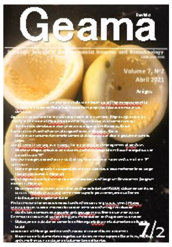

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# Characterization of cassava wastewaters from the processing of different cassava cultivars

## *Caracterização de águas residuárias da mandioca oriundas do processamento de diferentes cultivares de mandioca*

Andrezza Grasielly Costa[1], Luciano da Silva Souza[1], Francisco Alisson da Silva Xavier[2], Alide Mitsue Watanabe Cova[1], Thais Cristina de Souza Lopes[3], Fábio Luís Seixas Costa[1]

[1] Universidade Federal do Recôncavo da Bahia, Cruz das Almas, Bahia, Brasil
[2] Embrapa Mandioca e Fruticultura, Cruz das Almas, Bahia, Brasil
[3] Universidade Federal Rural do Semi-Árido, Mossoró, Rio Grande do Norte, Brasil

*Contato:* andrezzagrasielly@gmail.com

**Palavras-Chave**
*Manihot esculenta C.*
farinha de mandioca
moinho de farinha
manipueira
reúso

RESUMO

O presente estudo teve como objetivo determinar os atributos da água residuária da mandioca de diferentes cultivares utilizadas para a fabricação de farinha em unidades familiares de processamento no município de São Felipe-BA; e definir um indicador de qualidade nutricional para a mesma. Para tanto, foram selecionadas as principais cultivares utilizadas na fabricação de farinha pelos produtores do município de São Felipe, Bahia, Brasil: 'Salangó Preta', 'Cigana', 'Platina', 'Eucalipto', 'Graveto', 'Milagrosa', 'Cidade Rica' e 'Correnteza'. Além disso, as cultivares 'Kiriris', 'Formosa' e 'Poti Branca', desenvolvidas e cultivadas pela Embrapa Mandioca e Fruticultura, também foram avaliadas. A água residuária da mandioca foi obtida pela trituração e prensagem das raízes amostradas. Os atributos amostrados foram submetidos à estatística descritiva e multivariada. Os atributos das águas residuárias de mandioca apresentaram variabilidade baixa e média. Os atributos mais importantes para separar as diferentes cultivares, quanto à qualidade da água residuária da mandioca, foram: potássio, cálcio, condutividade elétrica, sólidos totais dissolvidos, fósforo e nitrogênio total. Tendo em vista a forte correlação entre os atributos K, Ca, CE e SDT, a CE pode ser considerada um indicador de qualidade nutricional da água residuária da mandioca de diferentes origens na região.

**Key-word**
*Manihot esculenta C.*
cassava flour
flour mill
manipueira
reuse

*ABSTRACT*

*The present study aimed to determine the attributes of cassava wastewater from different cultivars used for the manufacture of flour in family processing units in the city of São Felipe-BA; and define a nutritional quality indicator for it. For this, the main cultivars used for flour manufacturing by producers in the municipality of São Felipe, Bahia, Brazil, were selected: 'Salangó Preta', 'Cigana', 'Platina', 'Eucalipto', 'Graveto', 'Milagrosa', 'Cidade Rica' and 'Correnteza'. In addition, the cultivars 'Kiriris', 'Formosa' and 'Poti Branca', developed and cultivated by Embrapa Cassava & Fruits, were also evaluated. Cassava wastewaters were obtain by the crushing and pressing of the sampled roots. The attributes sampled were subject to descriptive and multivariate statistics. The attributes of cassava wastewaters showed low and medium variability. The most important attributes to separate the different cultivars, regarding the quality of cassava wastewater, were: potassium, calcium, electrical conductivity, total dissolved solids, phosphorus, and total nitrogen. In view of the strong correlation between attributes K, Ca, EC, and TDS, EC can be consider as a nutritional quality indicator of the cassava wastewaters from different origins in the region.*

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## Introdução

Cassava is one of the main sources of calories in the tropics, due to its tolerance to adverse climatic and edaphological conditions, being consume by around 800 million people worldwide and produced in more than 100 countries (HOWELER et al., 2013). The importance of cassava cultivation is relate not only to the food issue, but also as a source of employment and income, constituting an important element for family farming (SOUZA et al., 2019).

Cassava flour and starch are the main products in the production chain (SÁNCHEZ et al., 2017). However, the residues released during root processing are a problem for flour producers, mainly the liquid waste, due to the amount of water present in the roots (SOUZA et al., 2019; COSTA et al., 2020). It is estimate that 1 L of wastewater cassava is release during the processing of 3 kg of roots (COSTA et al., 2020).

In Brazil, cassava wastewater is usually discarded near flour mills, without any treatment (SÁNCHEZ et al., 2017). Its continuous disposal can cause numerous environmental impacts, especially on soil fertility, air quality, surface and groundwater quality (IZAH et al., 2018) and high level can be toxic to plants (MAGALHÃES et al., 2014).

The impacts caused by the disposal of cassava wastewater are relate to its composition, due to its high content of organic compounds, and to the presence of toxic substances to the environment, such as hydrocyanic acid (HCN). The concentrations of these components are not homogeneous, varying according to several factors, such as: varieties of cassava used in processing and different cultivation conditions (ZEVALLOS et al., 2018). In addition, the presence of toxic compounds tends to be greater in poor soils and in dry conditions (OKUNADE; ADEKALU, 2013; SÁNCHEZ et al., 2017; BAYATA, 2019).

The influence of these factors has been widespread, with no demonstrative results for the variation in the characteristics of the cassava wastewater obtained from different cultivars and collected under different cultivation conditions, thus creating an important assumption and gap to be assess by the research.

The present study aimed to determine the attributes of cassava wastewater from different cultivars used for the manufacture of flour in family processing units in the city of São Felipe-BA; and define a nutritional quality indicator for it.

## Material and Methods

The study was carry out in the municipality of São Felipe, which is located in the microregion of Santo Antônio de Jesus, Bahia, Brazil. In this microregion, São Felipe stands out for having a large amount of flour mills in operation. The municipality has a territorial extension of 222,408 km², at the following geographical coordinates: latitude 12º50’50” South; longitude 39º05’22” West; and altitude of 195 m.

According to the Köppen-Geiger classification, the municipality has an Af tropical climate, with monthly rainfall higher than 60 mm, annual rainfall around 1,200 mm and annual average temperature between 23 and 25 °C (ALVARES et al., 2013). The predominant soil in the municipality of São Felipe is Oxisol (MOREIRA et al., 2020).

Questionnaires were apply in 50 flour mills, in a universe of approximately 100 flour mills in operation, according to information provided by the Municipality of São Felipe, during the months of July and August 2018, in order to obtain information about the main cassava cultivars cultivated and used in the processing for flour production, as well as on the average yield, destination of production and disposal of residual products generate in the processing, among other relevant information.

Producers both grow and buy cassava for the production of flour. According to the information provided, producers use the following cultivars in processing, with the respective percentages of use: ‘Salangó Preta’ (89%), ‘Cigana’ (75%), ‘Platina’ (42%), ‘Eucalipto’ (42%), ‘Graveto’ (25%), ‘Cidade Rica’ (19%) and ‘Milagrosa’ (19%); for the other cultivars, the use ranged from 13% (‘Correnteza’) to 2% (‘Vermelhinha’, ‘Batatinha’, ‘Manoel Roque’, ‘Mucuri’ and ‘Mangue’).

After the knowing the cassava cultivars processed in the municipality of São Felipe, the most used were selected for characterization of cassava wastewater from their processing, such as: ‘Salangó Preta’ (S), ‘Cigana’ (C), ‘Platina’ (P), ‘Eucalipto’ (E), ‘Graveto’ (G) and ‘Milagrosa’ (M). Three samples roots were collected from each of these cultivars under different cultivation conditions.

In addition, the cultivars ‘BRS Kiriris’ (KR), ‘BRS Formosa’ (FM) and ‘BRS Poti Branca’ (PB), developed by Embrapa Cassava & Fruits, were collected and included in the study. These cultivars were fertilized with mineral fertilizers according to the needs of the crop. Thus, a total of 11 cassava cultivars were analyzed (Table 1).

Samples of cassava roots were collected at 16 farms, 15 of which are located in São Felipe. In the municipality of São Felipe, the communities where cassava roots were collected for processing and obtaining wastewater were: Jenipapo, Terrão, Copioba, Bom Gosto, Campo da Flores, and Boa Esperança. Along with the collection of cassava roots, questionnaires were applied to obtain relevant information on the type of fertilization, agricultural practices and planting time (Table 1).

Five kilograms of roots per cultivar, with age suitable for flour production, were collected. After collection, the roots were taken to the flour mill, located at Embrapa Cassava & Fruits, where they were kept in the shade to be processed the next day, similar to the procedure performed by the producers of the region. The cassava roots were manually peeled, crushed in a mechanical press and the mass obtained was subject to manual pressing. Cassava wastewater was collect during the pressing of the mass, stored in plastic bottles and kept under refrigeration for preserving the samples.

Cassava wastewater was characterized by the determination of the following attributes: electrical conductivity (EC), with a benchtop conductivity meter; total dissolved solids (TDS), with portable TDS meter;

hydrogen potential (pH), measured with a benchtop pH meter; total nitrogen (N), determined by spectrophotometry; phosphorus (P), calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K), determined by inductively coupled plasma optical emission spectrophotometry (HOU et al., 2016); and total organic carbon (TOC), determined according to methodology proposed by Mendonça and Matos (2017). The attributes were determined in triplicate to reduce the margin of error.

The data of cassava wastewater attributes were initially analyze by descriptive statistics, considering the mean, coefficient of variation (CV) and minimum and maximum values. The CV was classified as low (CV ≤ 10%), medium (10% < CV < 20%), high (20% ≤ CV < 30%) and very high (CV ≥ 30%) (ZONTA et al., 2014).

Pearson's correlation matrix was use to verify whether the variables analyzed had sufficient minimum correlations to justify their use in the multivariate analysis matrix. For this, 10 attributes were analyze in 23 cassava wastewater samples. Thus, for statistical analysis, the average of the triplicates of each attribute was taken into account.

In the sequence, the data were subject to cluster analysis, adopting the average distance method, from the Euclidean distance, to describe the similarity between the groups.

After standardizing the data, they were subject to principal component analysis (PCA), considering only the variables that had factor loading value above 0.60. Variables with low explanation in the principal components (PCs) were excluded from the database and a new analysis was perform. The Kaiser criterion was adopted to define the number of PCs that indicated the greatest explanation of variance, that is, only components with eigenvalues > 1 and accumulated variance ≥ 70% were maintained in the system.

The analyzes were performed with software R version 3.5.2, using the packages *Hmisc* (Pearson Correlation analysis), *FactoMineR* (cluster analysis), and *factoextra* (PCA).

Table 1. Cassava cultivars collected to obtain wastewater, with their respective cultivation conditions and plant age

| **Farms** | **Cassava cultivar (1)** | **Fertilizer used** | **Agricultural managements (2)** | **Plant age** |
|---|---|---|---|---|
| 1 | Salangó (S1) | Chicken manure | Crop rotation with *Arachis hypogaea* | 17 months |
| | Cigana (C1) | Chicken manure | Crop rotation with *Arachis hypogaea* | 17 months |
| 2 | Salangó (S2) | Cattle manure | Crop rotation with *Dioscorea rotundata* | 19 months |
| | Cigana (C3) | Cattle manure | Crop rotation with *Dioscorea rotundata* | 19 months |
| 3 | Salangó (S3) | Mineral fertilization | Area for the cultivation of cassava only | 18 months |
| 4 | Cigana (C2) | Chicken manure and Cattle manure | Area for the cultivation of cassava only | 17 months |
| 5 | Platina (P1) | Cattle manure | Consortium with orange tree | 13 months |
| | Graveto (G1) | Cattle manure | Consortium with orange tree | 13 months |
| 6 | Platina (P2) | Mineral fertilization, castor bean pie and flour house residue | Crop rotation with *Arachis hypogaea* | 15 months |
| 7 | Platina (P3) | Chicken manure | Area for the cultivation of cassava only | 14 months |
| 8 | Eucalipto (E1) | Mineral fertilization and Cattle manure | Crop rotation with *Dioscorea rotundata* | 18 months |
| 9 | Eucalipto (E3) | Mineral fertilization and Cattle manure | Consortium with orange tree | 13 months |
| | Graveto (G3) | Mineral fertilization and Cattle manure | Consortium with orange tree | 16 months |
| | Milagrosa (M3) | Mineral fertilization and Cattle manure | Consortium with orange tree | 16 months |
| 10 | Eucalipto (E2) | Cattle manure | Crop rotation with *Arachis hypogaea* | 15 months |
| 11 | Correnteza (CT) | Chicken manure | Crop rotation with *Dioscorea rotundata* | 26 months |
| 12 | Graveto (G2) | Mineral fertilization, cattle manure and castor bean pie | Consortium with orange tree | 15 months |
| 13 | Milagrosa (M1) | Mineral fertilization and flour house residue | Crop rotation with *Arachis hypogaea* | 14 months |
| 14 | Milagrosa (M2) | Cattle manure and flour house residue | Crop rotation with *Arachis hypogaea* | 15 months |
| 15 | Cidade Rica (CR) | Mineral fertilization | Crop rotation with *Arachis hypogaea* | 15 months |
| 16(2) | Kiriris (KR) | Mineral fertilization | Area for the cultivation of cassava only | 14 months |
| | Formosa (FM) | Mineral fertilization | Area for the cultivation of cassava only | 14 months |
| | Poti Branca (PB) | Mineral fertilization | Area for the cultivation of cassava only | 14 months |

(1) 1, 2 and 3 indicate that the cultivars were sampled under three different growing conditions; (2) There was no correction of soil acidity before planting the cultivars

Source: Authors (2018)

## Results and Discussions

Descriptive statistical analysis for the analytical data of cassava wastewater (Table 2) showed low variability (CV ≤ 10%) for pH, EC, TDS, P, K and Ca variables; medium variability (10% < CV < 20%) for TOC, Mg and Na, and very high variability (CV ≥ 30%) only for N content (ZONTA et al., 2014).

The low variability of the analyzed attributes is a very favorable result for recommend the use of this effluent as a soil conditioner for vegetable production. However, it is necessary to evaluate the variability of these attributes in field conditions, where the effluent produced in the flour mills may come from the mixture of different cassava cultivars or from different extraction processes.

For example, studies conducted with cassava wastewater from flour mills in the Northeastern Brazil report different concentrations of its attributes. In the municipality of Pombos (Pernambuco), Duarte et al. (2012) verified pH of 4.08 and concentrations (mg $L^{-1}$) of 980 of N, 740 of P, 1,970 of K, 240 of Ca, 360 of Mg, and 460 of Na in cassava wastewater. In the municipality of Puxinanã (Paraíba), Araujo et al. (2015) obtained pH of 4.50, EC of 8.43 dS $m^{-1}$, 2,050 mg $L^{-1}$ of N, 273 mg $L^{-1}$ of P, 475 mg $L^{-1}$ of K, and 985 mg $L^{-1}$ of Na. Dantas et al. (2016), in studies carried with cassava wastewater in Vitória de Santo Antão (Pernambuco), obtained values pH and EC equivalent to 6.60 and 7.27 dS $m^{-1}$. In Ceará-Mirim (Rio Grande do Norte), Bezerra et al. (2017) analyzed cassava wastewater and obtained (mg $L^{-1}$) 1,540 of N, 350 of P, 2,940 of K, 200 of Ca, 380 of Mg, and 440 of Na.

In Nigeria, Izah et al. (2018) found distinct values for attributes of different cassava wastewater samples obtained in flour mills such as: pH ranging from 2.5 to 5.0, EC of 1.55 dS $m^{-1}$, 766 mg $L^{-1}$ of TDS, 0.19 mg $L^{-1}$ of N, 0.18 mg $L^{-1}$ of P, between 0.58 and 50.9 mg $L^{-1}$ of K, between 1.48 and 94.3 mg $L^{-1}$ of Ca, between 0.82 and 110.9 mg $L^{-1}$ of Mg, and between 1.20 and 146 mg $L^{-1}$ of Na.

The divergence of the pH values among the studies can be assigned to the storage time of the cassava wastewater. Neves et al. (2014), when evaluating the cassava effluent four hours after pressing the root, observed that the effluent showed acidic pH (4.14) and, regardless of the physical treatment, the pH increased with the storage time, with stabilization after 80 days with values close to 9.0.

Table 2. Analytical results of the cassava wastewaters from the cultivars

| **Cassava cultivars** (1) | **pH** | **EC** | **TDS** | **TOC** | **N** | **P** | **K** | **Ca** | **Mg** | **Na** |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **dS $m^{-1}$** | **---------- mg $L^{-1}$ ----------** | | | | | | | |
| C1 | 4.70 | 7.35 | 3,423.33 | 39,035.63 | 41.73 | 758. 47 | 2,789.20 | 85.73 | 560.13 | 150.00 |
| C2 | 5.07 | 7.28 | 2,733.33 | 25,124.29 | 57.15 | 940.67 | 3,128.87 | 132.03 | 538.23 | 255.00 |
| C3 | 5.30 | 7.92 | 2,677.33 | 43,975.38 | 65.32 | 804.67 | 2,920.77 | 105.07 | 368.67 | 130.00 |
| S1 | 5.93 | 7.30 | 3,294.67 | 65,992.02 | 50.31 | 734.00 | 2,867.80 | 118.97 | 636.37 | 255.00 |
| S2 | 5.00 | 9.40 | 3,833.33 | 36,392.09 | 69.11 | 965.17 | 4,166.33 | 230.87 | 584.83 | 190.00 |
| S3 | 4.93 | 10.31 | 4,277.33 | 21,796.83 | 68.13 | 926.87 | 5,378.77 | 242.30 | 466.40 | 120.00 |
| M1 | 4.80 | 10.52 | 4,311.33 | 33,454.09 | 218.38 | 736.27 | 6,026.73 | 285.50 | 342.33 | 155.00 |
| M2 | 4.60 | 10.28 | 4,274.00 | 22,728.93 | 138.89 | 681.47 | 5,469.27 | 287.47 | 297.33 | 135.00 |
| M3 | 4.70 | 10.21 | 4,153.00 | 27,175.48 | 89.38 | 1,184.10 | 5,153.87 | 310.33 | 353.60 | 110.00 |
| G1 | 4.50 | 11.60 | 4,683.00 | 16,316.74 | 74.56 | 1,009.80 | 6,588.47 | 232.03 | 381.37 | 155.00 |
| G2 | 4.47 | 11.52 | 4,638.00 | 19,599.17 | 63.27 | 1,062.87 | 6,543.90 | 324.70 | 558.87 | 150.00 |
| G3 | 4.47 | 9.99 | 4,153.00 | 14,064.84 | 78.28 | 863.37 | 4,771.70 | 192.00 | 480.00 | 335.00 |
| P1 | 4.67 | 10.90 | 4,428.00 | 27,328.16 | 62.29 | 1,269.60 | 5,958.07 | 282.07 | 450.50 | 105.00 |
| P2 | 4.23 | 8.74 | 3,786.33 | 21,774.74 | 57.09 | 899.63 | 3,438.43 | 156.73 | 536.30 | 210.00 |
| P3 | 4.67 | 9.72 | 4,202.67 | 28,492.27 | 72.67 | 1,165.70 | 4,906.63 | 228.27 | 599.40 | 90.00 |
| E1 | 5.63 | 11.27 | 4,593.67 | 18,574.18 | 77.84 | 1,290.97 | 6,649.83 | 263.27 | 373.43 | 155.00 |
| E2 | 5.50 | 13.41 | 4,812.67 | 19,570.27 | 66.30 | 1,485.27 | 8,055.20 | 316.93 | 393.47 | 105.00 |
| E3 | 5.20 | 8.93 | 3,819.33 | 20,234.33 | 82.35 | 1,028.37 | 4,890.93 | 203.37 | 687.90 | 375.00 |
| CT | 6.83 | 9.43 | 4,032.67 | 42,354.53 | 81.78 | 950.17 | 4,514.67 | 180.83 | 642.83 | 210.00 |
| CR | 4.70 | 10.99 | 4,465.00 | 22,366.34 | 58.98 | 1,150.67 | 5,325.33 | 260.43 | 633.80 | 205.00 |
| KR | 4.93 | 5.98 | 2,943.33 | 26,269.48 | 60.43 | 1,038.83 | 3,339.87 | 136.43 | 488.77 | 213.33 |
| FM | 6.10 | 5.84 | 3,079.67 | 16,796.84 | 75.10 | 1,167.23 | 3,808.00 | 147.50 | 671.93 | 313.33 |
| PB | 6.23 | 6.97 | 3,347.00 | 27,128.85 | 71.66 | 982.70 | 3,817.97 | 202.57 | 453.80 | 400.00 |
| **Mean** | 5.1 | 9.4 | 3,911.4 | 27,675.9 | 77.4 | 1,004.3 | 4,804.9 | 214.1 | 500.1 | 196.6 |
| **CV (%)** | 3.5 | 3.0 | 2.2 | 10.2 | 30.5 | 5.7 | 4.1 | 5.5 | 10.2 | 12.4 |
| **Minimum** | 4.2 | 5.84 | 2,677.33 | 14,064.66 | 41.7 | 681.67 | 2,789.33 | 85.67 | 297.33 | 90 |
| **Maximum** | 6.8 | 13.41 | 4,812.67 | 65,992.33 | 218.38 | 1,485.33 | 8,055.33 | 324.67 | 688.00 | 400 |
| **Shapiro-Wilk** | $0.890^{*}$ | $0.948^{ns}$ | $0.929^{ns}$ | $0.840^{**}$ | $0.515^{**}$ | $0.973^{ns}$ | $0.959^{ns}$ | $0.960^{ns}$ | $0.954^{ns}$ | $0.892^{*}$ |

(1) S = 'Salangó Preta'; C = 'Cigana'; P = 'Platina'; E = 'Eucalipto'; G = 'Graveto'; M = 'Milagrosa'; CR = 'Cidade Rica'; CT = 'Correnteza'; KR = 'Kiriris'; FM = 'Formosa'; and PB = 'Poti Branca'. 1, 2 and 3 indicate that the cultivars were sampled under three different growing conditions; CV – Coefficient of variation; ns – Not significant; * - Significant at $p \leq 0.05$; ** - Significant at $p \leq 0.01$

Source: Authors (2018)

The variability of the attributes are associated with the different conditions of cultivation and cultivars of cassava used during the processing of the roots for the production of flour (OKUNADE; ADEKALU, 2013; SÁNCHEZ et al., 2017; BAYATA, 2019).

It is extremely important to evaluate the characteristics of the effluent before it is disposed of in the environment, since the high concentration of physicochemical attributes can reduce dissolved oxygen, favoring the process of eutrophication and contamination of water resources (DANTAS et al., 2014; AFUYE; MOGAJI, 2015).

In the soil, cassava wastewater can cause adverse and beneficial effects on the physicochemical properties (IZAH et al., 2018). Among the adverse effects can be highlighted the imbalance of nutrients, increased salinity and acidification caused by the presence of cyanide and acidity of the effluent (DANTAS et al., 2014; IZAH et al., 2018). Regarding the beneficial effects, Izah et al. (2018) point to the improvement in aeration processes with the increase of nitrate in the soil and Dantas et al. (2014) highlighted the increase in pH caused by the addition of exchangeable cations.

The concern with the adverse effects has influenced researchers to look for ways to use this effluent to guarantee an adequate destination, using it as insecticide, pesticide, animal feed, bioenergy production, cultivation of microalgae and, mainly, as organic fertilizer (IZAH, 2019; SOUZA, 2021). According to Costa et al. (2020), the use of cassava wastewater as a fertilizer is an opportunity to reduce the problems caused by its indiscriminate disposal in flour mills, increase crop productivity and reduce production costs due to less dependence on agricultural inputs.

The correlation matrix between variables related to the attributes of the cassava effluent is described in the Table 3. The analysis of correlation matrix did take into account the classification presented by Figueiredo Filho and Silva Júnior (2009), who describe as weak correlation the values between 0.10 and 0.30, moderate between 0.40 and 0.6, and strong between 0.70 and 1. It was possible to observe that TDS showed a strong positive correlation with EC, K, and Ca, and a moderate and negative correlation with TOC and Na variables. The EC variable was strongly and positively correlated with SDT, K and Ca, moderately and positively with P and negatively correlated with Na. Phosporus presented a moderate correlation with Ca, K, EC and TOC attributes. It was observed that Na correlated moderately and negatively with EC and TDS and positively with Mg. In turn, Mg showed a moderate and negative correlation with Ca and N, which was the only significant correlation observed for N.

The relationship between P and EC occurs due to the release and absorption of phosphorus in the form of orthophosphate with negative charge ($PO_4^{3-}$) in aqueous systems (KIM et al., 2007). Chen and Avnimelech (1986) reported that the release of P in its organic form is not well correlate with carbon, as commonly occurs with N, due to the reactions of sorption, fixation and precipitation of P with other soil constituents, which may indirectly influence the supply of P to plants and, consequently, the concentration of these elements in cassava wastewater. The negative correlation between Na (mean of 196.6 mg $L^{-1}$) and EC (mean of 9.4 dS $m^{-1}$) may be associated with the tropical climate of the region, with regular rainfalls that favor leaching of the element in the soil. Araújo et al. (2015), when characterizing cassava wastewater obtained in a flour mill in the municipality of Puxinanã, semi-arid region of Paraíba, found 985 mg $L^{-1}$ of Na and EC of 8.43 dS $m^{-1}$.

Table 3. Correlation coefficients between variables related to the attributes of cassava wastewater

| | pH(1) | EC | TDS | TOC | N | P | K | Na | Ca | Mg |
|---|---|---|---|---|---|---|---|---|---|---|
| pH | 1.00 | -0.33 | -0.31 | 0.38 | -0.09 | 0.10 | -0.18 | 0.39 | -0.27 | 0.28 |
| EC | | 1.00 | **0.93**(2) | -0.36 | 0.22 | **0.42** | **0.91** | **-0.54** | **0.83** | -0.40 |
| TDS | | | 1.00 | **-0.42** | 0.23 | 0.41 | **0.90** | **-0.44** | **0.85** | -0.28 |
| TOC | | | | 1.00 | 0.03 | **-0.47** | **-0.52** | -0.07 | **-0.45** | 0.20 |
| N | | | | | 1.00 | -0.30 | 0.29 | -0.19 | 0.38 | **-0.45** |
| P | | | | | | 1.00 | **0.57** | -0.19 | **0.47** | 0.03 |
| K | | | | | | | 1.00 | -0.41 | **0.89** | -0.41 |
| Na | | | | | | | | 1.00 | -0.41 | **0.46** |
| Ca | | | | | | | | | 1.00 | **-0.41** |
| Mg | | | | | | | | | | 1.00 |

(1) pH – hydrogen potential; EC – electrical conductivity; TDS – total dissolved solids; TOC – total organic carbon; N - nitrogen; P - phosphorus; K - potassium; Na - sodium; Ca - calcium; and Mg – magnesium; (2) The correlation coefficients in bold are significant ($p \leq 0.05$)

Source: Authors (2018)

The results of the principal component analysis (PCA) showed the eigenvalues of the first two PCs explained 75.52% of the accumulated variance (Table 4). According to Hongyu et al. (2015), a cumulative variance of around 70% can effectively summarize the total sampling variance. PC1 showed an eigenvalue of 4.51 and explained 56.42% of the variance. The variables that most contributed to the formation of PC1 were EC, TDS, K, and Ca. PC2 had an eigenvalue of 1.52 and was explained by the variables N and P, correlated with each other, representing 19.10% of the total variation. The integration with the cluster analysis show the separation of three groups of cassava cultivars based on the degree of similarity (Figure 1), namely: a) Group 1 – formed by the cultivars CR, E1, E2, G1, G2, P1, M3, P3, and S3; b) Group 2 – formed only by cultivars M1 and M2; and c) Group 3 – gathered 52% of the cultivars evaluated, being represented by C1, C2, C3, CT, E3, FM, G3, KR, P2, PB, S1, and S2.

The cultivars of Group 1, especially those that had a higher correlation with PC1, such as G1, S3, M3, and E1, differed from the others for having higher contents of Ca, K, and TDS, besides higher EC, which were the attributes with the highest correlation with PC1.

Table 4. Eigenvalues and accumulated variance obtained in the principal component analysis (PCA), from the original data of attributes of cassava wastewater from different cultivars

| Variables[1] | PC1 | PC2 |
|---|---|---|
| CE | **0.94419** | -0.08556 |
| TDS | **0.91813** | -0.12426 |
| N | 0.37519 | **0.77180** |
| P | 0.49294 | **-0.72334** |
| K | **0.95749** | -0.11863 |
| Ca | **0.92728** | -0.01313 |
| Mg | -0.52290 | -0.59612 |
| Na | -0.58786 | -0.12914 |
| Outlier | 4.51 | 1.52 |
| Explained variance (%) | 56.42 | 19.10 |
| Accumulated variance (%) | 56.42 | 75.52 |

[1] Variables with higher factor loads (scores in bold) were selected within each component

Source: Authors (2018)

All cultivars in Group 3 differed from those of Group 1 due to the higher contents of Na, mainly the cultivars S1, C2, KR, P2, C1, and PB.

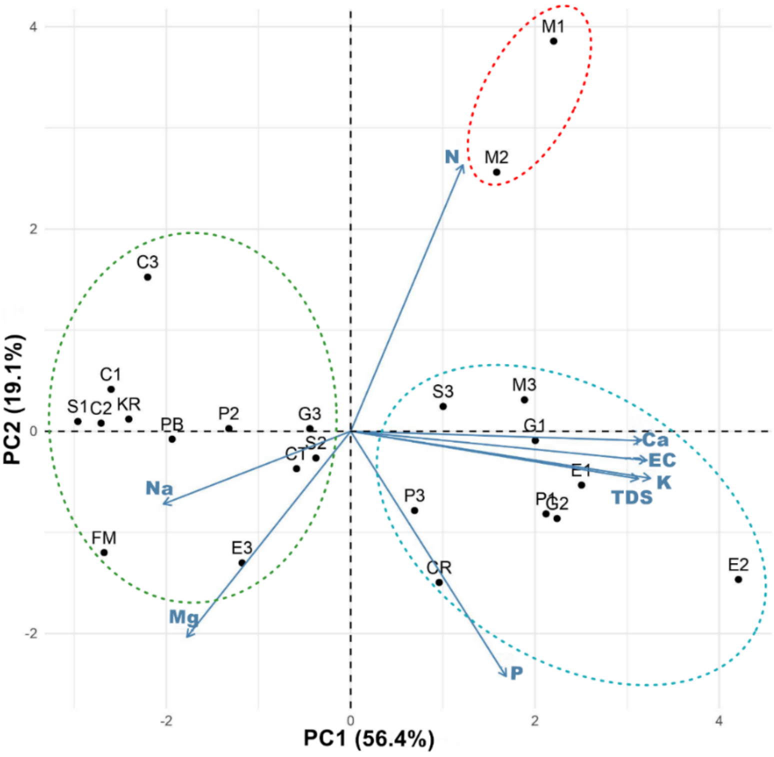
On the other hand, the two cultivars that formed Group 2 (M1 and M2) differed from the others for showing a tendency of higher N contents, although this separation is lower because it is correlated with PC2, whose explanation of variance was only 19.1%. In addition to the nutrient N, PC2 also showed a higher correlation with P contents (Table 4), and both were negatively correlated. Of the cultivars evaluated, CR and P3 were the ones that had the highest correlation with P contents, and this was the attribute, which most explained the difference of these cultivars from M1 and M2, which tended to show higher contents of N.

Cultivars that are close to the center of origin of the biplot graph, such as CT, S2, and G3, despite forming Group 3 in the cluster analysis, have low correlation with the selected PCs. Therefore, the distinction of these cultivars from the other cultivars cannot be evaluated by the attributes selected in this study.

Souza et al. (2009) described that soils of the Coastal Tablelands, where the soils sampled in the present study are located, provide satisfactory conditions for cassava cultivation, as long as they improved by liming and fertilization. However, in the survey carried out directly with the producers, they reported that there was no soil correction prior to cultivation, only fertilization of the area, even without prior analysis of soil fertility. Souza et al. (2009) emphasized the importance of soil analysis in order to avoid possible losses in cassava production, also highlighting that the practice of crop rotation is indispensable, because cassava removes many nutrients from the soil with little recycling of them.

Cassava absorbs the following nutrients in decreasing order: K > N > Ca > P > Mg (HOWELER, 2002; SOUZA et al., 2009). On the other hand, Embrapa (1980), considering the average of three genotypes, obtained the following decreasing order: N > K > Ca > Mg > P > S. At the end of the cycle, Howeler (2002) highlighted that cassava roots accumulated nutrients in the same decreasing order (K > N > Ca > P > Mg), while Embrapa (1980) obtained the following order of nutrients in the roots: K > N > Mg > Ca > P > S. This explains the significant concentrations of K in the cassava wastewater, contributing to the formation of PC1, together with Ca, and N contributing to the formation of PC2, together with P (Table 4).

Figure 1. Biplot graph of the principal components 1 and 2 integrating the attributes of the cassava wastewaters and the different cassava cultivars



The ellipses correspond to the separation of the groups indicated by cluster analysis.

Source: Authors (2018)

According to Howeler (2002), the absorption and distribution of nutrients in cassava crop depends on soil fertility, climatic conditions and characteristics of cultivars. Therefore, the different values for the attributes shown by the cassava wastewaters (Table 2) from the cassava cultivars sampled (Table 1) should be associated with the different cultivation conditions. For example, it was observed that the highest concentrations of P associated with high concentrations of K were promoted by cultivars of Group 1 (E2, E1, P1, P3, CR, G2, and G1) subjected to mineral fertilization and/or intercropping with orange or yam, in this case possibly involving the application of mineral fertilization to the secondary crop. On the other hand, it was observed that the highest concentrations of Na were promoted by cultivars of Group 3 (E3, G3, C2, S1 and P2) subjected to mineral fertilization or fertilization with chicken litter, in this case possibly including mineral salt residue added to the poultry feed.

Regarding the quality of cassava wastewater from different cassava cultivars (Table 5), considering those that were sampled in three different areas, it was observed that for the cultivars ‘Graveto’ and ‘Eucalipto’ there was high quality of cassava wastewater in two samples; for ‘Salangó Preta’ (S), ‘Platina’ (P), and ‘Milagrosa’ (M) the medium quality predominated, meanwhile ‘Cigana’ (C) cassava wastewater showed low quality in the three samples. Cultivars with only one sample, such as ‘Correnteza’ (CT), ‘Cidade Rica’ (CR), and ‘Formosa’ (FM), produced cassava wastewaters with medium quality, and ‘Kiriris’ (KR) and ‘Poti Branca’ (PB) led cassava wastewater to low quality.

These data showed that the quality of cassava wastewater was directly influence by cassava cultivar.

Given that, the cultivars ‘Formosa’ (FM) and ‘Kiriris’ (KR), both received chemical fertilization according to the recommendations for the cultivation of the cassava, presented wastewater classified as low quality. In addition, they were the ones with the lowest EC values, equivalent to 5.84 and 5.98 dS m$^{-1}$, respectively.

On the other hand, the varieties classified as high quality had the highest EC values, they were: E2 (13.41 dS m$^{-1}$), G1 (11.60 dS m$^{-1}$), G2 (11.52 dS m$^{-1}$), E1 (11.27 dS m$^{-1}$), and P1 (10.90 dS m$^{-1}$). Soon, higher concentrations of K were also provide by cultivars: E2 (8,055.20 mg L$^{-1}$), E1 (6,649.83 mg L$^{-1}$), G1 (6,588.47 mg L$^{-1}$), G2 (6,543.90 mg L$^{-1}$), and P1 (5,958.07 mg L$^{-1}$). These cultivars had in common fertilization with cattle manure and the use of conservation practices, such as crop rotation or consortium.

According to Souza et al. (2009), cassava culture presents satisfactory responses, in terms of root and aerial part production, to the application of organic fertilizers, mainly due to the physical, chemical, and microbiological improvements that occur in the soil. In addition, conservationist practices such as crop rotation and consortium, are also recommended maintaining or improve soil fertility in cassava cultivation.

After verifying the relationship between EC, TDS, K, and Ca attributes by PCA (Table 3), Pearson correlation analyses were tested between these attributes (Figure 2).

Table 5. Relationship between cassava cultivars and cassava wastewater composition

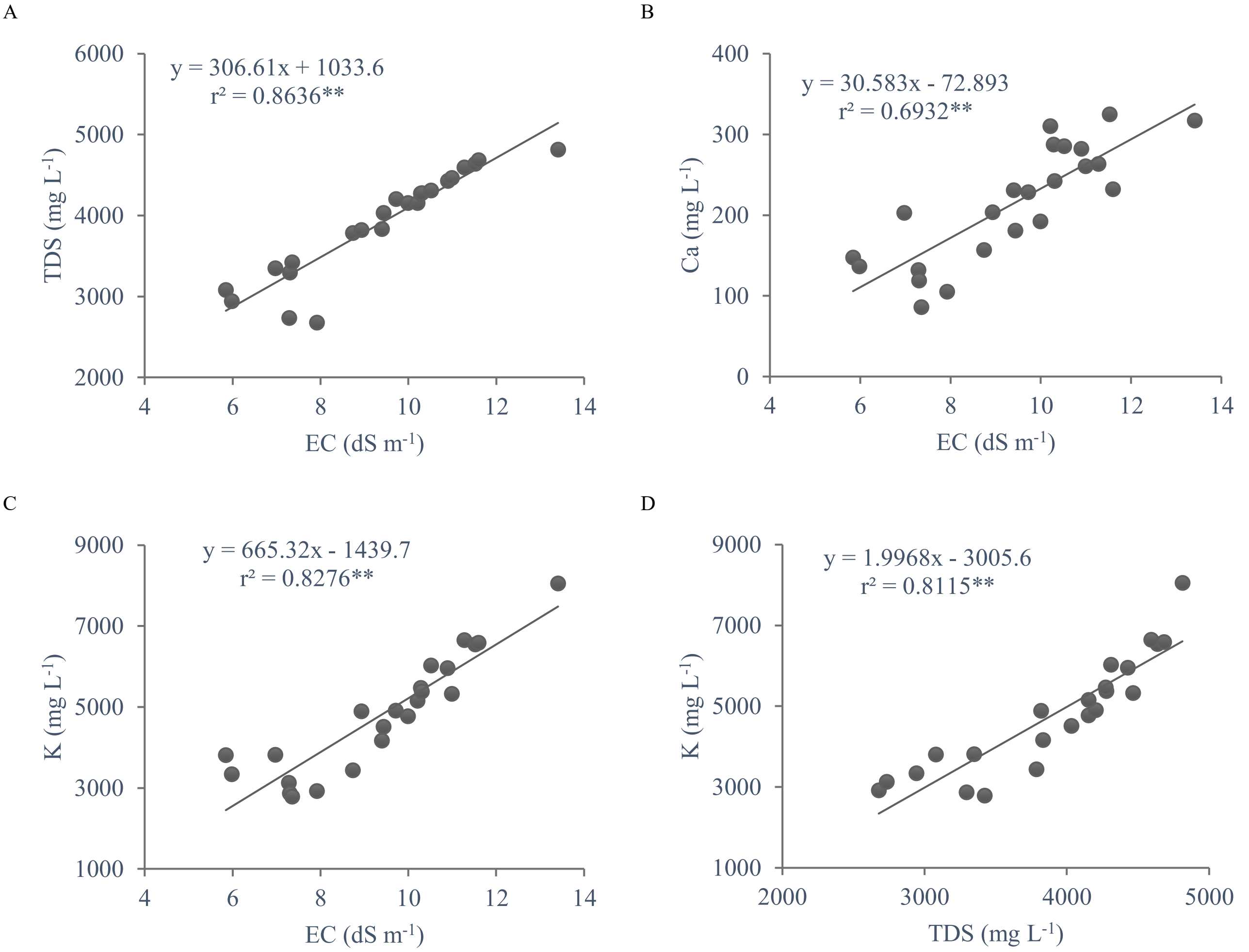
| Areas | Cassava cultivars (1) | Quality of cassava wastewater (2) |
|---|---|---|
| 1 | S1 and C1 | l |
| 2 | S2 and C3 | m, l |
| 3 | S3 | m |
| 4 | C2 | l |
| 5 | G1 and P1 | h |
| 6 | P2 | m |
| 7 | P3 | m |
| 8 | E1 and M3 | h |
| 9 | G3, E3 | m |
| 10 | E2 | h |
| 11 | CT | m |
| 12 | G2 | h |
| 13 | M1 | m |
| 14 | M2 | m |
| 15 | CR | m |
| 16 | KR and PB | l |
| 16 | FM | m |

(1) S = ‘Salangó Preta’; C = ‘Cigana’; P = ‘Platina’; E = ‘Eucalipto’; G = ‘Graveto’; M = ’Milagrosa’; CR = ‘Cidade Rica’; CT = ‘Correnteza’; KR = ‘Kiriris’; FM = ‘Formosa’; and PB = ‘Poti Branca’; 1, 2 and 3 indicate that the cultivars were sampled under three different growing conditions. (2) ACP-based levels: h = high, m = medium, l = low.

Figure 2A presents the linear correlation between TDS and EC, showing a strong relationship between these two attributes. Choo-In (2019) reported that the correlation between these attributes manifests itself in different ways for each water body and, after this correlation is established, the monitoring of TDS concentration, whose determination is slower, can be carried out by determining the EC.

It is observed that the linear relationship between Ca concentrations and EC was moderate, with r$^2$ of 0.69 (Figure 2B). K showed a strong linear correlation with EC (Figure 2C) and TDS (Figure 2D). This may be associated with the fact that K is the cation in greater abundance in cassava wastewater, with an average concentration of 4.804 mg L$^{-1}$, while the average concentration of Ca was 214 mg L$^{-1}$, contributing more markedly in the determination of EC and TDS.

Figure 2. Correlation between electrical conductivity (EC) and total dissolved solids (TDS) (A), electrical conductivity and calcium (Ca) (B), electrical conductivity and potassium (K) (C) and total dissolved solids and potassium (D), for cassava wastewaters from different cultivars



Source: Authors (2018)

## Conclusions

The attributes of the cassava wastewaters from different cassava cultivars showed low and medium variation, and the most important attributes to separate the different cultivars, regarding the quality of cassava wastewater, were: K, Ca, EC, TDS, P, and N.

Cassava wastewaters of high quality were obtained from the cultivars ‘Graveto’ and ‘Eucalipto’, of medium quality from ‘Salangó Preta’, ‘Platina’, ‘Milagrosa’, ‘Correnteza’, ‘Cidade Rica’, and ‘Formosa’, and of low quality from ‘Cigana’, ‘Kiriris’, and ‘Poti Branca’.

Given the strong correlation between the attributes K, Ca, EC, and TDS, the EC can be consider an indicator of nutritional quality of cassava wastewaters from different origins in the region.

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## Author contributions

The authors of this article declare that they contributed equally in its elaboration.

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