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AVALIAÇÃO E CALIBRAÇÃO DE CONDUTIVÍMETROS PORTÁTEIS PARA MONITORAMENTO NA ÁGUA RESIDUÁRIA DO PROCESSAMENTO DO AÇAÍ

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1 RESUMO

No tratamento, destinação ou reuso de águas residuárias, como as oriundas do processamento do açaí, o monitoramento da condutividade elétrica é crucial para qualificar e tomar decisões assertivas. Assim, objetivou-se avaliar e calibrar os condutivímetros portáteis para o monitoramento da condutividade elétrica das águas residuárias do processamento do açaí. Foi realizado estudo com águas residuárias do processamento do açaí da região de Tomé-Açu, Pará, Brasil, de quatro batedeiras (processamento e venda do açaí in natura), utilizando três condutivímetros portáteis (AK-50[b], adotado como referência; TDS® e Hidroponia Digital CE®). De cada água residuária, foram preparadas amostras com 11 diluições (0, 10, 20, 30, 40, 50, 60, 70, 80, 90 e 100%), tendo uma repetição adicional das diluições centrais (40, 50 e 60%). Foi realizado estudo de modelo de regressão linear, o qual foi avaliado quanto aos índices de performances (R^2, MAE, RMSE, r, d, c, NSE, PBIAS e AIC). Nota-se que ambos subestimaram os valores do condutivímetro AK-50® de referência, sendo recomendado o uso dos modelos de regressão para correção: y=1,3579x+39,526 e y=1,1619x+38,887, respectivamente, para os condutivímetros TDS® e Hidroponia Digital CE®. Portanto, os condutivímetros portáteis alternativos são viáveis economicamente, contudo é necessário o uso dos modelos de calibração obtidos.

Palavras-chave: reuso agrícola; fertirrigação; índices de performance

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EVALUATION AND CALIBRATION OF PORTABLE CONDUCTIVITY METERS FOR MONITORING WASTEWATER FROM AÇAÍ PROCESSING

2 ABSTRACT

In the treatment, disposal or reuse of wastewater, such as that from açaí processing, monitoring electrical conductivity is important for qualifying and making assertive decisions. Thus, the aim was to evaluate and calibrate portable conductivity meters for monitoring the electrical conductivity of wastewater from açaí processing. A study was carried out with wastewater from açaí processing in the Tomé-Açu region, Pará, Brazil, from four mixers (processing and sale of fresh açaí) using three portable conductivity meters (AK-50®, adopted as reference; TDS® and CE® Digital Hydroponics). From each wastewater sample, 11 dilutions (0, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100%) were prepared, with an additional repetition of the central dilutions (40, 50 and 60%). A linear regression model was used to evaluate the performance indices (R^2, MAE, RMSE, r, d, c, NSE, PBIAS e AIC). Both underestimated the values of the reference AK-50® conductivity meter, and the use of regression models for correction is recommended: y=1.3579x+39.526 and y=1.1619x+38.887, respectively, for the TDS® conductivity meters and CE® Digital Hydroponics, respectively. Therefore, alternative portable conductivity meters are economically viable; however, the use of the obtained calibration models is necessary.

Keywords: agricultural reuse; fertigation; performance indices

3 INTRODUCTION

The cultivation of açaí (*Euterpe oleracea* Mart.) is a fundamental activity in the lives of people from Pará, among other states, given that it is among the most common foods consumed in northern Brazilian communities. The açaí palm, also known as açaí, açaí-do-pará, açaí-de-touceira, açaí-do-baixo-amazonas, açaí-da-várzea, juçara, and juçara-de-touceira, can be considered the most important species of the genus *Euterpe* sp. (Carvalho, 2022).

Furthermore, açaí is marketed in national and international markets in many different forms, such as as as ice cream, popsicles, and energy food, and is accompanied by other fruits and cereals, energy drinks, and jams (Lopes *et al.*, 2021). Moreover, the state of Pará is among the main producers of this species; in 2022, the state's production was approximately 1.6 million tons of fruit, corresponding to approximately 93.8% of the national production, although an expansion process is underway for other states (SIDRA, 2024).

In this context, the ways in which açaí and its byproducts are processed are diverse, generating a large amount of waste such as pits and wastewater, which, in most cases, do not have a correct or reusable destination. Wastewater from açaí processing has the potential for negative environmental impacts, highlighting the importance of research based on its reuse, as it is a more sustainable alternative. Among some disposal strategies, agricultural reuse through fertigation stands out (Cordeiro *et al.*, 2020; Carvalho *et al.*, 2022; Tavares *et al.*, 2022).

For agricultural reuse to be managed correctly, monitoring wastewater parameters is crucial. Electrical conductivity stands out as the variable that represents the total concentration of soluble salts, making it possible to determine the salinization potential of reused water (Daliakopoulos). *et al.*, 2016).

To facilitate the monitoring of the electrical conductivity of wastewater, portable conductivity meters, which are multiparameter probes that, in addition to electrical conductivity, also measure total dissolved solids and temperature, can be used as accessible and low-cost methods because of the ease of online sales, with various options of conductivity meters on the market.

However, it is crucial to check the reliability of the data measured by portable conductivity meters in relation to a properly calibrated conductivity meter. For this purpose, Silva *et al.* (2020) propose a comparison with a laboratory benchtop conductivity meter and a statistical approach that considers performance indices of correlation, precision, accuracy, and errors.

Therefore, monitoring the electrical conductivity of wastewater from açai processing for agricultural reuse requires low data collection costs, necessitating the evaluation and calibration of portable sensors. Thus, the objective was to evaluate and calibrate portable conductivity meters for monitoring wastewater from açaí processing.

4 MATERIALS AND METHODS

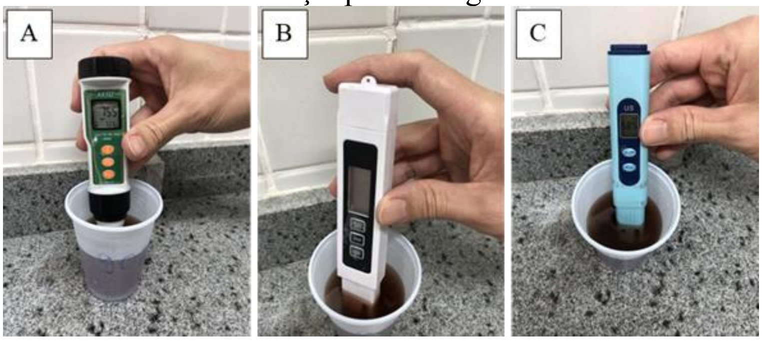
4.1 Location of sample collection and analysis

The experiment was conducted at the Water and Soil Engineering Laboratory of the Federal Rural University of the Amazon (UFRA), located in the municipality of Tomé-Açu, Pará, Brazil, where wastewater samples were collected from four açaí processing plants, where raw açaí is processed and *sold*.

4.2 Portable sensors used

To measure the electrical conductivity data of wastewater from açaí processing, three different types of conductivity meters were used. Among them, the AK-50® model serves as a reference for measuring electrical conductivity for the calibration and evaluation of other portable conductivity meters (Figure 1A). Finally, the TDS®, which is used in environmental water monitoring, is portable and multiparameter and is used to evaluate electrical conductivity measurements as well as total dissolved solids and temperature parameters (Figure 1B). A Hidroponia Digital CE® portable conductivity meter is typically used for monitoring nutrient solutions for fertigation and hydroponics (Figure 1C).

Figure 1. Portable AK-50 ® conductivity meter (A), portable TDS ® conductivity meter (B), and portable Hydroponics Digital CE ® conductivity meter (C) for monitoring the electrical conductivity of wastewater dilutions from açaí processing.



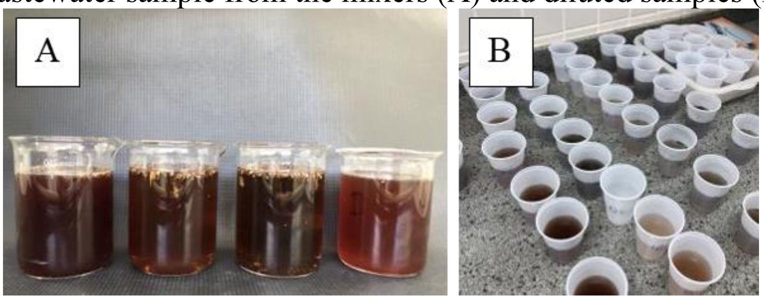
Source: Authors (2026)

4.3 Sample collection and dilution preparation

The water from the açaí processing from the four blenders was collected with specific care: the collection container (PET bottle) was properly cleaned and sterilized, the number of samples collected (4 samples) and the time of exposure to ambient temperature, and the evaluations were performed 12 hours after collection.

For the preparation of each wastewater sample from the mixers, different dilutions with central repetitions were performed (0, 10, 20, 30, 40, 40, 50, 50, 60, 60, 70, 80, 90 and 100%) to obtain different levels of electrical conductivity in the samples for the 4 wastewater collections, totaling 56 samples (Figure 2).

Figure 2. Raw wastewater sample from the mixers (A) and diluted samples (B).



Source: Authors (2026)

4.4 Statistical analyses and performance indicators

In summary, the data measured by the AK-50® conductivity meter were considered as a reference, and for modeling purposes, its data were considered as the dependent variable (y) to facilitate the use of the correction equation when necessary. In turn, the data obtained by the Hidroponia Digital CE® and TDS® portable conductivity meters were analyzed as predictor variables (x) to model a calibration and apply the indices for evaluation.

From the data, simple linear regression models were generated and subjected to analysis of variance at a 5% probability level. The models were evaluated for their performance quality using coefficients, errors, and statistical indices, namely, the coefficient of determination (R^2), Pearson correlation coefficient (r), mean absolute error (MAE), mean absolute error (EMAX), root mean square error (RMSE), Willmott's index of agreement (d) (Willmott, 1981), confidence index (c) (Camargo; Sentelhas, 1997), Nash–Sutcliffe efficiency (NSE) (Nash; Sutcliffe, 1970), and percentage bias (PBIAS) (Yoo). *et al.*, 1996) and the Akaike information criterion (AIC) (Akaike, 1974).

All analyses were performed using R software (version 4.0.1), and for qualitative evaluation of the statistical indices, the classification of the criteria values presented in Table 1 was used.

Table 1. Qualitative performance evaluation criteria for statistical indices.

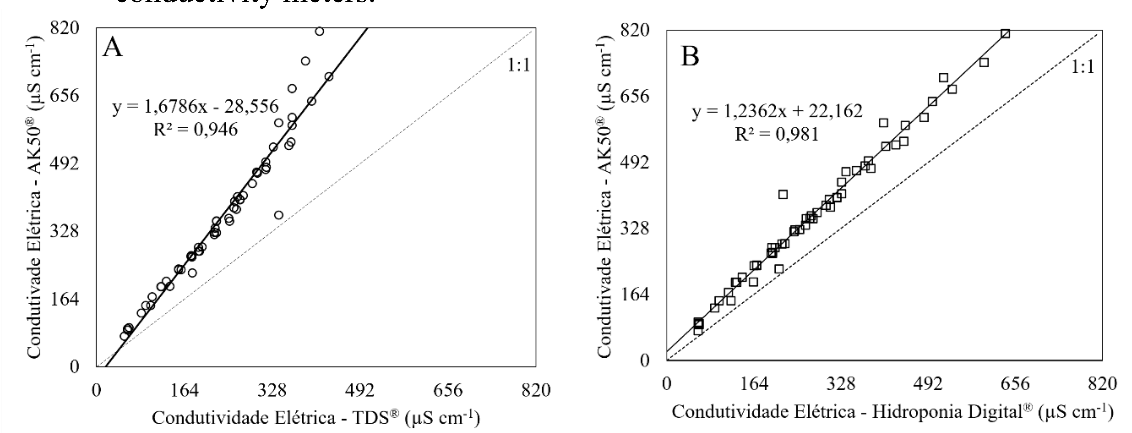
	Very good	Good	Satisfactory	Unsatisfactory
R^2	>0.85	$0.75 < R^2 \leq 0.80$	$0.60 < R^2 \leq 0.73$	≤ 0.60
R	>0.85	$0.60 < r \leq 0.80$	$0.40 < r \leq 0.60$	≤ 0.40
D	>0.90	$0.85 < d \leq 0.90$	$0.75 < d < 0.80$	≤ 0.75
W	>0.84	$0.66 < c \leq 0.80$	$0.61 < c \leq 0.66$	≤ 0.60
NSE	>0.80	$0.70 < NSE \leq 0.80$	$0.50 < NSE \leq 0.70$	≤ 0.50
PBIAS (%)	$< \pm 5$	$\pm 5 \leq PBIAS \leq \pm 10$	$\pm 10 \leq PBIAS \leq \pm 15$	$\geq \pm 15$

Source: adapted from Moriasi *et al.* (2015) and by Pacheco *et al.* (2020)

5 RESULTS AND DISCUSSION

The electrical conductivity of the wastewater was the highest at 812 $\mu S\ cm^{-1}$, while the supply water used for dilutions had an electrical conductivity of 95 $\mu S\ cm^{-1}$, as determined by an AK-50® conductivity meter. From the data collected from the sensors, linear regression models were obtained as calibration curves for the TDS® conductivity meter (Figure 3A) and the portable Hidroponia Digital CE® (Figure 3B).

Figure 3. Electrical conductivity of wastewater from açaí processing using an AK-50® conductivity meter and calibration curves of the TDS® (A) and Hidroponia Digital CE® (B) conductivity meters.



Source: Authors (2026)

The regression models obtained for the calibration of the TDS® and Hidroponia Digital CE® conductivity meters showed good fits, as observed by the R2 (0.946 and 0.981) and r (0.972 and 0.990) values, respectively; in general, the other performance indices showed good responses, with some exceptions (Table 2).

The sensors obtained a negative bias percentage in the calibration model ($PBIAS_{tds}$ = -35.7 and $PBIAS_{\text{Digital Hydroponics CE}}$ = -24.1) and unsatisfactory value classification, indicating high underestimation. Therefore, for the use of data from alternative portable sensors for monitoring wastewater from açai processing, correction using the calibration curve equation is necessary (Figure 3; Table 2). Silva *et al.* (2020), when studying portable sensors and methodologies for determining soil electrical conductivity, also reported underestimation by the Digital Hydroponics CE® sensor, reinforcing the need to use the obtained models.

Table 2. Performance indices for conductivity meter data in determining the electrical conductivity of wastewater from açaí processing.

Performance indicators	TDS ®	Digital Hydroponics CE ®
R²	0.946	0.981
R	0.972	0.990
MOTHER	129.5	871.7
EMAX	396	193
RMSE	151.8	960.6
D	0.760	0.913
W	0.848	0.947
NSE	0.235	0.694
PBIAS	-35.7	-24.1
AIC	578.8	517.8

where R² = coefficient of determination; MAE = mean error; RMSE = maximum error; r = Pearson correlation; d = Willmott's index of agreement; c = Camargo and Sentelhas performance index; NSE = model efficiency; PBIAS = percentage bias; and AIC = Akaike information criterion.
Source: Authors (2026)

However, when the efficiency of the Nash–Sutcliffe calibration model was evaluated, the TDS® sensor obtained a value of 0.235, indicating that the model was unsatisfactory and demonstrating its limitations, most likely due to a greater underestimation (PBIAS = -35.7). With respect to the CE® Digital Hydroponics, the efficiency was satisfactory (NSE = 0.694), which is in line with that observed by Silva *et al.* (2020), who obtained a "very good" classification for the same sensor model; in addition, the Akaike information criterion performed better than its alternative counterpart (AIC_{TDS} = 578.8 > $AIC_{\text{Digital Hydroponics CE}}$ = 517.8).

Notably, monitoring the electrical conductivity of wastewater is crucial for the proper management of this waste. Martinez-Burgos *et al. (2021) reported that these agro-industrial effluents can cause significant impacts because of their production in large volumes and high concentrations of organic matter, nitrogen, phosphorus, and potassium and that* management alternatives focused on creating opportunities for local development need to be adopted.

6 CONCLUSION

Portable conductivity meters offer low-cost options for accurate and rapid measurement of the electrical conductivity of wastewater from açaí processing; however, these meters have low accuracy if the data are corrected using a calibration model. Therefore, they are viable for monitoring wastewater for final disposal or agricultural reuse.

Notably, compared with the TDS®, the CE® Digital Hydroponics conductivity meter achieved higher quality.

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