to citric acid degradation in the fruit [51]. During the ripening, tomato pH usually varies between 4 and 4.5, with variations in titratable acidity between 0.3% and 0.6% [43]. For systems A1 and A2, pH and TA do not present significant differences, showing that the type of rooting did not influence their average values. However, A3 presents lower average pH and TA values, showing that a hydroponic system is more advantageous for tomato quality. These results coincide with those from Fernandes et al. [2] and Verdoliva et al. [52], who obtained higher average pH values for tomatoes cultivated in hydroponic systems when compared to those from organic and conventional systems. The results obtained for B1, B2 and B3 showed no significant differences in pH. Regarding TA, there are some differences, being that B2, the system with the water blade, presents the highest value. Still, it can be inferred that the height of the water line has little influence on the results. The average values of pH and acidity obtained for both setups are consistent with those reported for cherry tomatoes grown in different types of systems, such as hydroponic (pH between 4.51 and 4.62 and TA between 0.095 and 0.125), organic (pH 4.17) and conventional (pH between 4.16 and 4.21 and TA between 0.58 and 0.84) [2,53].

The total soluble solids content represents the percentage of soluble solids in the fruit and is used to characterize tomatoes throughout maturity and ripening. As a tomato is mostly water, TSS in a typical tomato varies between 5% and 10%, influencing the firmness and texture of the tomato, as well as the flavor. In fact, as most of the TSS in a tomato consists of sugars, it can be a good indicator of the fruit's flavor quality [34]. The average TSS results obtained for setup A did not show significant differences, although they can be considered high compared to most results found in the literature. Verdoliva et al. [52] obtained TSS values between 3.0–3.7 °Brix for soil systems and greenhouse hydroponics. Fernandes et al. [2] obtained values between 4.17–4.22 °Brix when studying different culture systems (organic, hydroponic and semi-hydroponic). Coyago-Cruz et al. [47] attained mean values of 3.3 °Brix when evaluating commercial cherry tomatoes. Tsouvaltzis et al. [51] reported values between 7.55 and 9.60 °Brix for cherry tomatoes grown hydroponically in rockwool slabs. In tomatoes, the TSS value increases with the color and maturity of the tomato and is mainly attributed to sugars like fructose and glucose, although it depends on the species, cultivation method and harvest time [54]. It is one of the characteristics that most affect consumer preference [55]. From the results obtained in setup A, A1 presented the highest mean TSS value (10.6), and A3 presented the lowest (9.67). These results can be explained by the "amount" of irrigation provided to the plant since the decrease in irrigation led to higher TSS levels, probably due to the decrease in water accumulation by the fruit without changing the accumulated sugars [56]. In A1, the plant has semi-confined roots, making it more difficult to access the nutrient solution. In system A3, the plant is in a pot with soil, tending to accumulate solution inside. As for setup B, the average values do not show significant differences between B1, B2 and B3 being smaller than those presented by setup A systems. At setup B, the plants were irrigated by a drip system, and the feeding solution was always available. Among the three systems, B1 attained the highest mean value (7.7), confirming that the decrease in irrigation results in higher TSS values. Therefore, it can be concluded that the access of the roots to the nutritive solution and the water line height influence the TSS values.

Table 4. Physicochemical characteristics of the cherry tomatoes (*Solanum lycopersicum* var. *cerasiforme*) produced in the different systems: pH, titratable acidity, total soluble solids, maturity index, flavor index, dry matter, ash content and firmness (mean value ± standard deviation, $n \geq 3$).

Parameter	Setup A			Setup B		
	A1	**A2**	**A3**	**B1**	**B2**	**B3**
pH (Sorensen)	4.22 ± 0.09 ^{a}	4.2 ± 0.4 ^{ab}	4.03 ± 0.01 ^{b}	4.08 ± 0.09 ^{a}	4.1 ± 0.1 ^{a}	4.06 ± 0.07 ^{a}
TA/(gCA/100 g)	0.70 ± 0.02 ^{a}	0.7 ± 0.2 ^{a}	0.82 ± 0.04 ^{b}	0.53 ± 0.01 ^{b}	0.62 ± 0.01 ^{a}	0.54 ± 0.01 ^{b}
TSS/°Brix	10.6 ± 0.8 ^{a}	10.1 ± 0.8 ^{a}	9.67 ± 0.08 ^{a}	7.7 ± 0.7 ^{a}	7 ± 2 ^{a}	7.4 ± 0.06 ^{a}
M_{index}	15.0 ^{a}	14.2 ^{a}	11.8 ^{a}	14.6 ^{a}	11.9 ^{a}	13.6 ^{a}
F_{index}	1.46 ^{a}	1.42 ^{a}	1.41 ^{a}	1.26 ^{a}	1.21 ^{a}	1.22 ^{a}
DM/%	13.9 ± 0.7 ^{a}	13.6 ± 0.1 ^{a}	13.6 ± 0.1 ^{a}	10.24 ± 0.06 ^{b}	10.9 ± 0.2 ^{a}	10.0 ± 0.1 ^{b}
Ash content/%	0.9 ± 0.1 ^{a}	1.0 ± 0.6 ^{a}	0.89 ± 0.03 ^{a}	0.68 ± 0.05 ^{a}	0.72 ± 0.02 ^{a}	0.64 ± 0.02 ^{a}
Firmness/N	3.4 ± 0.9 ^{a}	3.6 ± 0.9 ^{a}	4.0 ± 0.6 ^{a}	4 ± 2 ^{a}	4 ± 2 ^{a}	3 ± 1 ^{a}

^{a,b} Different letters in different lines indicate statistically significant differences ($p < 0.05$).

Generally, acidity tends to decrease with fruit maturity while sugar content increases [35]. The relationship between these two parameters can be measured by the flavor and maturity indexes, which can be used to characterize the quality and flavor of tomatoes. Fruit with F_{index} below 0.7 is considered to have little flavor [35]. Within setups A and B, the average values of M_{index} and F_{index} do not differ significantly, with all systems presenting average values of F_{index} higher than 1.0 and M_{index} higher than 11. A1 and B1 attained the highest indexes of flavor and maturation, which is in accordance with the average values obtained for TSS. Suárez et al. [35] evaluated the flavor and maturity indexes of tomatoes of varieties other than cherry, obtaining average F_{index} and M_{index} of 1.00 and 9.7, respectively.

Dry matter content is another maturity indicator used during harvesting, which correlates with TSS, increasing with fruit maturation [57]. In ripened fruit, tomato pulp DM consists of 50% soluble sugars, 25% insoluble solids, 13% organic acids, 8% minerals and 4% others [57]. Temperature is an influencing factor of DM, as higher temperatures increase transpiration and reduce the water content in the fruit, indirectly increasing DM and TSS [51]. The tomato processing industry prefers higher DM values [57]. The results of setup A show that the highest levels of DM were attained by the system with the highest TSS content and M_{index}, A1, as expected. The opposite was found in setup B, with the highest DM levels linked to the lowest TSS and M_{index} in the B2 system, where the nutritive solution is more available.

Firmness is one parameter that influences consumer acceptance and buying decisions [58]. Firmness, which represents the degree of resistance to movement, damage, and microorganism development, also influences how people perceive flavor and scent and helps predict shelf life and durability during transport [36]. The loss of fruit firmness depends on the deterioration of the cellular structure and the ripening degree [57]. The average values obtained for both setups show no significant differences between the tomatoes produced by the different systems, indicating that the test variables do not significantly influence the tomato firmness. Still, in setup A, the highest firmness result was observed for system A3, with the lowest M_{index}.

Antioxidants, vitamins and mineral contents of the cherry tomato produced in the different systems are presented in Table 5. Phenolic compounds are known for reducing the risk of cardiovascular diseases; therefore, they are considered important nutrients, especially in tomatoes [59]. Among the factors influencing the TPh content, the type of tomato variety and environmental factors, such as light, temperature, fertilization mode and growing season, are the most relevant. The method of analysis can also influence the TPh results, as the extraction efficiency depends on the solvent used [59,60], and the TPh content varies according to the tomato fraction under analysis, being higher in the skin, followed by the seeds and lower in the pulp [38,61]. Generally, cherry tomatoes have higher TPh content than other tomato cultivars since they have a higher skin/pulp ratio [62]. The average TPh results obtained for setup A showed no significant differences between the A1 and A2 systems, indicating that the type of rooting in the hydroponic system does not influence the TPh content. Tomatoes from A3 presented lower average TPh values than A1 and A2, disclosing an advantage of the hydroponic system over cultivating pots with soil.

Table 5. Characterization of the cherry tomatoes (*Solanum lycopersicum* var. *cerasiforme*) produced in different systems: total phenolic compounds, antioxidant capacity (TEAC and FRAP), vitamin C, carotene (lycopene and β-carotene), chlorophyll a and b and mineral content (mean value ± standard deviation, $n \geq 3$).

Parameter (Values per 100 g of Fresh Tomato)	Setup A			Setup B		
	A1	A2	A3	B1	B2	B3
TPh/g GAE	0.05 ± 0.02^{a}	0.05 ± 0.02^{a}	0.09 ± 0.05^{b}	$0.050 \pm 0.009^{a,b}$	0.06 ± 0.02^{a}	0.04 ± 0.01^{b}
FRAP/mmol Fe^{2+}	0.3 ± 0.2^{a}	0.3 ± 0.2^{a}	0.2 ± 0.1^{a}	$0.2 \pm 0.2^{b,c}$	0.6 ± 0.2^{a}	$0.09 \pm 0.08^{a,c}$
TEAC/mmol	0.2 ± 0.1^{a}	0.2 ± 0.1^{a}	0.3 ± 0.1^{a}	0.22 ± 0.06^{a}	0.12 ± 0.05^{b}	0.19 ± 0.08^{a}
Vitamin C/g	0.06 ± 0.02^{a}	0.07 ± 0.02^{a}	0.06 ± 0.02^{a}	0.07 ± 0.02^{a}	$0.069 \pm 0.008^{a,b}$	$0.06 \pm 0.01^{a,b}$
Lycopene/mg	0.72 ± 0.08^{b}	0.53 ± 0.09^{c}	1.15 ± 0.07^{a}	0.29 ± 0.04^{a}	$0.36 \pm 0.04^{a,c}$	$0.22 \pm 0.04^{b,c}$
β-Carotene/mg	0.51 ± 0.06^{b}	0.34 ± 0.04^{c}	0.91 ± 0.04^{a}	0.50 ± 0.04^{a}	0.39 ± 0.01^{a}	0.5 ± 0.1^{a}
Chlorophyll a/mg	0.025 ± 0.009^{a}	0.009 ± 0.008^{b}	0.005 ± 0.004^{b}	0 ± 0	0.01 ± 0.01^{a}	0.02 ± 0.02^{a}
Chlorophyll b/mg	0.033 ± 0.008^{a}	$0.01 \pm 0.01^{a,b}$	0.01 ± 0.01^{b}	0 ± 0	0.01 ± 0.01^{a}	0.01 ± 0.01^{a}
K^{+}/g	0.27 ± 0.02^{a}	0.27 ± 0.02^{a}	0.31 ± 0.07^{a}	0.230 ± 0.004^{a}	0.241 ± 0.009^{a}	0.288 ± 0.003^{a}
Na^{+}/mg	57 ± 4^{a}	43 ± 7^{b}	43 ± 1^{b}	$37 \pm 4^{a,c}$	41 ± 4^{a}	$25 \pm 5^{b,c}$

[a,b,c] Different letters in different lines mean statistically significant differences ($p < 0.05$).

Regarding setup B, the higher TPh results were attained by system B2, followed by systems B1 and B3, revealing that the drop-by-drop feeding system with a water line is beneficial for this parameter and that the water height influences the TPh content. Violeta et al. [62] evaluated the TPh content throughout the ripening stage of cherry tomatoes in a hydroponic system. They obtained average values of 28.8 mg GAE/100 g for the pink ripening state and 23.1 mg GAE/100 g for deep red ripeness. Fernandes et al. [2] reported higher tomato TPh content for organic cultivation (56.7 mg GAE/100 g) compared to hydroponic systems (38.6 mg GAE/100 g). They justified it with the soil compaction and availability of nutrients, which influence the TPh content. In the present study, the hydroponic systems were fed with NS from pretreated CWW and supplemented with macro and micronutrients, which should ensure the adequate availability of nutrients to achieve the desired TPh content.

The antioxidant activity, which is the ability to inhibit the oxidation process [63], was evaluated through FRAP and TEAC. FRAP measures the reducing potential, which increases with the TPh content in the sample [60]. Within setup A, no significant differences were found between the average FRAP results of the three systems, although a slightly lower value was attained by A3. In contrast, significant differences were found within Setup B, with the B2 fruit presenting the highest FRAP value. This suggests that plants with a higher availability of nutritive solutions have higher antioxidant capacity. Similar FRAP results were found by García-Valverde et al. [64] when studying the influence of ripening on the cherry tomato antioxidant activity and by Jesús Periago et al. [65], who investigated the cultivation of tomatoes using a hydroponic fertigation system in a commercial greenhouse, all disclosing a direct relation between FRAP and TPh content. Through a different methodology, TEAC determines the ability to capture stable radical species [66], usually increasing with the maturation state of the fruit [67]. Within setup A, although no significant differences were found between the average TEAC results of the three systems, an opposite relation was observed between TEAC and M_{index}, being that the highest TEAC value was found for the system with the lowest M_{index} (A3). This result may be related to the type of cultivation in potted soil. For setup B, an increase in average TEAC value with M_{index} was observed, consistent with the results usually found in the literature. Overall, it could be seen that the tomato fruit produced by plants with lower water availability in the roots presented higher TEAC antioxidant activity, as reported by García-Valverde et al. [64].

Vitamin C, or ascorbic acid content, is considered an index of the quality of fresh products, ranging between 10 to 260 mg/100 g in tomato fruit [68,69]. In setup A, the highest average value of vitamin C was attained by A2 fruit, showing that a system of tomato plants with free rooting and a higher availability of nutritive solution can be beneficial for the fruit quality. Regarding setup B, a lower average value of vitamin C was found for B3, compared to B1 and B2, supporting the finding that tomatoes produced in hydroponic systems with a higher availability of nutritive solutions have a higher vitamin C content. Vitamin C values similar to those observed in the present study were attained by Vinha et al. [70] (47.2–73.6 mg/100 g) for conventionally produced cherry tomatoes. Nevertheless, lower values have been reported, like those from Figàs et al. [53], ranging from 17.48 to 19.92 mg/100 g for cherry tomatoes produced in open fields.

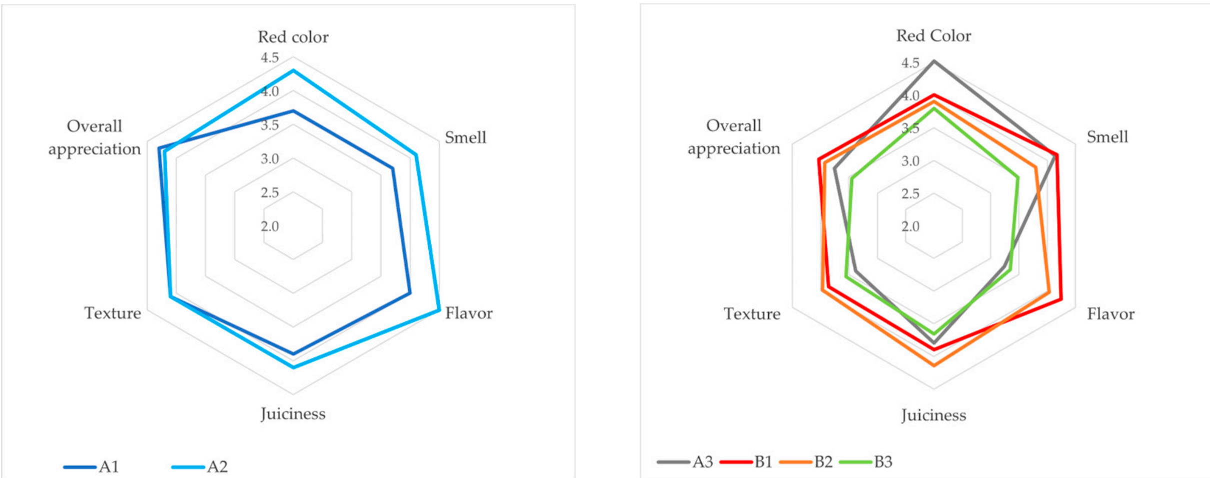
Due to their antioxidant properties, some of the most significant bioactive components of tomatoes are carotenoids, especially lycopene and β-carotene [63]. Lycopene is responsible for the tomato red color [38], and β-carotene, representing about 3 to 7% of the total carotenoid content, is the main provitamin A [59]. The average values obtained for lycopene and β-carotene in fruit from setup A show significant differences between systems A1 to A3, being higher for A3. For Setup B, significant differences are also found in lycopene results from the different systems, disclosing that tomato fruit produced by plants with higher availability of nutritive solution to the roots might have higher lycopene content, contrary to the observed for β-carotene content. Overall, the highest lycopene and β-carotene average results were observed in fruit from system A3, indicating that cultivation with soil can benefit the carotenoid content. This finding agrees with that of Fernandes et al. [2], who observed that lycopene and β-carotene contents in organic cultivation are higher than in hydroponic or semi-hydroponic systems. Although the average lycopene and β-carotene values obtained in this study are lower than those usually reported in the literature, they are similar to those obtained by Sani et al. [71] when evaluating the yield and quality of tomatoes produced in soil with application of Trichoderma and biochar to minimize fertilizer application.

Chlorophyll a and b contents in fruit were also assessed. With the tomato ripening, chlorophyll degradation occurs, and the lycopene and β-carotene content increases, changing the fruit color to red [72]. In fact, high chlorophyll content is associated with the green color and, thus, with the lower stage of maturation. As the tomato fruit in the present study was harvested at the stage of red maturation, chlorophyll a and b contents are very low. Still, it can be observed that in setup A, the lowest average chlorophyll content is associated with the highest average lycopene and β-carotene content (system A3) and, in setup B, the lowest average chlorophyll result matches the highest average value of M_{index} (B1).

Since the tomato fruit is considered a source of minerals, potassium and sodium contents were also evaluated. For potassium, no significant differences were found between the results obtained for the different systems in the two setups. As for sodium, differences were found, indicating that its fruit content depends on the plant root's type of confinement. The average potassium values obtained are similar to those reported by Costa et al. [42], who evaluated the mineral content in different cultivars and at different maturation stages, and with those observed by Gatta et al. [73], when analyzing the effect of applying treated agro-industrial effluent in tomato development on soil.

3.4. Sensory Analysis

The results from the sensory analysis are presented in Figure 2 and in Table S3 (Supplementary Material). In session 1 (Figure 2a), fruit from A2 obtained the highest scores for the parameters evaluated, except for the parameter "Overall appreciation", where the difference in A1 score is minimal and without statistical significance. In session 2, fruit from A3 attained the highest score in "Red color" and "Smell", but the lowest in "Flavor" and "Texture". This high score in "Red color" (4.5) is corroborated by the respective lycopene value (1.15 mg/100 g), the highest found from all the systems studied. From setup B, fruit from B1 scored the highest, although the best score for "Texture" and "Juiciness" was attained by fruit from B2.



(**a**) (**b**)

Figure 2. Sensory characteristics of the cherry tomatoes (*Solanum lycopersicum* var. *cerasiforme*) evaluated in (**a**) Session 1—fruit from systems A1 and A2; (**b**) Session 2—fruit from systems A3, B1, B2 and B3. 5 = extremely pleasant; 4 = pleasant; 3 = indifferent; 2 = unpleasant; 1 = extremely unpleasant.

Concerning the overall evaluation in both sessions, it is highlighted that the highest-scored fruit, in most attributes, was A2, with its highest score for the "Flavor" parameter, followed by A1, indicating that the type of hydroponic system may influence the tomato sensory properties. In a study performed by Constantino et al. [74], the sensory characterization of tomato cultivars involved the evaluation by consumers and chefs, comprising parameters like size, shape, color, aroma, flavor, texture and global acceptance. Both consumers and chefs showed a preference for cultivars, taking into account the flavor, which depends on parameters like TSS and TA. The fruit from system A1 presented the highest TSS content, confirming the evaluators' preference concerning the flavor. The lowest-scored fruit was one from the B3 system (hydroponic system of deep-bed tomato plants), followed by B1 and B2. Still, in parameters like flavor and smell, the B1 fruit score was above 4, indicating acceptability by the panelists. When applying delactosed whey permeate (DWP) treatment as a potential washing agent for fresh tomatoes, Ahmed et al. [75] found that attributes like the aroma and the texture were retained better in DWP-treated tomatoes than chlorine-treated tomatoes during storage.

3.5. Characterization of the Final Treated Effluent

Table 6 presents the medium characterization of the suspensions collected after being recirculated in setups A and B. Compared with the characterization of the initial nutrient solution presented in Table 2, it can be seen that although pH did not vary significantly, there was an increase in EC, TDS and salinity, mainly in setup A, which is likely due to water evaporation and/or water utilization by the plants. BOD_5 decreased mainly because there was no organic matter, as can be seen by COD concentration. The different forms of nitrogen and phosphorus were also reduced due to the uptake by the plants. Potassium presented a small increase, likely due to water evaporation and excessive utilization in preparing the nutritive solution. Nevertheless, the final effluent is in accordance with the environmental limit values for discharge in surface waters, according to Portuguese legislation [76].

Table 6. Physicochemical characterization of the different nutritive solutions, after utilization in setups A and B, presented as medium values of the effluents collected during assays (mean value ± standard deviation, $n \geq 3$).

Parameter	Setup A	Setup B
pH (Sorensen)	8.1 ± 0.5	8 ± 1
DO/mg L^{-1}	6 ± 1	6.5 ± 0.7
EC/mS cm^{-1}	6 ± 2	3.7 ± 0.5
TDS/g L^{-1}	3 ± 1	1.9 ± 0.3
Salinity/PSU	3 ± 1	2.0 ± 0.3
BOD_5/mg L^{-1}	1.6 ± 0.9	5 ± 2
COD/g L^{-1}	0.05 ± 0.02	0.08 ± 0.02
$[K^+]$/g L^{-1}	0.3 ± 0.1	0.2 ± 0.1
P_{total}/mg L^{-1}	12 ± 5	5 ± 1
Total hardness/g$CaCO_3$ L^{-1}	0.49 ± 0.04	0.7 ± 0.2
AN/mg L^{-1}	1.2 ± 0.7	–
TKN/mg L^{-1}	4.2 ± 0.9	1.1 ± 0.5

4. Conclusions

CWW pretreated with immediate one-step lime precipitation, followed by natural carbonation, was successfully utilized as a nutritive solution in the hydroponic culture of cherry tomatoes, thus promoting agro-industrial effluent reutilization and contributing to lower amounts of freshwater and nutrient consumption by cultivars. Two different hydroponic configurations were utilized to evaluate the importance of the tomato root confinement and the level of feed solution near the root. Table 7 summarizes the scores of the different hydroponic systems regarding some of the most relevant parameters for tomato characterization, namely, tomato marketable production, content in antioxidants, vitamins and minerals, and overall appreciation in sensory analysis. In each parameter, only the three most scored hydroponic systems are mentioned. One of the most relevant parameters is the increased number and weight of tomato fruit per plant in the deep-bed system B3, which is considerably high (Tables 3 and S1). Also, the maximum marketable weight per plant was 682 g for B3, 540 g for A1, and 527 g for A2, with A2 presenting the highest median. However, regarding the marketable diameter, B3 presented the worst result of all the systems. This shows that the increase in quantity in system B3 was accompanied by a decrease in tomato size. Since this work refers to cherry tomato, which is not adequate for tomato preparations, like juices or canned fruit, due to its high peels and seeds mass ratio to pulp, other parameters may be so or more important than quantity. In fact, considering the overall appreciation by a consumer panel, A1 and A2 had the highest scores, followed by B1.

Table 7. Summary of the scores of the different hydroponic systems regarding the most relevant parameters for tomato characterization. ✓✓✓ Most scored; ✓✓ 2nd most scored; ✓ 3rd most scored.

Parameter	**Setup A**			**Setup B**		
	A1	**A2**	**A3**	**B1**	**B2**	**B3**
Total marketable weight/plant	✓✓	✓				✓✓✓
Total fruit	✓	✓✓				✓✓✓
Marketable fruit	✓	✓✓				✓✓✓
Marketable diameter	✓✓	✓✓✓	✓			
M_{index}	✓✓✓	✓		✓✓		
F_{index}	✓✓✓	✓✓	✓			
Firmness			✓✓✓	✓✓	✓✓	
TPh	✓✓	✓✓		✓✓	✓✓✓	
Vitamin C		✓✓✓		✓✓✓	✓	
Lycopene	✓✓	✓	✓✓✓			
K^+	✓	✓	✓✓✓			✓✓
Na^+	✓✓✓	✓✓✓		✓		
Overall appreciation	✓✓✓	✓✓✓		✓		

Regarding antioxidant TPh, A3 led to lower average values when compared to A1 and A2, showing the advantage of hydroponics over cultivation in pots with soil. As for setup B, the drop-by-drop feeding system with a water line presents better results, showing that the water height influences TPh concentration. On the other hand, system A3 presents increased contents of vitamins and minerals. Concerning the liquid effluents obtained from setups A and B, the final physicochemical characteristics are similar, with both in accordance with the environmental limit values for discharge in surface waters according to Portuguese legislation. Alternatively, these effluents can be reutilized in new hydroponic cultures as dilution water, thus avoiding the utilization of fresh groundwater, leading to a circular economy in water consumption and sustainable development.

One of the main limitations of the utilization of CWW in the hydroponic culturing of tomatoes is the transportation of this effluent to the hydroponic farm. On the other hand, this type can serve as an example for the cheese industries, showing the possibility of producing other food products by vertical diversification, increasing the variety of marketable products, and utilizing the resulting effluent from hydroponics to irrigate the factory's green spaces. In the near future, agroindustry must consider these types of initiatives; otherwise, we all must pay for the consequences of a degraded environment.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/su16010315/s1, Table S1. Nutritive solution supplementation throughout the development phase of the tomato plants. Table S2. Characterization of the plants and fruit grown in the different hydroponic systems fed with nutritive solution from pretreated CWW (mean value ± standard deviation, $n \geq 10$). Table S3. Sensory characteristics of the cherry tomatoes (Solanum lycopersicum var. cerasiforme) produced in the different hydroponic systems, evaluated in two different sessions. 5 = extremely pleasant; 4 = pleasant; 3 = indifferent; 2 = unpleasant; 1 = extremely unpleasant (mean value ± standard deviation, $n \geq 30$).

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Abbreviations

A_{453}	absorbance at 453 nm
A_{505}	absorbance at 505 nm
A_{645}	absorbance at 645 nm
A_{663}	absorbance at 663 nm
AN	ammonia nitrogen
BOD_5	biochemical oxygen demand
CA	citric acid
CB	carbonation
COD	chemical oxygen demand
CWW	cheese whey wastewater
DM	dry matter
DO	dissolved oxygen
DWP	delactosed whey permeate
EC	electrical conductivity
F_{index}	flavor index
FRAP	ferric reducing antioxidant power
GAE	gallic acid equivalent
IOSL	immediate one-step lime precipitation
LECA	light expanded clay aggregates
Max	maximum
MED	median
Min	minimum
M_{index}	maturity index
NS	nutritive solution
P_{total}	total phosphorus
PVC	polyvinyl chloride plastic
TA	titratable acidity
TDS	total dissolved solids
TEAC	Trolox equivalent antioxidant capacity
TKN	total Kjeldahl nitrogen
TPh	total phenolic compounds
TSS	total soluble solids
UN	United Nations
UV-Vis	ultraviolet–visible

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