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# PRODUÇÃO E USO DA ÁGUA NO CALÁDIO FERTIRRIGADO COM ÁGUA RESIDUÁRIA DO PROCESSAMENTO DO AÇAÍ NA REGIÃO AMAZÔNICA

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## 1 RESUMO

No estado do Pará o fruto açaí (*Euterpe oleracea* Mart.) é um dos principais alimentos consumido pela população, sendo a região indicada como a maior produtora e consumidora de açaí do país. O processo de despolpamento do açaí gera uma água residuária rica em nutrientes a qual pode ser reutilizada na agricultura. O trabalho avaliou as condições hídricas do *Caladium* sp. sob diferentes diluições da água residuária do açaí no município de Tomé-Açu, Pará. O experimento foi conduzido no campus da Universidade Federal Rural da Amazônia. O delineamento experimental foi inteiramente casualizado (DIC) com quatro repetições e 13 tratamentos fracionados, com variação de bulbos (1, 2, 3, 4 e 6) e porcentagens de água residuária (0, 25, 50 e 100%). Foi utilizado um sistema de fertirrigação por gotejamento e as condições hídricas foram avaliadas por meio do índice de estresse hídrico, consumo e eficiência do uso de água residuária pela cultura. O uso da água residuária do processamento do açaí utilizada para a fertirrigação apresentou maiores benefícios para os parâmetros estudados nas porcentagens de 0, 25 e 50% e com variação de bulbos de 3, 4 e 6 para o cultivo do caládio.

**Palavras-chave:** *Euterpe oleracea* Mart., *Caladium* sp., irrigação por gotejamento.

**CARVARLHO, R. F.; JESUS, F. L. F.; OLIVEIRA, J. C.; PACHECO, A. B.; SANCHES, A. C.; LISBOA, C. F.**
**WATER PRODUCTION AND USE IN THE CALADIUM FERTIRRIGED WITH WASTEWATER FROM AÇAÍ PROCESSING IN THE AMAZON REGION**

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## 2 ABSTRACT

In the state of Pará, the açaí fruit (*Euterpe oleracea* Mart.) is one of the main foods consumed by the population, being the region indicated as the largest producer and consumer of açaí in the country. The açaí pulping process generates a nutrient-rich wastewater that can be reused in agriculture. The present work evaluated the water conditions of Caladium sp. under different dilutions of açaí wastewater in the municipality of Tomé-Açu, Pará. The experiment was conducted at the campus of the Rural Federal University of Amazônia. The experimental design was completely randomized (DIC) with four replications and 13 fractional treatments, with variation of bulbs (1, 2, 3, 4, and 6) and percentages of wastewater (0, 25, 50, and 100%). A drip fertigation system was used and the water conditions were evaluated through the water stress index, consumption, and efficiency of wastewater use by the crop. The use of wastewater from the processing of açaí used for fertigation showed greater benefits for the parameters studied in the percentages of 0, 25, and 50% and with the variation of bulbs of 3, 4, and 6 for the cultivation of caladium.

**Keywords:** *Euterpe oleracea* Mart., *Caladium* sp., drip irrigation.

## 3 INTRODUCTION

The Acará Valley, located in northeastern Pará, boasts a wide variety of plant crops, with agribusiness production based on crops grown locally, such as the açaí berry (*Euterpe oleracea* Mart.). This fruit is widespread and can be found throughout the state, resulting in many commercial establishments processing açaí.

Açaí is an annual crop, with the highest harvest period occurring between October and November (summer harvest) and the lowest harvest period occurring from June to December (winter harvest). In January, February and June, the açai off-season occurs (HOMMA *et al*., 2006).

During the processing of açai palm fruit, wastewater is produced, which is often improperly disposed of, causing pollution to the receiving body (SOARES; CRUZ; SILVA, 2019). Notably, the state of Pará does not have its own current legislation on the discharge of effluents into water bodies (MORAIS; SANTOS, 2019). Wastewater can result from the combination of domestic effluents, commercial and institutional establishments, industrial waste, and rainwater from urban drainage, as well as effluents from agricultural activities (VAN HAANDEL; VAN DER LUBBE, 2012).

Owing to the environmental impact of improper wastewater disposal, alternative and mitigating measures are being adopted to reuse this water. One alternative is its use in agriculture, as this water contains nutrients (N, NA, P, Ca, K, Mg, B, and Cl), which are essential for crop development (CHEN *et al*., 2013; PEDRERO *et al*., 2010), especially caladium. According to Jesus *et al*. (2020), wastewater for irrigation purposes offers benefits for agricultural production; however, cautious measures are required for its reuse.

Several crops have been the target of research using agro-industrial wastewater for the cultivation of various species through fertigation. Bezerra *et al* . (2019), when cassava wastewater (*Manihot esculenta*) was used in the cultivation of marandu grass (*Urochloa brizantha*), an increase in pH and K and P concentrations in the soil (depth of 10--20 cm) was observed. These results were also observed in the study by Sena; Ferreira; Silva (2020), who, when observing changes in soil chemical attributes after the application of wastewater, reported increases in pH and K and P concentrations at depths of 0--20 cm. The reuse of effluents with the addition of fertilizers has been a way of replacing water in conventional hydroponic gladioli cultivation establishments (BIZARI *et al*., 2018).

A strategic crop for the reuse of wastewater from açaí processing in the Acará Valley could be caladium (*caladium* spp.), as it has commercial value and is an ornamental plant. This crop is popularly known as tinhorão (GERON, 2014), Taiá, or Coração-de-Jesus (Heart of Jesus). It is part of the Araceae family, has a perennial life cycle, is considered a bulbous species, is native to Brazil, and is present throughout almost all of South and Central America (SANTOS, 2011).

Furthermore, Horsfall and Spiff (2004), when studying the agronomic development of *Caladium bicolor* as an agent for removing cationic pollutants from wastewater, concluded that this crop is an excellent biosorbent for reducing heavy metals in contaminated water and can act as an alternative adsorbent to conventional media. Sánchez *et al*. (2015), who studied the same crop under different doses of irrigation wastewater, reported that fertigation with wastewater positively influenced the starch concentration in tubers at different physiological stages and the protein concentration. These results were corroborated by those of Cuong and Loan. (2017), who also studied the performance of *Caladium bicolor* in treatments irrigated with wastewater in humid lands and reported faster growth (shoots and roots) and high efficiency for treatments subjected to fertigation with wastewater.

With the vast number of small farmers living in the Acará Valley, *the cultivation of this species* would present an opportunity for additional income, as its commercialization is valued in this region, and production can be sold to local businesses. Over the years, the market for ornamental plants and flowers has been gradually growing. In 2013, sales reached a total of R$4.8 billion, and its gross production value (GPV), which represents the amount actually received by producers, reached R$1.37 billion in 2012 (JUNQUEIRA; PEETZ, 2013).

The use of wastewater from açaí processing for ~~fertigation~~ enables ~~the~~ correct disposal of this effluent, thus promoting the preservation of water resources, a reduction in the cost of caladium production and increased knowledge.

This study evaluated the water conditions used for the cultivation of *Caladium* sp. under dilutions of wastewater from the processing of açaí fruit and different varieties of bulbs in pots in the Tomé-Açu region, northeastern Pará.

## 4 MATERIALS AND METHODS

The experiment was carried out between 12/01/2021 and 01/03/2021 at the Federal Rural University of the Amazon on the Tomé-Açu Campus (2° 24' 08" S and 48° 09' 59" W), which is located in the Northeast Pará Microregion (SANTOS *et al*., 2019). The climate of the region, according to the Köppen–Geiger classification, is mesothermal and humid and of the Ami type, with a relative humidity of approximately 85% and an average annual temperature of 26°C (SANTOS *et al*., 2019).

The caladium was grown in a protected environment, the roof of which was covered with transparent polyethylene with a thickness of 150 microns and shaded with cloth (50% shading) to avoid interference from rainfall.

To establish the culture in the pots, caladium bulbs collected from an agroforestry system of similar sizes were used to maintain homogeneity. After collection, the bulbs were grown in 14 pots approximately 1 dm³ in volume using substrates collected from a family farm compost bin. The physical and chemical characteristics of the substrate are presented in Table 1, along with the analysis of wastewater collected from establishments located in the vicinity of Tomé-Açu.

**Table 1.** Physical and chemical characterization of the substrate, water and açaí wastewater used in caladium cultivation, Tomé-Açu – Pará, 2021.

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **SOIL CHARACTERIZATION** | | | | | | | | | | | |
| Sand | | silt | | Clay | | | | | | | |
| ------------------------------ (%) ------------- | | | | | | | SANDY SOIL | | | | |
| 58 | | 8 | | 34 | | | | | | | |
| pH | Al | Here | Mg | K | P | H+Al | T | t | V | m | MO |
| C to Cl 2 ------ (cmol c /dm 3 ) ------- ---- (mg/dm 3 ) ---- ------- (cmol c dm -3 ) ----- (%) ---------- | | | | | | | | | | | |
| 3.8 | 0.70 | 0.2 | 0.1 | 0.08 | 20.0 | 6.1 | 6.48 | 1.08 | 5.86 | 35.19 | 2.3 |
| **WATER CHARACTERIZATION** | | | | | | | | | | | |
| Water source | N | P | K | Here | Mg | S | Ass | Faith | Mn | Zn | In the |
| | --------------------------------------------- mg L $^{-1}$ ----------------------------------------- | | | | | | | | | | |
| Natural | 11.8 | 0.2 | 8.0 | 25.7 | 29.4 | 2.6 | 0.01 | 4.1 | 0.1 | 0.1 | 10 |
| Residual | 86.6 | 14.0 | 172.0 | 7.2 | 1.9 | 69.2 | 0.01 | 0.93 | 0.6 | 0.04 | 100.0 |
| Water source | pH | | | CE | | | RAS | | | SST | |
| | - µS cm- $^{1}$ | | | - ppm | | | | | | | |
| Natural | 6.93 | | | 101.5 | | | 1.1 | | | 50.0 | |
| Residual | 5.56 | | | 904.3 | | | 11.7 | | | 451.7 | |

Al: Aluminum; Ca: Calcium; Mg: Magnesium; K: Potassium; P: Phosphorus; N: Nitrogen; S: Sulfur; Fe: Iron; S: Sulfur; Cu: Copper; Mn: Manganese; Zn: Zinc; Na: Sodium; H+Al: Potential acidity; T: Cation exchange capacity (CEC) at pH 7.0; t: Effective CEC; V: Base saturation; m: Aluminum saturation; MO: Organic matter; CE: Electrical conductivity; RAS: Sodium adsorption ratio; TSS: Total suspended solids.

Wastewater was collected from açaí sales establishments located in the municipality of Tomé-Açu. The chemical characteristics of natural water (urban supply water) and wastewater are presented in Table 1.

The sodium adsorption ratio (RAS) values were calculated via Equation (1).

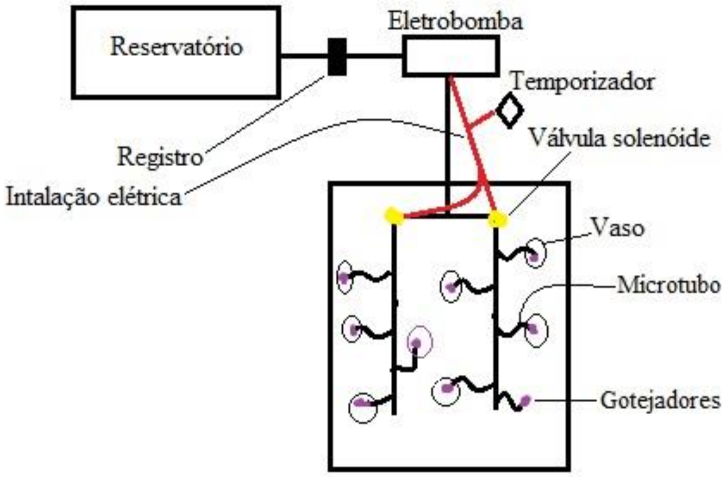
$$\mathrm{RAS} = \frac{Na}{\sqrt{\frac{\mathrm{Ca+Mg}}{2}}} \qquad (1)$$

where:
Na = Sodium content in water, mmol $_c$ L $^{-1}$;
Ca = Calcium content in water, mmol $_c$ L $^{-1}$; and
Mg = Magnesium content in water, mmol $_c$ L $^{-1}$.

The experimental design used was completely randomized (DIC) in a 5x5 fractional factorial scheme, with the factors being five quantities of bulbs at planting (1, 2, 3, 4 and 6 bulbs per pot) and five percentages of wastewater for fertigation (0, 25, 50, 75 and 100%), with four replicates, totaling 52 experimental units. The fractionation was performed on the basis of the central compound adapted from Littell and Mott (1975), which reduces the treatments of the conventional factorial scheme from 25--13 treatments, which presented the following combinations (number of bulbs - % of wastewater): 1--0, 1--50, 1--100, 3--20, 3--60, 5--0, 5--40, 5--80, 7--20, 7--60, 9--0, 9--40, and 9--80.

An independent drip irrigation system was installed for each wastewater treatment, consisting of a 100 dm3 reservoir for each water dilution studied; a 2.9 mca electric pump; polyvinyl chloride (PVC) pipes for the main, branch and lateral lines and accessories; a return to the excess flow reservoir; microtubes; and adjustable drippers with an average flow rate of 0.3 $dm^3$ $h^{-1}$ (Figure 1).

**Figure 1.** Diagram of fertigation in the experimental area.




The irrigation systems were evaluated for Christiansen's coefficient of uniformity (CUC) and emission uniformity (UE) according to the methodology described by Frizzone *et al*. (2012) (Table 2).

**Table 2. Values obtained from the** Christiansen uniformity coefficient (CUC) and emission uniformity (UE) tests.

| **(% Dilution)** | **0** | **25** | **50** | **75** | **100** |
|---|---|---|---|---|---|
| CUC | 89.61 | 92.97 | 90.23 | 92.52 | 88.85 |
| EU | 81,82 | 90.81 | 84.08 | 82.24 | 81.85 |

The CUC and UE values have shown high efficiency for the fertigation system since Frizzone *et al. (2012) recommended that* microirrigation projects have a UE and CUC above 80%.

Three pots were filled with the substrate and weighed; then, water was added so that the soil was saturated by capillarity, and the water was allowed to drain. When drainage stopped, the pots were weighed again, and the field capacity of each pot was obtained on the basis of this difference (CASAROLI; LIER, 2008; BONFIM-SILVA *et al*., 2011).

To maintain the maximum water retention capacity, 1,054 g was weighed from the pots containing the plants. During the experiment, the pots were weighed, and for those that did not reach this value, the respective dilutions of their treatments were added.

During crop irrigation, water consumption was analyzed through the relationship between evapotranspired water and potential evaporation.

The irrigation system was automated, using timer and solenoid valves, with daily watering and a fixed blade. However, the moisture content in the pots was corrected via the gravimetric method four times during the study (February 2, 2021; February 10, 2021; February 15, 2021; and February 27, 2021).

Fertigation was administered once a day with a fixed blade to maintain the moisture of the substrate close to 80% of its maximum water-holding capacity. Wastewater treatments began after planting and continued until the 40th day after planting.

The stored processing wastewater was periodically monitored in relation to its pH value, electrical conductivity and total dissolved solids (TDS) (Table 3) via a benchtop pH meter model mPA-210 from MS Tecnopon® and a digital TDS® probe.

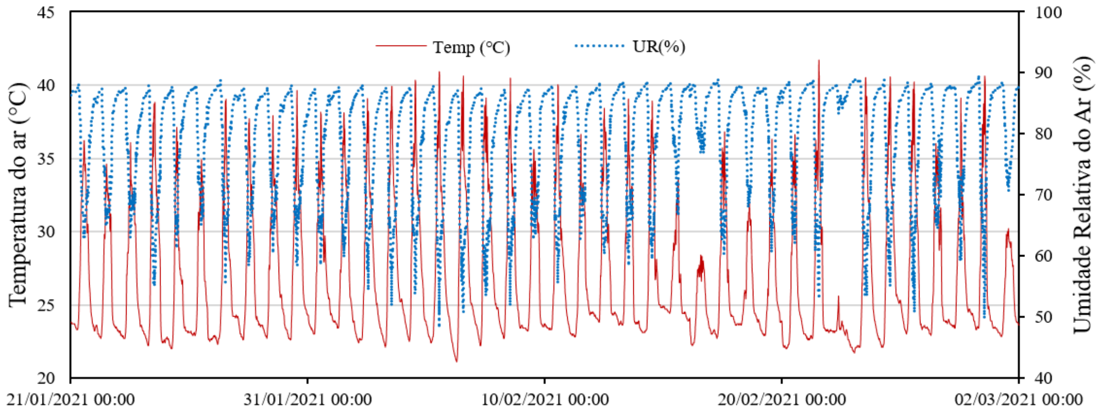
**Table 3. pH, electrical conductivity (EC) and** total dissolved solids (TDS) values of wastewater from açaí processing.

| Dilutions | pH | | | EC (µS/cm) | | | SDT (ppm) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 26/01 | 05/02 | 15/02 | 26/01 | 05/02 | 15/02 | 26/01 | 05/02 | 15/02 |
| 0 | 7.05 | 6.95 | 6.97 | 97 | 102 | 102 | 48 | 51 | 49 |
| 25 | 5.12 | 5.26 | 6.18 | 341 | 315 | 326 | 172 | 156 | 160 |
| 50 | 4.98 | 4.9 | 6.22 | 540 | 518 | 527 | 270 | 258 | 264 |
| 75 | 4.74 | 4.46 | 5.75 | 649 | 623 | 687 | 327 | 312 | 343 |
| 100 | 4.77 | 4.9 | 6.09 | 914 | 883 | 986 | 455 | 444 | 493 |

The parameters analyzed above are of utmost importance, as they provide information on the quality of irrigation water (AYERS; WESTCOT, 1976). Very high pH values can cause corrosion; when very low, they cause problems of incrustation in pipes as a result of chemical precipitation (LIBÂNIO, 2005). EC is a parameter used to observe the salinity level (RIBEIRO; MAIA, MEDEIROS, 2005), whereas SDT is used to observe the formation of biofilms, which can obstruct dripper emitters (SILVA *et al*., 2013).

Thirty-five days after the bulbs were transplanted, between 11:50 AM and 1:00 PM, the leaf temperature was determined via a GOLD-PRO® industrial-type digital infrared thermometer. Two leaves were selected from each pot, one located at the top and the other at the bottom of the plant. The ambient air temperature was obtained for every 10 pots. The data were stored via a thermohygrometer (Bside, model: BTH01) installed in the greenhouse, which ~~was~~ programmed to record readings every ten minutes. The average ambient temperature was calculated (Figure 2), and from these values, the crop's water stress index was determined.

**Figure 2.** Temperature and relative humidity during the experimental period, Tomé-Açu, PA, 2021.




The index used to determine crop water stress according to leaf temperature is the crop water stress index (CWSI). To calculate the CWSI, the methodology described by Jackson *et al. was used*. (1981) was used, according to Equation 2.

$$\text{CWSI} = \frac{(T_c - T_a) - (T_c - T_a)_{LBI}}{(T_c - T_a)_{LBS} - (T_c - T_a)_{LBI}} \qquad (2)$$

where:
CWSI = Crop water stress index.
$T_c$ =Temperature of crop leaves, °C.
$T_a$ = average air temperature, °C.
$(T_c - T_a)_{LBI}$ = lower temperature baseline, corresponding to the difference between the air and crop temperatures without water stress, °C; and
$(T_c - T_a)_{LBS}$ = upper temperature baseline, corresponding to the difference between the air temperature and when the resistance to canopy water loss increases without or corresponding to the dry surface temperature, °C.

After harvesting, botanical separation was performed, distinguishing leaves, petioles, roots, blades, and bulbs. After this procedure, the materials were placed in paper bags and then placed in a forced-air oven at 75°C to dry until a constant mass was obtained. The plants were then weighed on a Latinmax® I-2000 digital scale, and the dry mass of the aerial part (MSPA) and the root system (MSsisRad) were determined.

The dry mass of the aerial part (MSPA), fresh mass of the aerial part (MFPA), dry mass of the root system (MSsisRa), fresh mass of the root system (MFSisRad), percentages of water in the aerial part (PorcAPA), and root system (PorcASR) and dry matter in the aerial part (PorcmsPA) were calculated via Equations 3, 4 and 5, respectively.

•Aerial water percentages (PorcAPA)

$$\text{PorcAPA} = (MFPA - \text{MSPA}) * \frac{100}{MFPA} \qquad (3)$$

• Root system water percentage (PorcASR)

$$\text{PorcASR} = \frac{(MFSisRad - MSsisRad)}{MFSisRad * 100} \qquad (4)$$

•Percentage of dry matter of the aerial part (PorcmsPA)

$$\text{PorcmsPA} = MSPA * \frac{100}{\text{MFPA}} \qquad (5)$$

Efficiency (WUE) was calculated as the ratio between shoot dry mass production (g pot $^{-1)}$ and crop wastewater consumption (dm $^3$ pot $^{-1}$), as exemplified in the equation below:

$$\text{EUA} = \frac{MSPA}{CARes} \quad (6)$$

where:
MSPA = Dry mass of aerial part; and
CARes = Wastewater consumption by the crop.

The results obtained were statistically analyzed with the aid of SISVAR® *v.5.7* *software* (FERREIRA, 2011), with tests at probability levels of 5, 1 and 0.1%; in cases of significance, linear and quadratic polynomial regression analyses were performed.

## 5 RESULTS AND DISCUSSION

### 5.1 Summary of analysis of variance

The variables analyzed presented different levels of significance for the factors number of bulbs, wastewater and their interaction (Table 4).

**Table 4.** Summary of analysis of variance (ANOVA) and coefficient of variation by variable (cv).

| FV | Number of Bulbs (B) | Wastewater (A) | B*A | CV (%) |
|---|---|---|---|---|
| | Mean Square | | | |
| CWSI | 0.01 ns | 0.07*** | 0.002 ns | 21.67 |
| MFPA | 693.92*** | 352.82*** | 67.45 ns | 32.38 |
| MSPA | 6.35*** | 4.07*** | 0.66 ns | 30.14 |
| MSsisRad | 94.8*** | 13.15*** | 0.01 ns | 23.8 |
| PorcAPA | 2.37** | 5.31*** | 0.01 ns | 0.77 |
| PorcmsPA | 2.38** | 5.31*** | 0.01 ns | 7.84 |
| PorcASR | 47.84*** | 20.49** | 0.01 ns | 2.43 |
| CARes | 0.26* | 0.38** | 0.18 ns | 11.14 |
| USA | 0.71*** | 0.44*** | 0.01 ns | 29.3 |

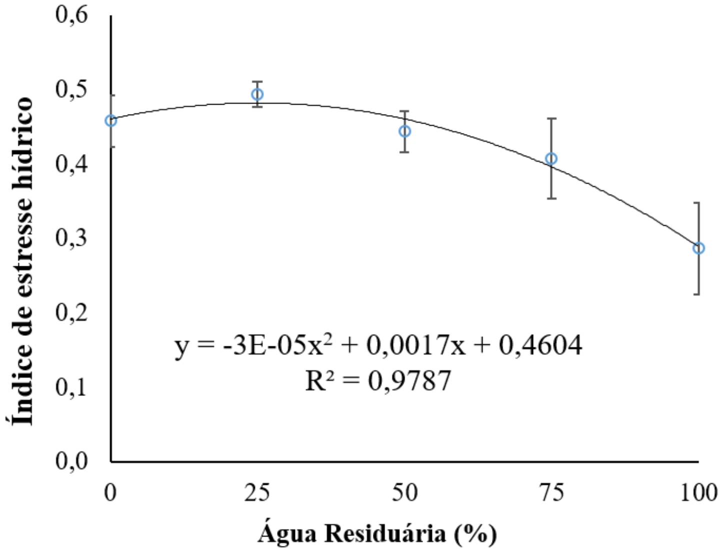
*** significant at the 0.1% probability level ($p > 0.01$), ** significant at the 1% probability level ($p < 0.01$), * significant at the 5% probability level ($0.01 =< p < 0.05$) and ns not significant ($p >= 0.05$). FV: source of variation, MFPA: fresh mass of shoots, MSPA: dry mass of shoots, MSsisRad: root system dry mass, PorcAPA: percentage of shoot water, PorcmsPA: percentage of shoot dry matter, PorcASR: percentage of root system water, CARes: wastewater consumption, CWSI: water stress index and EUA: water use efficiency.

All variables analyzed for the caladium crop presented significant differences in isolation for both factors: bulb density at planting (number of bulbs) and percentage of residual water in fertigation (residual water), except for the variable crop water stress index (CWSI), which presented significance only for the percentage of residual water (Table 4).

### 5.2 Water stress index (CWSI)

The crop water stress index significantly differed with respect to the wastewater factor according to the quadratic regression model (Figure 3).

**Figure 3.** Quadratic regression model for the water stress index (CWSI).




The maximum water stress point was observed in the 25% wastewater treatment (Figure 3), with minimum and maximum CWSI values of 0.4498 and 0.4842, respectively. Notably, the water stress that occurs mainly affects water consumption and phytomass production. In this sense, water stress can influence several plant processes, including water potential and canopy temperature. Therefore, these identifications have been used as useful tools in characterizing the water status of crops (FERNANDES; TURCO, 2001).

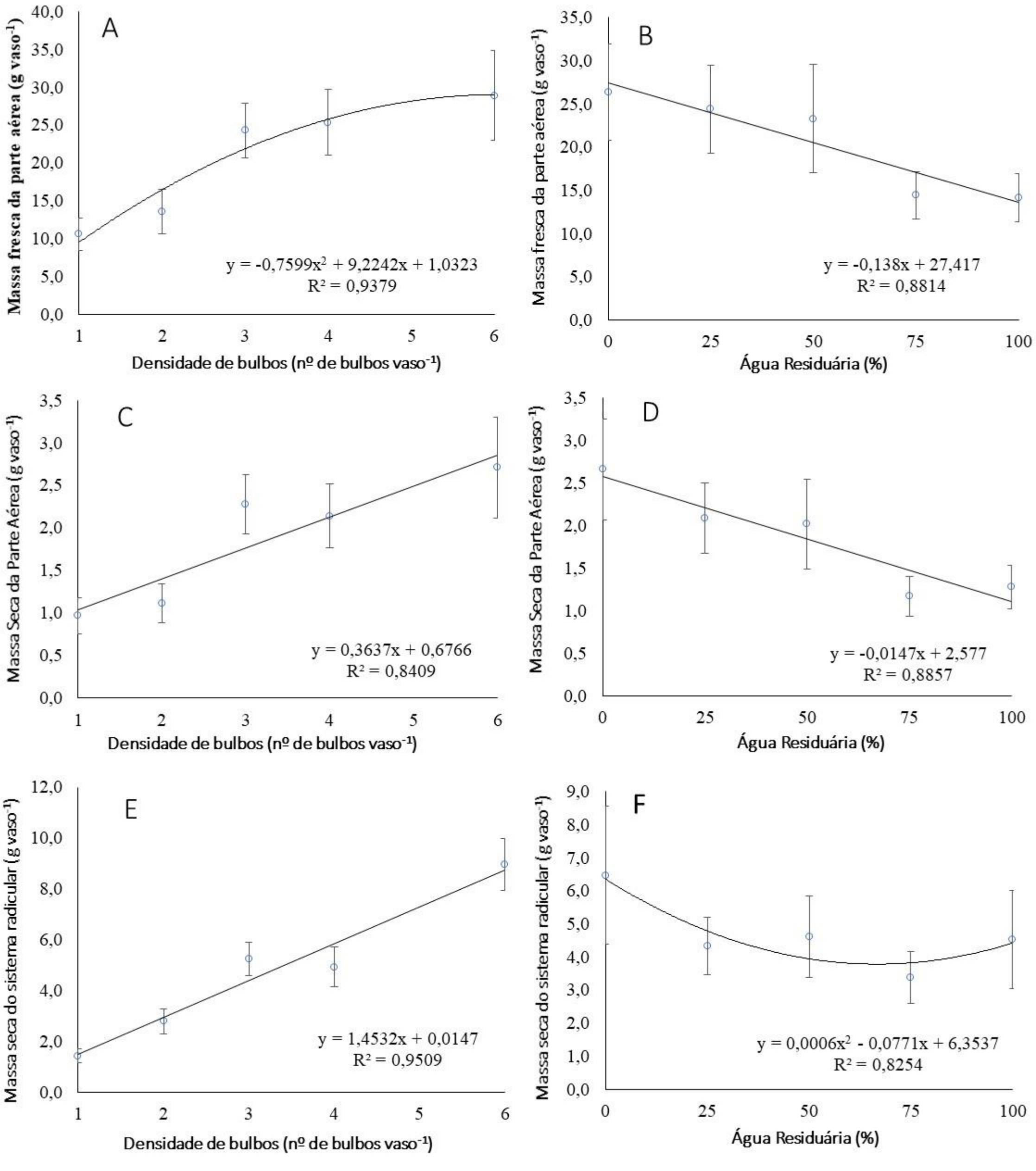
According to Jackson *et al*. (1981), plant development conditions are considered adequate when the crop water stress index corresponds to 0.2 £ CWSI < 0.4 and reasonable when 0.1 £ CWSI < 0.6. Thus, the CWSI values vary proportionally to the soil moisture deficit. As observed in this study, this index denoted adequate development in wastewater of 50, 75, and 100% (Figure 3), and at other times, the development conditions of the caladium were considered reasonable.

According to Fageria (1989), in situations of water stress, plants seek alternatives to reduce water consumption, mainly reducing their transpiration and decreasing their leaf area. Souza *et al*. (2019) reported that water stress also causes a reduction in leaf dry matter. Jones *et al*. (1997) concluded that the use of the CWSI can be convenient for indicating the need for irrigation, despite being less suitable for indicating the amount of water needed.

### 5.3 Fresh and dry matter

The analysis of variance revealed a significant difference in the bulb density and wastewater factors. For the bulb density factor, the variables shoot dry mass and the root system were adjusted to the linear model of increasing regression (Figure 4, graphs C and E). Moreover, the variable shoot fresh mass was adjusted according to the quadratic regression model (Figure 4A), and the maximum production efficiency was reached for the crop with a variation of 6 bulbs (29.02 g pot $^{-1}$), whereas the minimum production (9.49 g pot $^{-1}$) was reached for the crop containing 1 bulb.

**Figure 4.** Average values for the fresh mass of the aerial part (graphs A and B), dry mass of the aerial part (graphs C and D) and dry mass of the root system (graphs E and F) in relation to the factors bulb density and wastewater (%) of açaí processing, Tomé-Açu, PA.




For these variables, high phytomass production is due to the greater number of bulbs implanted and, consequently, greater dry mass of the roots. Tuberous roots, such as those of caladium, play a crucial role in plant development because of their ability to transport and absorb nutrients, thus providing, over a given period, greater mass production per area.

In a study with sweet potato that aimed to study nutrient absorption and the distribution of fresh and dry mass, Echer, Dominato, and Creste (2009) confirmed that tuberous roots are a large source of nutrient export. In this same study, the authors achieved a dry mass production of 6,290 kg ha $^{-1}$.

Smaller populations generally produce low yields of MSPA (Figure 4A), MFPA (Figure 4C), and MSsisRad (Figure 4E). In contrast, a proportional increase in bulb density was observed in relation to MSPA (Figure 4A), MFPA (Figure 4C), and MSsisRad (Figure 4E). However, Resende and Costa (2006) highlighted that in crops with a high number of plants, there is a reduction in bulb production, with a decrease in size and the occurrence of nonuniformities. This factor was not detected in this study, suggesting that the maximum number of bulbs grown in pots was not reached for this reduction in production.

When observing the wastewater factor from açaí processing in the context of caladium cultivation, the MFPA and MSPA variables were adjusted to the linear model of decreasing regression (Figure 4, graphs B and D), suggesting that the production of caladium is reduced in proportion to the increase in the concentration of wastewater.

The relationship between MSsesRad and wastewater was adjusted via a quadratic regression model, in which the highest and lowest production values, with 0 and 50% wastewater, were 6.35 g vessel $^{-1}$ and 3.35 g vessel $^{-1}$, respectively, indicating that natural water (supply water) presented the best performance in the production of this variable.

Higher production of MFPA (2.66, 2.09 and 2.02 g pot $^{-1}$) and MSPA (26.38, 24.37 and 23.29 g pot $^{-1}$) was observed at dilutions of 0, 25 and 50% wastewater, indicating the influence of the higher concentration of wastewater from açaí processing on reducing the production of caladium. Thus, a low concentration of wastewater, up to 50%, did not cause great damage to crop development.

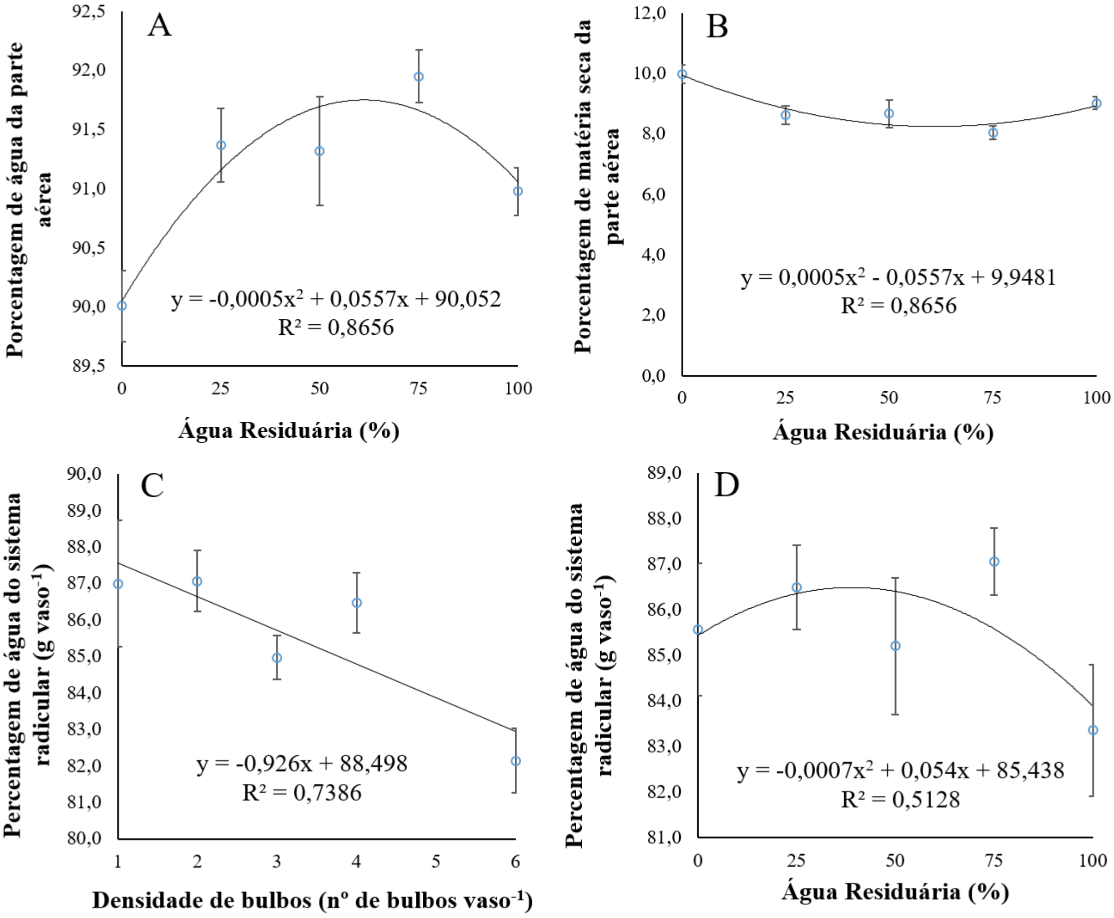
The reduction in production under higher dilution percentages and under the use of 100% wastewater can be explained by the value of the sodium adsorption ratio of the wastewater (11.7), which was much higher than that of the supply water (1.1) (Table 1), resulting in chemical changes in the water and soil aggregates, hindering water percolation into the soil.

According to Telles and Costa (2010), salt and sodium levels in relation to calcium and magnesium levels can compromise soil water infiltration. Silva (2018) emphasized that the soil water infiltration capacity can decrease with increasing sodium adsorption ratio (RAS) and increase with increasing salinity. Irrigation with waters high in sodium can result in sodic soil, leading to the displacement of adsorbed calcium and magnesium, resulting in colloid dispersion (ALLISON, 1964; FULLER, 1967). Ayers and Westcot (1976) reported that the main problem with excess salts in irrigation water is their deposition in the soil, as salts can accumulate in the soil as water evaporates or is consumed by crops. Under these circumstances, the Water Research Council (1989) considers the unviability of arable land due to the decrease in production and death of salt-sensitive plants caused by soil sodification. According to the values presented in Table 1, when analyzing wastewater from açaí processed for irrigation purposes, it receives the C3 S2 classification; therefore, according to the Richards (1954) classification, it is a high-salinity water and cannot be used in soils with poor drainage because it has a medium sodium content. It should be used in sandy soils or in organic soils with good permeability, since sodium in fine-textured soils represents a hazard.

## 5.4 Percentages of shoot water, shoot dry matter, and the root system

The percentage of water in the aerial part and the percentage of dry matter in the aerial part of the root system significantly differed with respect to wastewater dilution. The results of the regression analysis for these variables are shown in Figure 5.

**Figure 5.** A) Percentage of water in the aerial part and B) percentage of dry matter in the aerial part as a function of wastewater, C) percentage of water in the root system as a function of bulb density and D) wastewater, Tomé-Açu, PA, 2021.



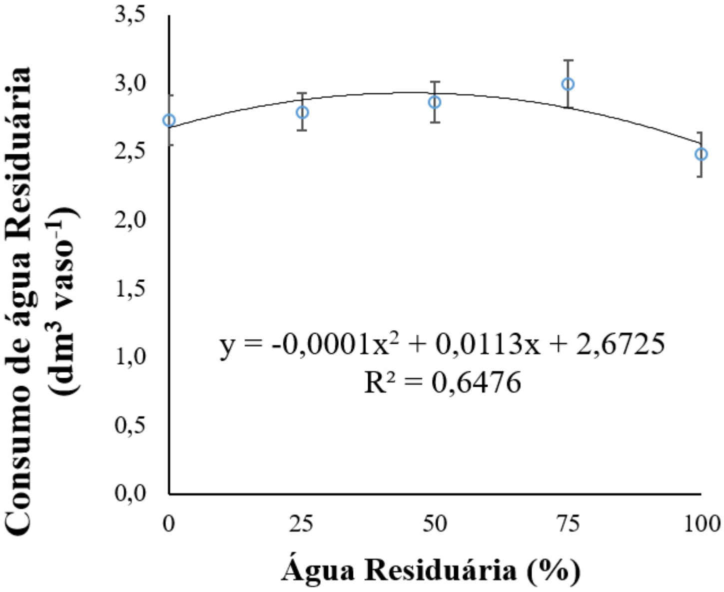

The results of the quadratic regression for the effects of the wastewater factor on the percentage of water in the aerial part and the percentage of water in the root system are presented in Figure 5 and graphs A and D, respectively. The highest PorcAPA was observed in the 75% wastewater, reaching 91.47% (Figure 5A), whereas for PorcmsPA, the highest value was 9.94%, which was observed in natural water (0%) (Figure 5B). Moreover, PorcASR (Figure 5D) in relation to wastewater (%) presented a maximum value of 86.38% and a minimum value of 83.38%.

With the increase in the number of cultivated bulbs, PorcASR decreased linearly (Figure 5C), which can be explained by competition for water and nutrients between plants. According to Castro and Garcia (1996), for competition to occur between plants of the same species, sufficient overlap of the niches of the evolved individuals is necessary so that all utilize the same resources. Rockenbach *et al.* (2018) reported that competition between plants is also responsible for changes in the secondary metabolism of species, which could explain this decline in the PorcASR (Figure 5C) and PorcAPA (Figure 5A) variables. According to Nobre *et al.* (2009), the aerial part of the plant grows until water absorption by the roots becomes limiting; conversely, roots grow until their demand for photoassimilates from the aerial part equals the supply.

### 5.5 Wastewater consumption and efficiency

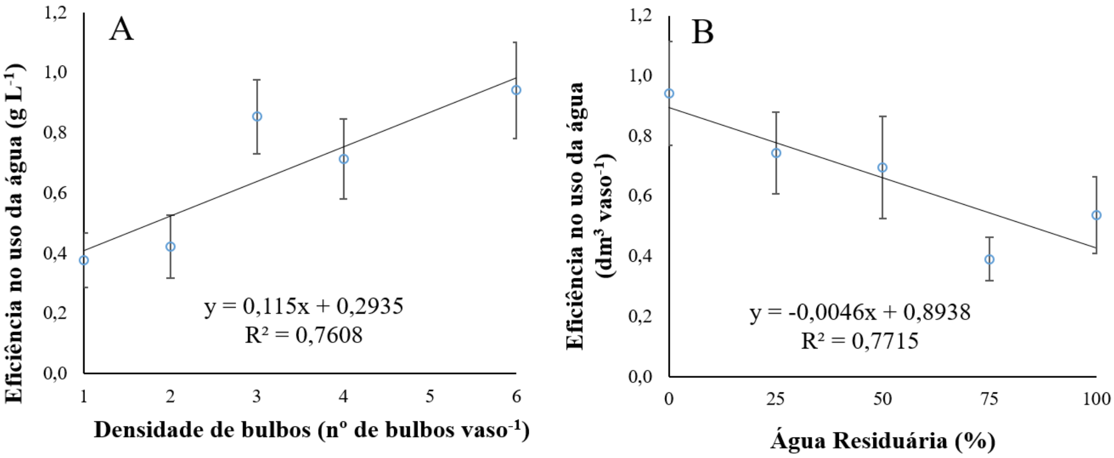
Figure 6 shows the regression of the wastewater consumption (CARes) variable for the caladium crops as a function of the dilution of wastewater from açaí processing. At the dilution point of 56.5% wastewater, the highest water consumption was observed (3 $dm^3$ $pot^{-1}$). Sandri; Matsua; Testezlaf (2007) studied the development of Elisa lettuce in different wastewater irrigation systems. The authors observed a greater percentage of plants with the addition of wastewater.

**Figure 6.** Wastewater consumption from açaí processing as a function of the wastewater applied (%) by the caladium plants growing in pots, Tomé-Açu, PA, 2021.




The EUA was significantly different for the wastewater and bulb density factors (Figure 7).

**Figure 7.** Efficiency of wastewater use from açaí processing (USA) as a function of wastewater and number of caladium bulbs, Tomé-Açu, PA, 2021.



When observing the wastewater variable (Figure 7A), the effect of this variable on caladium cultivation was again noted. According to Bovi; Spiering; Barbosa (1999), the use of inadequate fertilization, which provides insufficient or excess nutrients, inhibits growth to the detriment of the plant, altering its morphological and productive components.

Water use efficiency is one of the parameters used to quantify crop productivity under a given volume of applied water (LOOMIS, 1983). It is clear that dilutions of 0, 25, and 50% were more efficient for the crop under study when the variable bulb density was considered (Figure 7B).

The water use efficiency reached a maximum value of 0.98 g $L^{-1}$ when 6 bulbs were cultivated per pot. The lowest value was observed with 1 bulb per pot, 0.40 g $L^{-1}$ (Figure 7B). This result assumes proportionality for this variable, since the greater the number of bulbs installed is, the greater the water consumption, which highlights the efficiency of wastewater in planting.

## 6 CONCLUSION

Given the results obtained, the use of wastewater together with the variations in bulbs during planting directly interferes with the development of the caladium crop.

Wastewater from açaí processing used for fertigation presented greater benefits for the parameters studied at percentages of 0, 25 and 50% and with variations in bulbs of 3, 4 and 6 for growing caladium.

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